Review of 2030 Proposed Revised Water Thresholds - Gnangara groundwater system

Christopher Kavazos, Grant Buller, Pierre Horwitz, Ray Froend

Centre for Ecosystem Management, School of Science,

Edith Cowan University

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Executive Summary

This report presents a detailed analysis of the likely ecological effects of proposed revisions of water level criteria.

Currently, Ministerial Statement 819 minimum water level criteria must be met by the Department of Water and Environmental Regulation (DWER) at wetlands and groundwater dependent terrestrial vegetation sites covered by the Gnangara groundwater allocation plan. However, groundwater abstraction combined with declining rainfall in the region means that it is unlikely water levels at many sites will meet the criteria into the future

DWER is proposing to reduce groundwater abstraction from the Gnangara groundwater resources to help improve water levels where possible. A reduction of groundwater abstraction of up to 44 GL/yr. by 2030 is being planned by DWER and modelling has been conducted to understand the effect this will have on water levels. As a result of this modelling, revised water level criteria or thresholds have been proposed where the modelling showed that existing criteria could not be met even with reduced abstraction.

This report describes the likelihood that thresholds proposed by DWER will maintain the values and managerial objectives of twelve wetland sites and five terrestrial sites on the Gnangara groundwater system. At a few wetlands in the East Wanneroo area, water levels are projected to increase. At these sites maximum thresholds are suggested for those rises to ensure values and managerial objectives are upheld. Finally, the management objectives for one additional wetland, Lake Gwelup, are reviewed with the aim of providing DWER with minimum and maximum thresholds that will maintain its ecological integrity.

In most cases the projected water levels are an improvement over the current (2019) situation, however water levels for 2030 are projected to continue being non-compliant with existing water level criteria at eight wetlands and five terrestrial sites. Accordingly, DWER has proposed to lower the existing criteria at these sites to levels that modelling projects is achievable under a dry climate scenario.

Loch McNess and Lake Yonderup are currently experiencing dramatic shifts in ecological processes that are being driven by changes in hydrological regime. The projected 2030 water levels are not going to return these lakes to their previous hydrological regime and nutrient enrichment and terrestrialisation will continue to be a problem. At wetlands such as Lake Nowergup and Pipidinny Swamp, diminished habitat for water birds will persist. Other sites, such as Lexia 186 and Melaleuca Park 173 and 78, are likely to contain increasingly stressed wetland vegetation as the ecological water requirements for some species are not met. These sites may experience terrestrialisation of vegetation at outer extremities. Similar shifts are described for the five terrestrial sites examined here, albeit the effects of terrestrialisation are assured and perhaps already well underway.

On the other hand, Lake Goollelal, Lake Joondalup, Lake Mariginiup and Lake Jandabup are projected to have water levels significantly greater than 2013 levels (the start of the modelled period), hence it is proposed to increase minimum thresholds where the current minimum criteria are seen to be too low to protect ecosystem values. For these wetlands, maximum thresholds (levels that surface waters should not exceed) are also proposed to ensure that fringing vegetation is maintained at these sites.

The proposed thresholds are predicted to have a significant impact on the management values and objectives of many of the sites. It is predicted that 25 of the 44 cumulative site values for the sites presented in this report will be retained and 31 of 51 management objectives will be retained. For wetlands where water levels are projected to rise, overall a total of 90% of values will be retained, and 100% management objectives will be upheld. For wetlands where water levels are projected to fall and new thresholds are proposed, overall a total of 47% of values are projected to be retained and 38% management objectives are projected to be upheld.

Finally, minimum and maximum thresholds are proposed here that will achieve the proposed management objectives of Lake Gwelup. A minimum threshold of 5.4 mAHD at the staff gauge 6162504 will ensure permanent water exists in the lake and thus protect the site as a drought refuge for water birds. This threshold also ensures that the ecological water requirements for surrounding vegetation are met which will ensure the lake provides for a diverse range of aquatic macroinvertebrates that benefit from the habitats provided by fringing vegetation.

Contents

Introduction

The Gnangara groundwater system is located on the Swan Coastal Plain in south-western Australia. The system covers an area of 220,000 ha, extending from the Swan River in the south to the Moore River and Gingin Brook in the north and from the Darling Scarp in the east to the Indian Ocean in the west (Figure 1). The system consists of three major aquifers: The Superficial aquifer, Leederville aquifer and the Yarragadee aquifer. Wetlands supported by the Gnangara groundwater system are expressions of the Superficial aquifer, an unconfined aquifer composed of Quaternary-Tertiary sediments of the Swan Coastal Plan that is in direct connection with the lower Leederville aquifer at locations where the Osborne Formation has eroded (Salama et al., 1991). Aquifers of the Gnangara system, provide almost half of all the water used in the Perth metropolitan area each year, supplying drinking water, water for agriculture and water for irrigating parks, ovals and gardens.

The Gnangara groundwater system supports a series of groundwater dependent ecosystems, including wetlands in the form of permanently inundated lakes and rivers, seasonally inundated sumplands and brooks and seasonally waterlogged damplands (Semeniuk 1987). These groundwater dependent ecosystems provide important habitat for an array of vegetation communities and fauna. Environmental gradients caused by variation in hydrological regimes provides a complex mosaic of vegetation across the Gnangara groundwater system and within the wetlands themselves. The range of hydrological regimes that define these groundwater dependent ecosystems provides a mosaic of important habitat for aquatic fauna, including endemic fishes, turtles, mammals and waterbirds that reside throughout the Swan Coastal Plain. Groundwater dependent ecosystems are therefore an integral component of the ecological value of the Gnangara groundwater system and have unquestionable value as remnants of a once more widespread coastal wetland system (Horwitz et al. 2009b).

The biophysical characteristics and the ecological health of groundwater dependent ecosystems overlying the Gnangara groundwater system are directly related to the hydrological regime of the shallow Superficial aquifer and, to a lesser extent, the deeper aquifers. The shallow Superficial aquifer responds to the seasonal climatic patterns of the region, which experiences a Mediterranean-type climate with hot dry summers and cooler wet winters. June to August represent the wettest months of the year and December to March usually have little rainfall (Figure 2 Right), hence groundwater in the system generally rises during winter to a spring peak and declines in summer to an autumn minimum. Vegetation and wetland associated fauna of these groundwater dependent ecosystems are largely determined by a given wetland's hydrological regime, mostly influenced by these groundwater fluctuations.

Water levels in the Gnangara groundwater system have been declining due to disruptions in the water balance caused by declining rainfall as a result of climate change, and abstraction. Land use change has also had an impact. Major uses of groundwater from the Gnangara groundwater resources include for public water supply, for private self-supply (such as for horticulture, irrigation of public open space and domestic gardens), and by native vegetation, pine forest plantations and wetlands (Salama et al., 1991). Replacing native vegetation with pine plantations has been shown to reduce recharge to groundwater as pines (planted at high densities) transpire more than the native plants they replace, and they are also able to directly access deeper levels of the water table. Groundwater recharge has been hampered by declining rainfall in the south west region of Australia; it is estimated that since the 1970s rainfall has been declining by approximately 12mm/year (England et al., 2006), with up to 64 % less runoff occurring in the region in 2003 compared to 1974 (Yesertener, 2007). Since the mid-1990s, rainfall has generally been below the long-term average (Figure 2 Left). The combined effects of groundwater abstraction, changes in vegetation and declining annual rainfall have contributed to long term declines in groundwater of the Gnangara groundwater system (Yesertener, 2007) and associated declined health of many groundwater dependent ecosystems (Buller et al., 2019, Judd & Horwitz, 2019).

Drawdown of groundwater affects the mortality and health of plant communities that depend on groundwater access (Groom et al., 2000; Muler et al., 2018; Zencich et al., 2002) and the composition of aquatic invertebrate communities that inhabit the surface waters of wetlands of the Gnangara groundwater system (Horwitz et al., 2008, 2009b). Changes in hydrological regimes directly affect the distribution, health and composition of fringing wetland vegetation by altering the depth to groundwater, depth of surface water and length of inundation periods (Froend, Loomes & Rogan, 2005). When water requirements are no longer being met for fringing vegetation species, the vigor of individuals within a population declines, eventually causing altered species distributions or complete loss of a population from a wetland. Often the loss of native species due to drying increases the likelihood of invasion by exotic species or in extreme cases, terrestrialisation through the establishment of xeric species.

Fauna associated with groundwater dependent systems tend to have specific life history stages that require surface water. Therefore, the spatial and temporal distributions of such fauna are determined primarily on where there is surface water and when it occurs (Horwitz et al. 2009b). Alteration of these regimes affects the persistence of these organisms and, in some cases, may enhance the survival and reproduction of others (Horwitz et al. 2009b). Organisms requiring permanent water, such as fish, are at most risk under a scenario of declining water levels as loss of permanent surface water in a lake will almost certainly cause the local extinction of those species. Most aquatic insects, on the other hand, can travel between wetlands as adults for reproduction and require surface water for only short periods.

Finally, the physicochemical integrity of groundwater dependent ecosystems can be compromised as groundwater and surface water levels decline. The seasonal exposure of sediments leads to drying and the beginning of acidification processes that affect the pH and water chemistry of surface waters (Horwitz et al. 2009b). The loss of mesic species can also add further organic matter to already organically rich peats which, when dry, are at risk of combustion. Generally, repeated fire disturbance to these sediments facilitates terrestrialisation of these wetlands through loss of peat sediments. Terrestrialisation ultimately leads to the permanent loss of the ecological values we associate with groundwater dependent ecosystems.

Groundwater dependent ecosystems provide important habitat for fauna, including amphibians such as Litoria adelaidensis.

Scope of report

Schedule 1 of Ministerial Statement 819 specifies minimum or minimum peak water level criteria that the Department of Water and Environmental Regulation (DWER) must meet at staff gauges and/or monitoring bores at 14 wetlands and 16 bushland sites in the area covered by the Gnangara groundwater allocation plan, north of Perth (Figure 1). Due to groundwater declines caused by groundwater abstraction and declining rainfall, DWER has been unable to meet the criteria levels at approximately half of the sites in recent years. DWER is currently in the process of preparing a draft Gnangara groundwater allocation plan for public comment. As part of the planning process, the department has modelled scenarios that reduce public and private groundwater abstraction in the plan area by a total of up to 44 GL/year by 2030. Even with these reductions in abstraction, modelling projects DWER will still not be able to achieve the current 'absolute minimum' levels at around half of the criteria sites and compliance rates will remain very similar to current rates because the expectations are for a continued drying climate regime into the future.

DWER is therefore proposing to alter the water level criteria at sites where the modelling projects absolute minimum levels are not likely to be met in the future despite reductions in abstraction. The department has developed a new set of water level criteria (or minimum 'thresholds', in line with the Environmental Protection Authority's recommended terminology (Environmental Protection Authority, 2018). The proposed minimum thresholds have been based on what groundwater modelling has indicated can likely be met at the respective wetland or bushland criteria sites following reductions in groundwater abstraction, and (in some areas) planned land use changes. Reductions to groundwater abstraction will come into effect before 2030, while land use changes have started to occur in some areas already and will happen progressively over the plan period.

There are five key tasks that are addressed in this report:

Task 1: Assess what effect altering absolute minimum threshold water levels may have on:
  a) achieving the original stated site management objectives
  b) the original stated site values
  c) where these are different from b), additional values as described in recent monitoring reports.

These assessments are based on whether the proposed 2030 minimum threshold levels will meet the water requirements for these specific ecological values:
  a) species composition
  b) key, priority or threatened species
  c) existing ecohydrological states

Task 2: For each site, an assessment of the significance of the impacts/changes found in Task 1 (taking into account guidance from the Environmental Protection Authority on the definition of "significant' effects (EPA, 2018b)).

Task 3: For each site, an assessment of whether the proposed new minimum threshold water levels will meet proposed new management objectives. Where the proposed thresholds and proposed management objectives do not align, recommend amendments to the management objectives.

Task 4: For the wetlands likely to be affected by planned land use changes in East Wanneroo, an assessment of whether the original maximum water level criteria stated in WAWA (1995):
  a) are appropriate to meet the proposed management objectives proposed by DWER in the scope of works, and protect site ecological and social values, or
  b) require revision.
  c) If b), recommend appropriate maximum thresholds with justification.

Task 5: Review the proposed management objectives for Lake Gwelup and consider the ecological, social and cultural values of the lake. Propose a minimum water level threshold, and if required, a maximum threshold, at bore GLP_EC to meet the management objectives.

Structure of report

A detailed desktop review of all data collected during the *Gnangara Mound Environmental Monitoring Programme* and *Surveys of Gnangara Mound Wetland Vegetation Monitoring* will be presented in this report (see Appendix 1 & 2). An initial analysis of vegetation and aquatic assemblages is provided to understand the general trends of change for the Gnangara groundwater system in terms of changes in diversity, loss/gain of taxa, homogenisation of communities and the impact of invasive species. This general assessment provides a context of how historical shifts in diversity have shaped each wetland relative to other wetlands and illustrates the general changes being experienced by Gnangara groundwater-dependent ecosystems.

To understand the shifts that have occurred in aquatic and vegetation communities and the role groundwater levels have had in driving ecological changes at each of the monitored sites, a detailed examination of each wetland is provided. For each wetland, a summary of historical groundwater/surface water levels and current water quality information is presented. Each wetland vegetation community has been modelled to understand the role of groundwater level on the abundance of plant species and a discussion is provided on the causes of historical and contemporary shifts in vegetation composition and the likely trajectory of change should the proposed threshold levels be adopted. A similar interpretation is provided for the aquatic macroinvertebrate communities. Considering the role of groundwater on vegetation structure and the historical shifts in aquatic assemblages, an assessment of the ecological consequences of the revised 2030 thresholds on the stated site values and site management objectives is provided for each wetland.

Many terrestrial fauna rely on groundwater dependent woodlands for habitat, including lizards such as Ctenophorus adelaidens

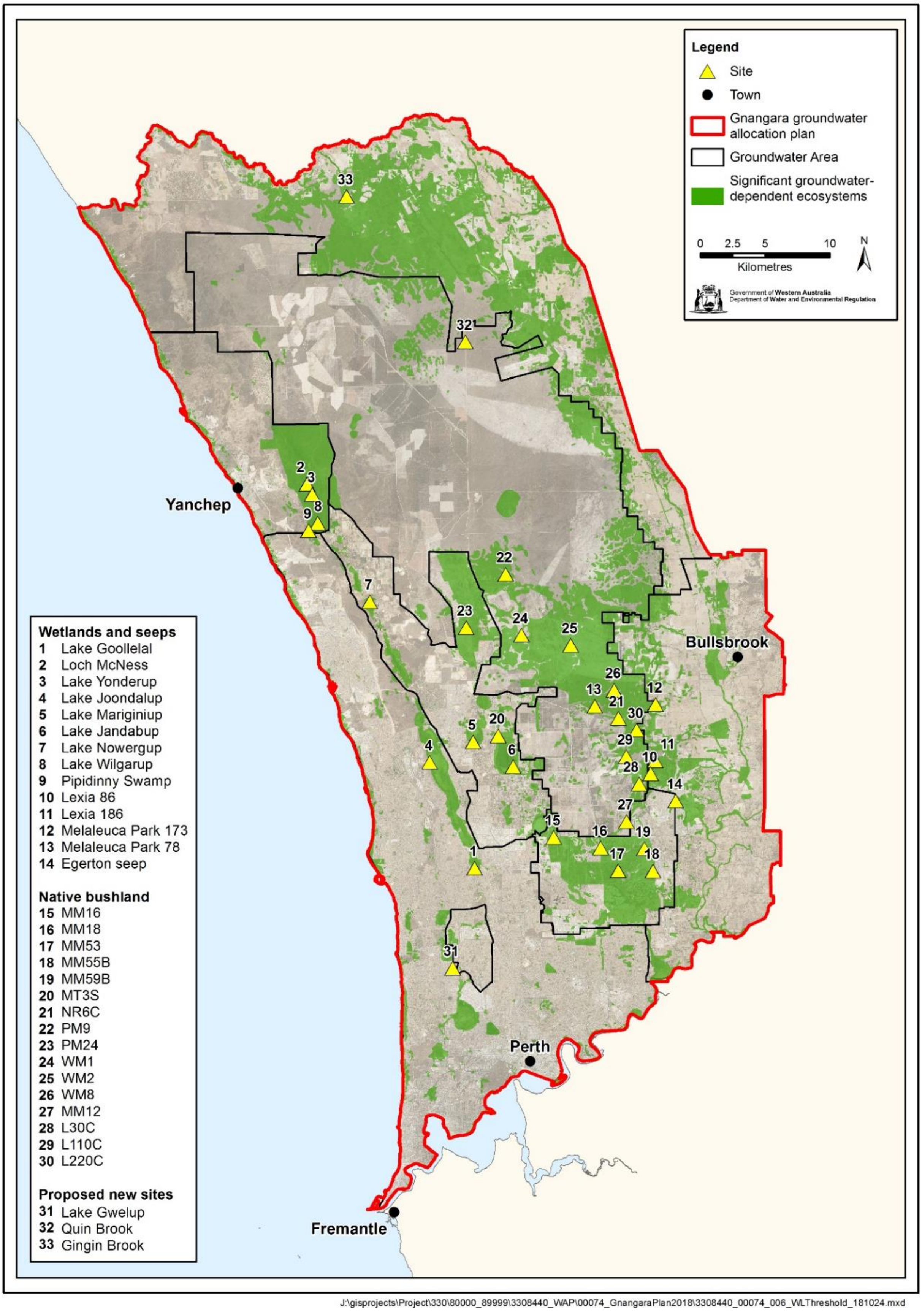


Figure 1 Gnangara groundwater allocation plan area and location of wetland and terrestrial sites investigated in this report.

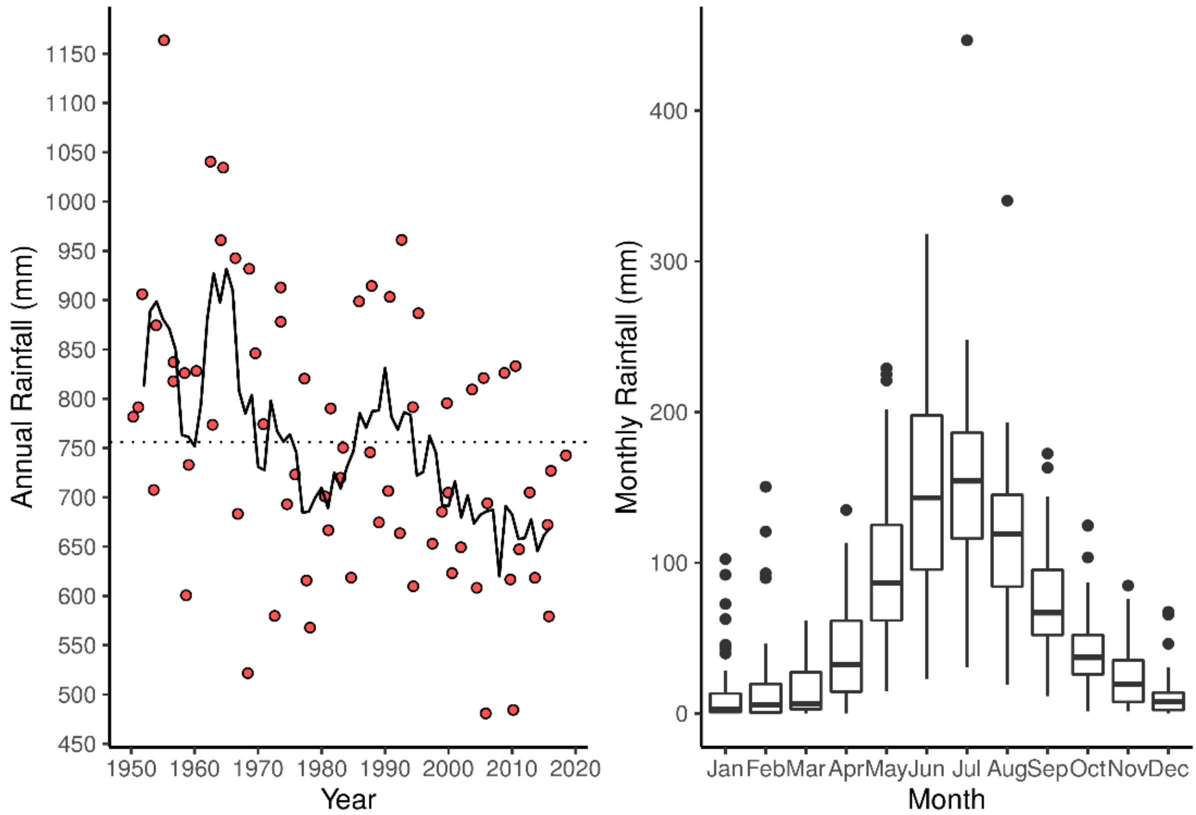


Figure 2 Left: Annual rainfall data reported for Perth Airport (BOM Site 9021) for 1950 - 2018. Red dots represent total rainfall for a given year and dotted line represents average annual rainfall for the entire period. Solid line represents a 5-year moving average of annual rainfall data. Right: Boxplots of monthly rainfall data reported for Perth Airport representing mean and range of monthly rainfall at BOM Site 9021 for 1950 - 2018.

Methodology

Twelve wetlands and five terrestrial (bushland) environments from the Bassendean and Spearwood Dune systems are analysed in this report to assess the ecological and managerial impacts of revised groundwater thresholds (Figure 1 and Table 1). For each site, vegetation and aquatic macroinvertebrate communities, where applicable, are considered when determining the consequences of the proposed minimum thresholds on the site values and management objectives. The findings of these analyses are provided in summary tables for each site where the original site values and managerial objectives and the proposed management objectives are discussed in terms of the ecological consequences and likely future changes. An assessment of the data was made by the authors (using an 'expert panel approach') to decide whether the site values and management objectives are achievable, given the proposed changes to the minimum threshold. These assessments are provided in terms of a likelihood scale (whether achievement is very unlikely, unlikely, possible, likely or very likely).

Table 1 Summary information for wetlands that have been systematically surveyed on an annual basis and those that have been sampled for the purposes of this report. For each wetland, information is provided on their morphological properties, the dunal system they are found on, whether systematic surveys of vegetation, aquatic macroinvertebrates and water quality have occurred and their location in the Swan Coastal Plain.

Wetland	Morphology	Dunal System	Vegetation	Macroinvertebrates	Water Quality	Coordinates
Lake Goollelal	Lake	Urban Spearwood Dunes	Annually	Annually	Annually	31.817°S 115.815°E
Loch McNess	Lake	Peri-Urban Spearwood Dunes	Annually	Annually	Annually	31.548°S 115.682°E
Lake Yonderup	Lake	Peri-Urban Spearwood Dunes	Annually	Annually	Annually	31.555°S 115.686°E
Lake Joondalup	Lake	Urban Spearwood Dunes	Annually	Annually	Annually	31.743°S 115.779°E
Lake Mariginiup	Lake	East Wanneroo Interdunal	Annually	Annually	Annually	31.729°S 115.815°E
Lake Jandabup	Lake	East Wanneroo Interdunal	Annually	Annually	Annually	31.746°S 115.847°E
Lake Nowergup	Lake	Peri-Urban Spearwood Dunes	Annually	Annually	Annually	31.630°S 115.732°E
Lake Wilgarup	Dampland; was a lake	Spearwood Dunes	Annually	No	No	31.574°S 115.692°E
Pipidinny Swamp	Sumpland	Spearwood Dunes	2019 survey	No	No	31.580°S 115.683°E
Lexia 186	Sumpland	Bassendean Dunes	Annually	No	No	31.743°S 115.963°E
Melaleuca Park 173	Lake	Bassendean Dunes	Annually	Annually	Annually	31.704°S 115.963°E
Melaleuca Park 78	Dampland	Bassendean Dunes	Annually	No	No	31.704°S 115.915°E
MM59B - Whiteman Park East	Terrestrial	Bassendean Dunes	2019 survey	No	No	31.804°S 115.954°E
PM9 - Pinjar North	Terrestrial	Bassendean Dunes	2019 survey	No	No	31.612°S 115.843°E
WM1 - Pinjar	Terrestrial	Bassendean Dunes	2019 survey	No	No	31.655°S 115.855°E
WM2 - Melaleuca Park North	Terrestrial	Bassendean Dunes	2019 survey	No	No	31.662°S 115.895°E
WM8 - Melaleuca Park	Terrestrial	Bassendean Dunes	2019 survey	No	No	31.694°S 115.930°E
Lake Gwelup	Lake	East Wanneroo Interdunal	Annually	No	No	31.878°S 115.791°E

Vegetation monitoring

The overall objectives of the wetland vegetation monitoring on the Gnangara groundwater system are:

- to determine the impact of altered groundwater regimes on the ecological condition of wetland vegetation
- to monitor the condition and composition of fringing vegetation at selected Gnangara wetland sites, and to determine if observed changes to vegetation are associated with changes in groundwater and wetland water levels
- to identify vegetation monitoring parameters relevant to monitoring objectives.

Vegetation is monitored every spring at selected wetland sites. Spring provides the best opportunity to capture the greatest plant diversity as well as enhancing identification as most Swan Coastal Plain flora are in flower. Annual surveys permit direct comparisons of vegetation changes to be made, especially in response to rapidly declining groundwater levels.

Extensive methodological details can be found in the annual Wetland Vegetation Monitoring reports (see Buller et al., 2019). The data analysed here primarily deals with the longitudinal cover abundance data set that has been compiled between 1996 and 2018. This data set has been collected by surveying the species present at established transects at each wetland. The standard design of these transects is a series of 3 to 4 10x10 m plots extending from the wetland end (Plot A) to the terrestrial end (generally Plot D). In some instances, when surface water declines are significant, the transect has been extended to include new plots at the current water edge. It is important to note that not every wetland is sampled every year, and some wetlands have gone a number of years since last survey (Figure 3). The vegetation at the wetland Pipidinny Swamp and four terrestrial sites, WM1, WM2, WM8 and Whiteman Park East, were surveyed for the first time in spring (2019). Only a brief description of those sites is given in this report and a more detailed analysis will be given in the 2020 Wetland Vegetation Report.

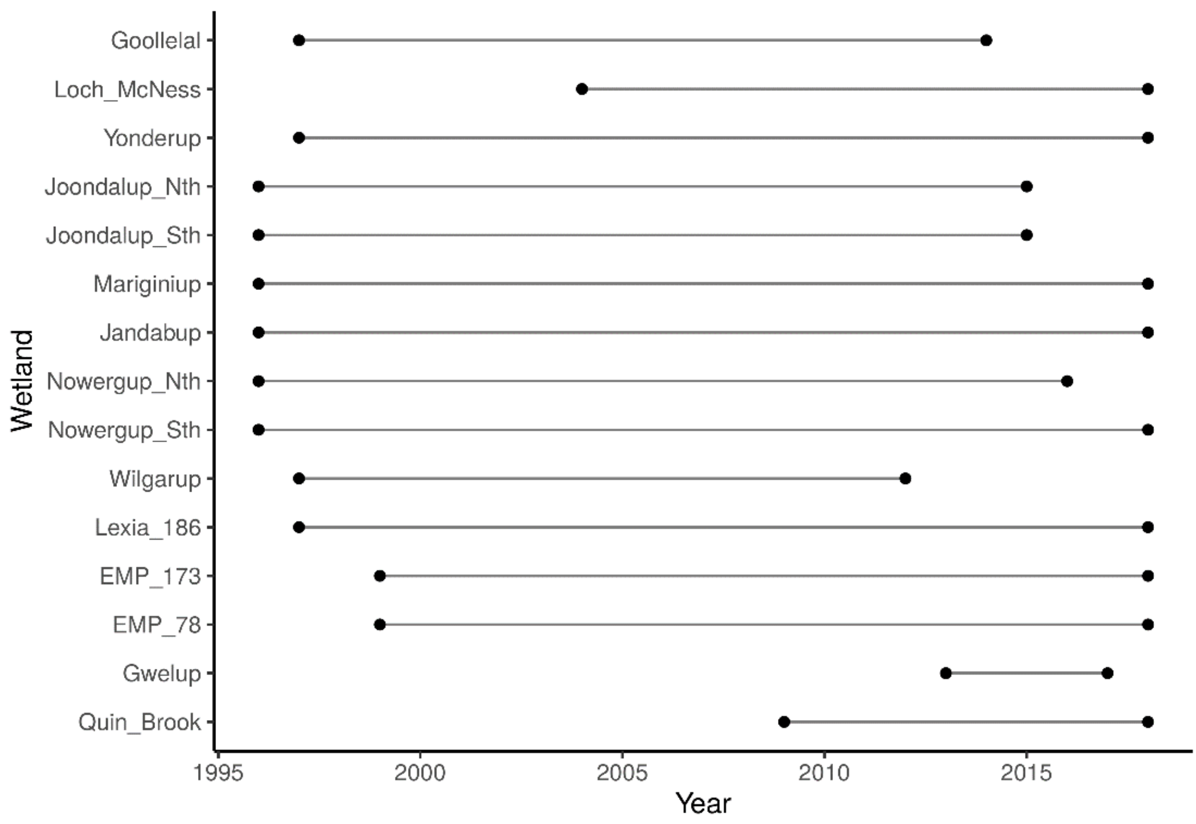


Figure 3 Period of vegetation monitoring for each wetland.

Aquatic invertebrate monitoring

Data for aquatic macroinvertebrate communities have been compiled during the Gnangara Mound Environmental Monitoring Programme - Macroinvertebrate and Water Quality Wetland Monitoring since 1996 (see Judd and Horwitz (2019) for latest report and comprehensive methodology). The wetlands included in this report where macroinvertebrate data has been collected include Lake Jandabup, Lake Mariginiup, Loch McNess, Lake Nowergup, Lake Yonderup, Lake Goollelal, Lake Joondalup and Melaleuca Park 173. All these wetlands are either permanently or ephemerally inundated.

For each wetland, a series of habitat types are sampled using 250 μm mesh nets and identified under a microscope to family levels. An abundance score for each taxon is recorded (rare = 1-2 specimens, scarce = 3-10 specimens, common = 11-100 specimens, abundant = 100-1000 specimens and extremely abundant = > 1000 specimens). Sampled habitats are subject to availability, therefore not all habitats can be sampled each year for each wetland. Sampling occurs when spring high water levels are reached for each wetland each year to ensure maximum availability of habitats and potential diversity of macroinvertebrates. For the purposes of this report, sampled habitats for each wetland have been pooled for each year. Nonetheless, the disappearance of habitats when surface water levels are not high enough to make them available, or if habitats disappear due to loss of fringing vegetation, needs to be considered when considering the role of groundwater level on the aquatic ecology of these wetlands.

Water quality monitoring

For selected wetlands, *in-situ* measurements of water chemistry at each site/location were undertaken for pH, conductivity (EC), temperature and dissolved oxygen concentration (DO). For each wetland, one sample for further analysis was usually pooled from the three most representative surface water habitats, for analysis of:

- Nitrates & Nitrites (NO_x), Ammonia as N (NH_4^+) Total Kjeldahl Nitrogen (TKN),
- Orthophosphate (PO_4^{2-}), Total Phosphorus (TP),
- Sulphate (SO_4^{2-}), Chloride (Cl^-),
- Iron (Fe), Aluminium (Al), Sulphur (S),
- Calcium (Ca_2^+), Potassium (K^+), Magnesium (Mg_2^+), Sodium (Na^+),
- Acidity, Alkalinity,
- Chlorophyll-a, Turbidity

Patterns in these data were drawn from the most recent report and described qualitatively and extrapolated according to projected water regimes where applicable.

Statistical analyses

Generalised additive models (GAMs) were used to model non-linear trends in water level time series data (Wood, 2011). Historical water level data for each of the wetlands in this report was accessed from the DWER website (http://www.water.wa.gov.au/maps-and-data/monitoring/water-information-reporting). To simplify modelling, mean monthly water levels were calculated and used for modelling. A cyclic cubic spline with 12 dimensions was used as a smooth term to ensure there was no discontinuity between January and December water levels. To account for correlated errors, an ARMA process, nested within each year, was fitted to the residuals using the R package *nlme* v 3.1-141 (Pinheiro et al., 2019). All GAMs were fitted using the R package *mgcv* v 1.8-30 (Wood, 2019). During periods when the staff gauge measuring surface water levels has been dry, the minimum reading of the staff gauge has been used in the modelling. These results need to be treated with caution as water level declines will be underestimated by our model.

A multivariate analysis was used to explore the effects of ground/surface water level on vegetation communities. This fits a multivariate generalised linear model to the data so that the effects of species covariates (including groundwater level) on each species can be modeled (Hui, 2016). Species abundances (vegetation and macroinvertebrates) were fitted to negative binomial distributions and the models fitted with two latent variables. The models were fitted and unconstrained model-based ordinations were carried out on the macroinvertebrate and vegetation data using the *boral* package v 1.7 (Hui, 2018). The resulting ordinations enable graphical representations of communities for each wetland to be made, with points closer to each other more similar in terms of taxonomic composition than those more distant. Wetland specific boral models were run using the mean fitted water level for each survey year as a covariate in order to understand species specific interactions with water levels. All analyses were conducted using R (version 3.6.1) and results are presented in Appendices 1 and 2.

Tasks 1-3: Assessment of 2030 proposed minimum thresholds

This section provides an assessment for each wetland or bushland site on what effect managing levels to the proposed 2030 absolute minimum threshold water levels will have on the original site management objectives and values as well as possible effects on species composition, key, priority or threatened species and existing ecohydrological states. A brief summary is provided in Table 2 that provides the key findings for each site. For each site, a description of past hydrological patterns is provided with an emphasis on understanding periods of changing hydrological regimes. A summary table is provided for each site detailing the ecological consequences of the proposed changes on the management objectives and values.

The summary table (Table 2) also provides an assessment of whether the proposed changes to water level criteria will have a significant impact on the values of each site. The definition used to make these assessments of a significant impact is provided in EPA (2018b). The potential for a significant impact on site values was assessed in terms of:

a) the impact on values, sensitivity and quality of the environment

b) extent, intensity, duration, magnitude and geographic footprint of impact

c) consequences of impact

d) resilience of a system to cope with impact

e) cumulative impact with other disturbances such as land use

f) holistic impact on whole environment

g) confidence of predictions

h) public interest

These summaries are based on a thorough analysis of aquatic macroinvertebrate and wetland vegetation data from systematic annual monitoring, when available. The results of these analyses are provided in Appendix 2, detailing specific patterns of change and predicted future effects for water quality, aquatic macroinvertebrates and vegetation. Multivariate modelling using the vegetation and macroinvertebrate monitoring data was used to determine trends in compositional change throughout the survey periods and to understand which components of each community were shifting due to changing water levels. These results are presented as biplots and regression coefficient plots in the respective appendices. Historical elevation ranges determined during the vegetation surveys are also presented in the respective appendices and were used to assess the implications of future water levels on meeting the ecological water requirements for some key wetland species. These results provide a picture of how each wetland community has changed in taxonomic composition, how each species has responded to historical changes in water levels and the likelihood of key wetland vegetation species retaining their ecological water requirements in the future. Based on these results, assumptions were made as to:

1) which species are likely to become more and less abundant given the projected groundwater regimes

2) the effect these responses will have on maintaining each site's values and management objectives.

Within each site summary table, additional values are suggested that reflect the current ecological status of the site and proposed management objectives are assessed. When the proposed management objectives are unlikely to be achievable, suggestions are made that will protect the site's existing and additional values.

Table 2 Summary of ecological consequences of proposed threshold levels in terms of compliance of stated site values and site management objectives at wetlands and bushland sites on Gnangara groundwater system. An assessment of whether the proposed changes to water level criteria represent a significant effect (as defined by the Environmental Protection Authority 2018b) on the original and additional values of each site is made. Assessments are only made for additional values for sites where new additional values are proposed in this report. Green shading indicates the site's originally stated values will be retained (no predicted impact of the proposed thresholds on the state's originally stated values; WAWA, 1995 and WRC, 1997). Red shading indicates the site's originally stated values will be lost (significant impact of the proposed thresholds on the site's originally stated values; WAWA, 1995 and WRC, 1997).

Wetland or bushland site	Current minimum level criteria (mAHD)	Proposed minimum level threshold (mAHD)	Ecological consequences	Will site values be retained by proposed thresholds?
Lake Goollelal	26.0	26.4	If levels at the lake are maintained above the proposed threshold level, the lake will remain permanently inundated at similar levels as present. As long as water quality does not deteriorate from other causes, fringing vegetation will persist and provide habitat for the current diversity of aquatic invertebrates. The site will continue acting as a drought refuge for water birds and provide important habitat to important native fish species.	Additional values: Yes Original values: Yes
Loch McNess	6.95	6.20	Managing levels to the proposed threshold will increase the current extent of surface water at the lake and maintain its current ecological and social values. The additional values of Loch McNess have been impacted by declines in groundwater that have caused major shifts in vegetation and aquatic invertebrate communities. In particular, the unique assemblage of macroinvertebrates present within the lake has been partly replaced by more common taxa and nuisance species. Declining water levels have also caused the disappearance of *B. articulata*, an important fringing macrophyte. Declining water levels have caused significant increases in nutrient levels and sustained low water levels are likely to have serious consequences for an important population of Rakali. If lake levels increase from current minimum levels to the proposed threshold level, the rises beyond current water levels will not be sufficient to reverse these ecological shifts and characteristic features and ecological processes of the system are unlikely to return. It is recommended that the current minimum level criteria (6.95 mAHD) be retained for this site and the hydrological regime be restored.	Additional values: Yes Original values: No

Lake Yonderup	5.9	5.7	If current levels at the lake increase to above the proposed threshold the lake's macroinvertebrate community will likely remain stable and the higher levels may have beneficial effects for the surrounding *Bankisa* woodland and fringing vegetation. The once very stable hydrological regime is not likely to return to this wetland if the wetland remains non-compliant with the current Ministerial criteria. Nonetheless, the aquatic macroinvertebrate community has remained relatively stable in composition, a feature likely to persist if further declines do not occur. Further declines in water level before 2030 may cause significant changes in water quality, especially nitrogen levels, which may impact aquatic invertebrate communities before reductions in abstraction take effect and the proposed threshold can be achieved. Vegetation around the monitoring area is likely to remain impacted by exotic species and water stress.	Additional values: Yes Original values: No
Lake Joondalup	15.8	16.2	Managing levels to the proposed threshold will see water levels maintained at levels higher than current levels. This will have a positive impact for fringing sedge vegetation and fish and bird habitat. There is the possibility that surrounding urbanisation may prevent existing terrestrial vegetation from migrating further up-slope as downslope environments become wetter. This may eventually reduce the area available to terrestrial vegetation to colonise. Nutrient enrichment remains an issue for the lake and further increases in nutrient levels may cause a shift in ecological processes and change the character of the lake.	Additional values: Yes Original values: Yes

Lake Mariginiup	41.5 (minimum spring peak)	42.1 (minimum spring peak)	The projected increase in current water levels due to urbanisation in the catchment and implementation of the proposed (higher) minimum spring peak may be sufficient to halt acidification of the lake. It is possible to restore the water quality of the lake, but this requires the sediments to have sufficient capacity to buffer the acidification once re-wetted. Nonetheless, if acidification cannot be reversed, the current assemblage of macroinvertebrates is likely to persist. The expected increases to groundwater levels will enhance the extent of habitat available to wading birds. With the expected increases to surface water levels, the entire distribution of *E. rudis* is likely to become seasonally inundated. This may reverse the current trend of declining health of *E. rudis*. Prolonged inundation (> 3 years) will cause death of *E. rudis* individuals, therefore minimum summer levels should fall below 41.7 mAHD (at least). Given the past declines in water level and the acidification that has occurred, it is likely that the native fish *P. olorum* is locally extinct from the lake and it will not return unless water quality is restored and it is somehow able to migrate back to the lake. It is predicted that fringing vegetation, particularly *B. articulata*, will undergo distributional changes as surface water levels increase.	Original values: Yes
Lake Jandabup	44.3	44.3	Acidification has caused a decrease in richness of the aquatic macroinvertebrate community. Recent evidence suggests that under the augmentation regime, acidification may have been halted however the wetland remains at risk for further acidification. Managing levels to the proposed threshold is likely to continue this trend. Otherwise, the predicted increases in surface water levels associated with managing levels to the proposed threshold will have a beneficial effect on native vegetation, sedges and wader bird habitat. Elevated nutrient levels may continue to remain a concern.	Additional values: Yes Original values: Yes
Lake Nowergup	16.8 (spring peak)	16.0 (summer minimum)	Maintaining water levels above 16.0 mAHD represents a possible lowering of the current water level criterion, but an elevation above existing water levels. Managing levels to the proposed threshold will increase the current extent of surface water at the lake and maintain its current ecological and social values. The planned reductions in groundwater abstraction may increase the distribution of sedges, maintain deep-water habitats, prevent further declines in macroinvertebrate richness and reduce the risk of acidification. The capacity of this wetland to act as a drought refuge for birds and an important habitat for native fish will be enhanced compared to current water levels.	Original values: Yes

Lake Wilgarup	4.5	3.9	Lake Wilgarup, as a wetland, has been severely compromised by a combination of declining groundwater levels and fire. The site no longer resembles a wetland and is dominated by terrestrial woodland vegetation. Managing levels to the proposed threshold is unlikely to reverse the terrestrialisation of this site. Future management objectives should aim to maintain the wetland sediment processes in order to restore new habitats.	Original values: No
Pipidinny Swamp	1.6	1.1	Aquatic macroinvertebrate communities have been seriously compromised at Pipidinny Swamp due to past declines in water levels. Although managing levels to the proposed threshold would mean levels will be higher than they are currently, this state will be much lower than pre-2000 levels. Managing levels to the proposed threshold is unlikely restore the aquatic macroinvertebrate communities to what was once typical of the swamp, and exotic plants will remain a feature of the vegetation community. Nonetheless, if levels are managed to the proposed threshold, fringing vegetation is likely to persist and continue to provide habitat for aquatic fauna. It is unlikely that the site will provide habitat for the abundant bird populations that visited and resided at the swamp prior to 2000.	Original values: Yes, but loss of value as a bird habitat
Lexia 186	47.2	46.5	A significant shift in hydrological regime has occurred at Lexia 186. The site has transformed from a seasonally waterlogged dampland to a system where saturation of surface sediments no longer occurs. The site has retained the high richness of native species and is still an important habitat for fauna. Managing levels to the proposed threshold is likely to maintain the system in a state that currently exists. The proposed threshold will increase the likelihood of not meeting the ecological water requirements for *M. preissiana* during periods of low water. Maintaining water levels above 47.0 mAHD will reduce this risk.	Original values: No

Melaleuca Park 173	50.2	48.5	Managing levels to the proposed threshold will see the wetland managed in a state similar to what currently exists. The wetland has shifted from a permanently inundated wetland to a seasonally inundated dampland, hence there have been shifts in vegetation and aquatic fauna. The site no longer provides habitat to fish species, an important value of the wetland. Fringing vegetation is likely to continue shifting in composition as key wetland species are lost and more terrestrial species migrate down-slope. Aquatic fauna is likely to persist with much less diversity as available habitats are diminished and change. Considering a higher minimum water threshold of 49.0 mAHD would ensure surface waters occur every year and halt, or even reverse, the terrestrialisation of the vegetation community.	Additional values: Yes Original values: No
Melaleuca Park 78	65.1	64.7	Despite the dramatic declines in groundwater, the site still retains a high richness of native vegetation species. Some wetland species have disappeared, notably *B. articulata*, however, multivariate modelling predicts that many key wetland species will remain at the site despite the projected declines in groundwater levels. Managing levels to the proposed threshold will retain many of the values that currently exist at the site. Peak ground water levels that reach 65.5 mAHD will alleviate water stress of *M. preissiana* at higher elevations of the site and may reverse the trend of declining health of these individuals.	Original values: Yes
MM59B - Whiteman Park East	36.3	36.2	No long-term vegetation monitoring exists at this site. Current vegetation is impacted by predation from rabbits and despite the declining groundwater levels, the vegetation appears in good health. Managing levels to the proposed threshold will require water levels to be substantially higher than current levels, suggesting the health of the woodland will improve. Woodland health will be maintained by groundwater levels being maintained within 5 m of the surface (36.2 mAHD). Although the proposed minimum threshold is unlikely to have an adverse effect on the vegetation community at this site, sustained predation from rabbits is disturbing phreatophytic vegetation and facilitating the establishment of invasive plants and diminishing the value of this woodland.	Original values: Yes

PM9 - Pinjar North	56.3		The declines projected to occur in groundwater at this site will make it impossible for wetland species to exist. The projected changes suggest water levels will decline to more than 10 m below the surface. The understory is likely to be dominated by dryland species (such as *Acacia*). *Banksia* woodlands may persist, but it is unlikely they will be dependent on groundwater and will need access to rainfall to meet their requirements. No vegetation data has been considered in this determination. Therefore, the existing Ministerial criteria level should be removed for this site.	Original values: No
WM1 - Pinjar	55.7	53.7	If levels are managed to the proposed threshold, they would decline to more than 6 m below the surface, suggesting that this site will be less dependent on groundwater. It is likely that changes in vegetation have occurred as the site is currently dominated by a dryland understory. Remaining *Banksia* individuals appear in good health and may be meeting their water requirements from rainfall and recent increased access to groundwater as a result of higher water levels since 2016. However, further declines in *Banksia* health are predicted given the projected declines in groundwater levels.	Original values: No
WM2 - Melaleuca Park North	66.5	64.7	If levels are managed to the proposed threshold, they would decline to more than 7 m below the surface, suggesting that this site will be less dependent on groundwater. It is likely that changes in vegetation have occurred as the site is currently dominated by a dryland understory. Remaining *Banksia* individuals appear in good health and may be meeting their water requirements from rainfall and recent increased access to groundwater as a result of a jump in water levels in 2016. However, minimum water levels have since been on a declining trajectory and further declines in *Banksia* health are predicted given the future projected declines in groundwater levels.	Original values: No
WM8 - Melaleuca Park	64.8	63.7	If levels are managed to the proposed threshold, they would decline to more than 7 m below the surface, suggesting that this site will be less dependent on groundwater. It is likely that changes in vegetation have occurred as the site is currently dominated by a dryland understory. Remaining *Banksia* individuals appear in good health and may be meeting their water requirements from rainfall and recent increased access to groundwater as a result of higher water levels since 2016. However, water levels have declined substantially in 2019-20 and further declines in *Banksia* health are predicted given the future projected declines in groundwater levels.	Original values: No

Fringing vegetation along the margin of Lake Goollelal 2019.

Lake Goollelal

Lake Goollelal, located within the Yellagonga Regional Park, is recognised as an important water bird habitat and drought refuge (Froend, et al., 2004a) as well as habitat for the Swan River Goby (*Pseudogobius olorum*) and the Western Pygmy Perch (*Edelia vittata*; Water Authority of Western Australia (1995)). The permanent deep waters found in the lake not only provide significant habitat for fauna and fringing vegetation, but also hold significant value as a place of public enjoyment. The lake is surrounded by a highly urbanised area, with much of the lake buffered by a belt of fringing vegetation, although some residences are near the lake's margin.

Current hydrological regime

Surface water levels recorded at Lake Goollelal reveal peak levels generally occur between September and November and lowest water levels between March and May (Table 3). Annually, water levels have consistently varied by about 0.7 m during this period. Since 1995, there has been a general trend of decreasing surface water levels, although recent increases since 2016 show surface water at a similar depth to 1990 levels (Figure 4). Surface water levels show similar trends to groundwater levels at a nearby bore (61611870) as the lake is largely fed by groundwater. Although the current absolute minimum criteria of 26.0 mAHD has not been breached, it is likely the criteria is set too low as acidification of waters in the lake is a concern (Quintero Vasquez and Lund, 2018). Proposed changes to the Ministerial criteria include adopting a higher minimum threshold level of 26.4 mAHD. Based on the modelling, the proposed threshold can be met at 2030.

Table 3 Five-year summaries of surface water level data at Lake Goollelal recorded at staff 6162517.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	27.5 (Oct)	26.8 (May)	0.78	207
08/1999 – 07/2004	27.5 (Sept)	26.7 (Mar)	0.80	206
08/2004 – 07/2009	27.4 (Sept)	26.6 (Apr)	0.75	137
08/2009 – 07/2014	27.2 (Oct)	26.5 (Apr)	0.73	190
08/2014 – 07/2019	27.4 (Nov)	26.7 (Apr)	0.68	139

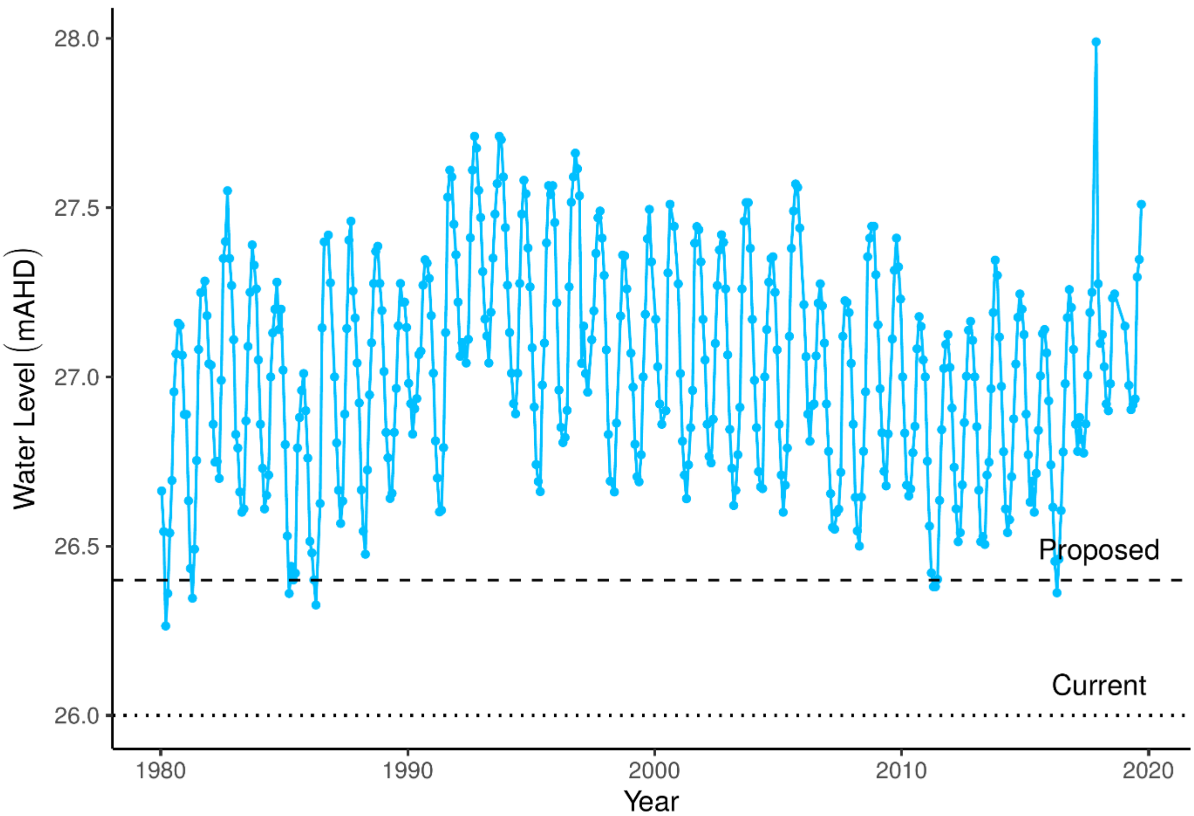


Figure 4 Surface water levels recorded at staff 6162517 for Lake Goollelal. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of the proposed threshold

Groundwater modelling of the planned reductions in groundwater abstraction project that the current hydrological regime of Lake Goollelal can be maintained. Managing levels to a minimum threshold of 26.4 mAHD (0.4 m higher than current threshold) will minimise the risk of acidification at Lake Goollelal. If levels are managed to the proposed threshold, vegetation composition is likely to remain distinct across the elevations of the basin, with *B. articulata* and *Lepidosperma gladiatum* persisting along the lake margin. The richness of exotic plant species in the higher areas of the basin are likely to persist or decline if surface water levels remain at, or greater than, present levels. It is therefore likely that the predicted higher post-2030 water levels due to reduced abstraction will have a positive impact on the vegetation structure of the lake. Similarly, it is expected that the aquatic invertebrate community will remain stable as fringing vegetation preserves habitat availability and water quality. The continuation of higher than present water levels, combined with low nutrient concentrations, will facilitate the return of aquatic invertebrate assemblages to pre-2007 compositions. Research suggests that nuisance midges will not proliferate under conditions of higher water levels and decreased periods of exposure of nutrient rich sediments to shallow water (Lund and Gonzalez-Pinto, 2016).

Managing levels to the proposed threshold will likely maintain ecological conditions similar to the present (Table 4). The most important impact of managing to the threshold is that it will ensure water levels remain at, or higher than, present levels which has positive implications for habitat availability and risk of acidification. Maintaining permanent water will ensure that Lake Goollelal acts as a drought refuge for water birds, with seasonal fluctuations in water levels ensuring feeding habitats are available for waders during the summer months. The preservation of fringing vegetation, submerged macrophytes and deep water will also ensure the wetland continues to support important native fish species (*P. olorum* and *E. vittata*), a feature becoming rarer among wetlands in the Swan Coastal Plain. Conservation of these values will maintain the site as a place for public enjoyment and maintain the current landscape amenity values.

Table 4 Ecological consequences of proposed 2030 minimum threshold (26.4 mAHD) in terms of compliance of stated site values and site management objectives at Lake Goollelal set for the current absolute minimum Ministerial criteria (26.0 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. "Additional values" refers to additional wetland features that were not originally recognized, and that might now be regarded as features worth managing to protect.

	Likely effect of 2030 proposed threshold (26.4 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Water bird habitat and drought refuge	Permanent water will ensure site as drought refuge. Seasonal variation in water levels will preserve feeding habitats	Likely
Supports good populations of native fish species, Swan River goby (*Pseudogobius olorum*) and the western pygmy perch (*Edelia vittata*)	Maintenance of deep waters, fringing vegetation, submerged macrophytes and water quality will ensure the wetland remains an important habitat for these fish species	Likely
Site management objectives (WAWA, 1995)		
Conservation and public enjoyment of natural and modified landscapes	Fringing vegetation and woodlands will remain healthy and the site will continue to provide habitat for fauna. The site will continue to remain a place of public enjoyment.	Likely
Protect and, if possible, enhance fringing wetland vegetation including woodland and sedge vegetation	Maintenance of surface water levels at, or slightly higher than, current levels will ensure that woodland and sedge vegetation remain healthy. The distribution of sedges may increase slightly.	Likely
Maintain permanent, deep water for water bird habitat and as a drought refuge	Managing to the proposed threshold level would ensure that permanent and deep water will remain a feature of the wetland. The capacity of the wetland to act as a drought refuge will continue.	Likely
Maintain permanent water for fish and other dependent species	Managing to the proposed threshold level would ensure that permanent and deep water will remain a feature of the wetland. Permanent water will preserve fish habitat and water quality.	Likely

Maintain the landscape amenity values of the wetland	Healthy vegetation and abundant bird life will remain a feature of the wetland if water levels are sustained at current levels, ensuring the amenity values of the wetland.	Likely
Additional values		
Aquatic macroinvertebrate values	Healthy populations of the glass shrimp *Palaemonetes australis*	Likely
Proposed site management objectives		
Maintain permanent surface water for fauna habitat and visual amenity	Managing to the proposed threshold level would ensure permanent surface water at the site which will continue to provide faunal habitat and protect the visual amenity of the lake.	Likely
Maintain fringing vegetation	Permanent inundation of this site will ensure that fringing vegetation will continue to occupy available habitat at the site.	Likely
Minimise risk of acidification and nuisance midge proliferation	The projected changes to groundwater levels will reduce the risk of acidification by ensuring sediments remain wet. Unpublished research suggests that nuisance midges will not proliferate under conditions of higher water levels and decreased periods of shallow water over sediments.	Likely

Surface waters in the southern reach of Loch McNess 2019

Loch McNess

Loch McNess, located in Yanchep National Park, is a relatively undisturbed wetland with large areas of intact Herdsman Complex vegetation. The lake was regarded as having relatively good water quality, having provided an important habitat for water birds and other aquatic fauna (Froend, et al., 2004a). Permanent water is required to support a local Rakali (*Hydromys chrysogaster*) and terrestrial habitat is important for the native Bush rat (*Rattus fuscipes*) population (McIlduff, et al., 2014) as well as both resident and visiting populations of waterbirds and waders. The southern lake at Loch McNess is one of the few wetlands known to contain the nightfish *Bostockia porosa* and has one of the richest aquatic macroinvertebrate communities of the Swan Coastal Plain (Horwitz et al. 2009). Loch McNess has previously been a wetland of high conservation value because of its intact vegetation, largely unaltered aquatic processes and important populations of fauna (Froend, et al., 2004a). Dramatic declines in surface water levels since 2007 have likely affected the conservation values of this wetland.

Hydrology

Surface water levels were remarkably stable before 2003 at 7 mAHD and have declined at least 1.5 m to present levels. These declines have been mirrored in surrounding bores (Figure 5). Mean maximum and minimum seasonal water levels have declined by 0.9 m since 1994-2004 levels (Table 5). Changes in seasonal patterns are difficult to interpret due to staff gauge 6162564 being mostly dry since 2014, but during the period 2009-2014, minimum water levels were not being reached until May, compared to March in the decade 1994-2004. A recent increase in water level, as seen in surrounding wetlands during the last few seasons, has not been observed at Loch McNess although monitoring suggests groundwater levels have stabilised in the last few years (M. Hammond, pers. comm.). The dramatic decline in water levels is causing the terrestrialisation of the lake as much of the lakebed is now undergoing recruitment by fringing vegetation. Substantial parts of the lakebed are now covered by floating beds of rushes and sedges. Open water consists of a very shallow layer of clear water on top of very deep unconsolidated sediments.

The lake has been non-compliant with Ministerial water level criteria since 2003 and water levels are now approximately 1.0 m below the criterion. Modelling of groundwater levels under planned abstraction reductions projects that there will not be sufficient increases in groundwater level to make this wetland compliant with existing criteria. Under the new plan, a proposed threshold of 8.0 mAHD at bore 61612104 will satisfy the proposed threshold of surface water in the lake at 6.2 mAHD (0.75 m below existing criterion). This will result in water levels being similar to 2010 levels which are more than 0.3 m higher than current levels.

Prior to 2006, water flowed through the lake from springs and the lakebed and outflowed along the western margin. Evapotranspiration from the lake and its vegetation could be sufficient to account for minor seasonal fluctuations; the increased amplitude of seasonal variations experienced in recent years mirrors more closely the fluctuations of the groundwater. Kretschmer and Kelsey (2016) suggest that spillover along the lake's western margin into caves and a karstic aquifer previously controlled maximum water levels in the past. However, due to declining inflows associated with a sustained decline in water table depth, inflow has been reduced sufficiently below outflow levels and hence lake surface water levels have declined (Kretschmer and Kelsey 2016). An alternative hypothesis suggests that the karst barrier on the western/southern side of the lake, which has maintained constant water levels, has been breached, probably due to an event-related erosion (Muirden pers comm.).

Table 5 Five-year summaries of surface water level data at Loch McNess. No data is available for the 2014-2019 period due to the staff gauge being dry.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	7.1 (Sep)	7.0 (Mar)	0.11	123
08/1999 – 07/2004	7.1 (Jul)	6.9 (Mar)	0.12	91
08/2004 – 07/2009	7.0 (Jun)	6.8 (Feb)	0.21	131
08/2009 – 07/2014	6.5 (Oct)	6.2 (May)	0.31	229
08/2014 – 07/2019	NA	NA	NA	NA

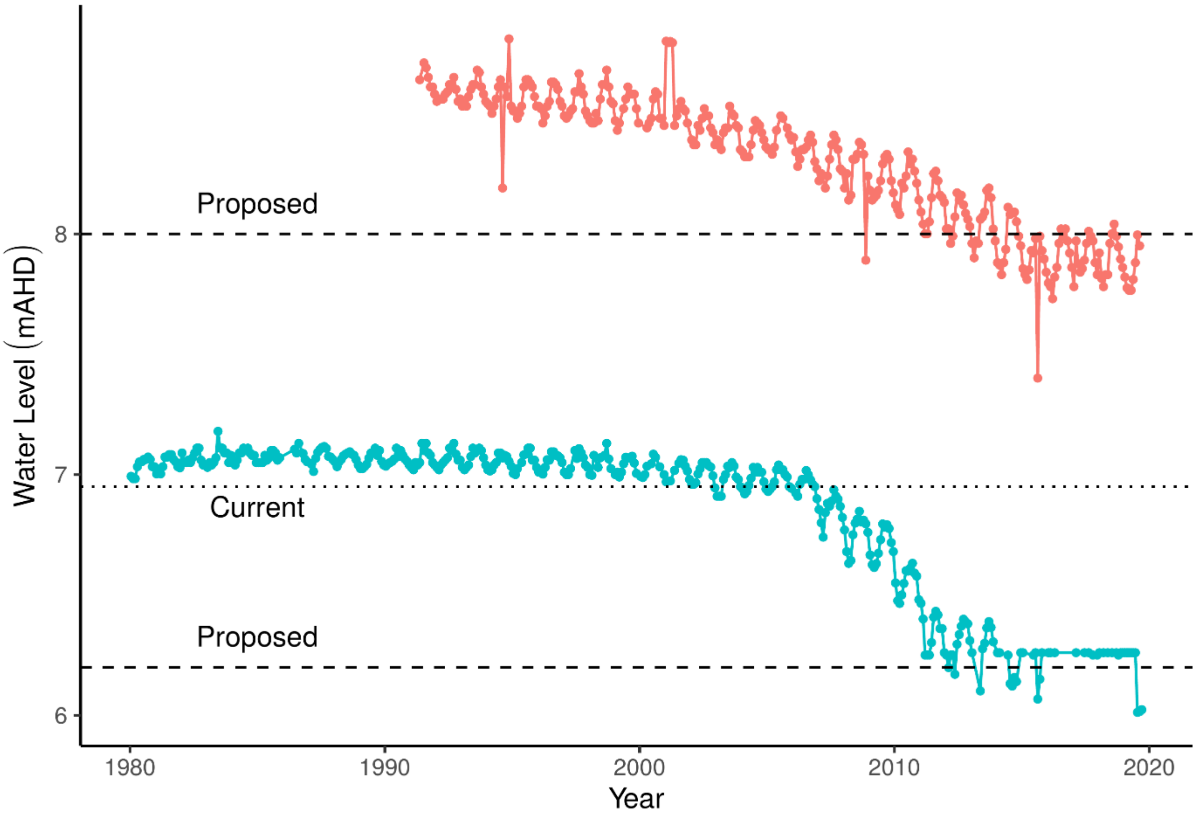


Figure 5 Ground and surface water levels recorded at bore 61612104 (red) and staff gauge 6162564 (blue) that represent changes in water levels at Loch McNess. Dotted line is the current Ministerial criteria water level for surface water at the staff gauge. Dashed lines are proposed thresholds for the staff gauge and bore. Since 2015, water levels for the staff gauge have consistently been below the minimum reading of 6.25 mAHD. These observations therefore underestimate the decline in surface water levels since 2015 which are likely to have continued to decline at a slower rate than as before 2014. Accordingly, the water levels in Loch McNess should be showing a continued decline in recent years much like the bore which suggests a slower rate of decline and possible stabilisation since 2018.

Implications of the proposed threshold

The unique hydrogeology of this system that once sustained stable water levels, high inflow and low nutrient levels has been compromised. Without the re-establishment of these hydrogeological drivers, the risk of eutrophication is likely to increase as the lake transitions away from a system that is well flushed from high inflow to one of shallower nutrient enriched waters. Despite representing an improvement on the current state (2018), managing the lake at the proposed threshold (0.75 m below the current criteria) will not reverse the deterioration of site values at Loch McNess (Table 6). The proposed threshold will ensure conditions similar to the 2011/season recorded by Kretschmer and Kelsey (2016) whereby less than one-third of the lake area was inundated with shallow, turbid water. Coverage of large areas of once inundated lakebed will continue, open water above metaphyton will become shallower, nutrient levels may stay elevated and important habitats for Rakali may be lost.

The characteristic stable water levels have been severely disrupted by a changing hydrological regime, and the proposed threshold will not manage surface water at a sufficient level to return to this state. Altered ecological processes have already caused shifts in nutrient levels and the composition of macroinvertebrate assemblages. Even with the predicted rises in levels associated with planned reductions to abstraction, it is unlikely that the macroinvertebrate community will return to compositions similar to pre-2008. Again, the values of Loch McNess as stated in WAWA (1995) are unlikely to return to normal given the proposed lowering of threshold levels.

Table 6 Ecological consequences of proposed 2030 minimum threshold (6.2 mAHD) in terms of compliance of stated site values and site management objectives at Loch McNess set for the current absolute minimum Ministerial criteria (6.95 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. "Additional values" refers to additional wetland features that were not originally recognized, and that might now be regarded as features worth managing to protect. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 proposed threshold (6.2 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Undisturbed wetland	Sustained low water levels will continue to cause a shift in vegetation composition as once inundated regions of the lake become terrestrialised or covered by floating mats. The disappearance of *B. articulata*, an important fringing sedge, along much of the southern margin of the lake marks a significant change in composition of the wetland vegetation.	Unlikely
Unusual hydrologic regime	Surface water levels appeared to reach a tipping point in 2003. There has been significant disruption of once stable water levels which are not projected to return to normal under reduced abstraction.	Unlikely
Rich aquatic fauna	Declining water levels have not changed the richness of the aquatic invertebrate assemblage. However, there has been a shift in the composition of the assemblage. Managing water levels above the minimum proposed threshold may prevent the assemblage returning to pre-2003 composition, and instead will likely maintain an assemblage composed of more common taxa and nuisance species. The fate of the nightfish population is currently unknown.	Disrupted
Vegetation largely intact, provides a range of habitat types	The health of fringing *M. rhaphiophylla* and *E. rudis* appears good, despite the lower water levels. *Carex fascicularis*, *M. rhaphiophylla* and *Triglochin centrocarpa* are likely to have reduced distributions/abundance compared to historical data. *Baumea juncea* will increase in abundance as its distribution has extended downslope. Loss of *B. articulata* will alter fringing fauna habitat. Fire events, including the recent 2019 summer fire, are likely to have impacted vegetation composition. Loss of islands in lake may affect the Rakali population.	Likely

Supports good populations of water birds and acts as a drought refuge	Managing levels to the proposed threshold will sustain slightly deeper permanent water at the site compared to current levels. Permanent water is fundamental to the lake acting as a drought refuge for birds.	Likely
Excellent water quality	The altered hydrological regime of the lake will not be sufficiently reversed if levels are managed to the proposed threshold. This will prevent the lake returning to a state of high inflow that maintains low nutrient levels due to the low residence time of the water. Instead, higher than normal nutrient levels will persist, and the lake may be at risk of eutrophication.	Unlikely
Site management objectives (WAWA, 1995)		
Maintain the environmental quality of the lake	The environmental qualities that characterized the lake will not be maintained; instead it is a reasonable supposition that they will change unless the hydrological regimes of the past are re-instated.	Unlikely
Maintain North Loch McNess' pristine state	An erosion of the buffering capacity of the wetland system has been detected, probably due to drying and re-wetting regimes; even though levels maintained at above the current ones will reduce the frequency of these cycles, acidification of this wetland is possible under proposed threshold.	Unlikely
Continue to use south Loch McNess for low key recreation	The deep unconsolidated sediments and floating mats make the wetland treacherous for any form of in-lake recreation. The use of the popular walking track around the lake will not change, however exposed sediments may make it less appealing.	Unlikely
Maintain east Loch McNess in a natural state, to restore, where possible, natural flow	No data.	Unknown
Maintain the existing hydrological regime	The loss of stable water levels (once a characteristic of the lake) has deteriorated to the point where water levels have declined more than 1.0 m and are susceptible to further declines under a drying climate despite the proposed threshold. In-lake evapotranspiration as the dominant contributor to seasonal fluctuations has been lost.	Unlikely
Additional site values		
Important habitat for native mammals	Rakali (*Hydromys chrysogaster*) and bush rat (*Rattus fuscipes*) inhabit the Loch McNess region. Maintaining fringing habitat and island refuges will ensure important habitats remain available. Other measures may need to be considered, including predator control.	Likely

Aquatic macroinvertebrates	Only monitored wetland on the Gnangara groundwater system to have a population of simuliid blackfly	Likely
Proposed site management objectives		
Increase surface area of permanent water for fauna habitat and visual amenity	Managing water levels to the proposed threshold will increase the current surface area of permanent water and ensure at least 1/3 of the lake will remain inundated. However, the new water levels will not return the lake to the previous extent and conditions. These low water levels have already severely shifted ecological processes in the lake. Continuation of these low water levels will continue to impact faunal habitat, particularly for Rakali. It is possible visiting bird assemblages will shift from diving birds to waders. Visual amenity may not improve as vegetation continues to encroach into the lakebed and surface water remains obscured from view from visitors to the park.	Likely (slight improvement on current conditions)
Maintain healthy, intact fringing vegetation	There has been a marked decline in *B. articulata* at the site and it is possible that it is absent from the wetland all together now. Fringing vegetation is now dominated by *Lepidosperma gladiatum* and *E. rudis*. The projected changes in water levels will ensure permanent water at the site and maintain fringing vegetation stands, however it is unlikely *B. articulata* will reestablish.	Very likely (continued absence of *B. articulata*)
Maintain diverse habitat types and excellent water quality	Maintaining water levels at 1/3 of the normal coverage will continue to negatively impact the diversity and availability of habitats. These effects have already been observed in the dramatic shift in the aquatic macroinvertebrate assemblages. It is unlikely that the previously rich consortium of habitats will return under the projected changes. Furthermore, the once excellent water quality of the site depended upon the low residence time of the water as inflow and outflow were sufficiently high to maintain high flushing rates and low nutrient levels. This process will continue to be disrupted even if levels increase to the propose threshold and high nutrient levels will remain a concern. Nonetheless, the well-developed sedge habitats will ensure some diversity of habitats for aquatic fauna and limit nutrient run-off into the lake.	Likely (but not to the degree that once typified this lake)

Fringing vegetation along the margin of Lake Yonderup 2019.

Lake Yonderup

Located to the south of Loch McNess and north of Lake Wilgarup in Yanchep National Park, Lake Yonderup has a high conservation value as it represents a largely undisturbed wetland with high macroinvertebrate richness and excellent water quality. The permanently filled lake is dependent on groundwater to maintain habitats and biophysical processes (Froend, et al., 2004a). Like other lakes in the region, Lake Yonderup has experienced a consistent decline in surface water levels that has affected the condition and health of fringing vegetation and aquatic processes. A fire also affected the fringing vegetation in 2004/2005 (Rogan et al., 2006). Permanent water is required to support a local Rakali (*Hydromys chrysogaster*) and terrestrial habitat is important for the native Bush rat (*Rattus fuscipes*) population (McIlduff, et al., 2014). The hydrological processes sustaining water levels at Lake Yonderup have been compromised, probably from the same processes responsible for the decline in water levels at Loch McNess.

Hydrology

There has been a continual decline in surface water levels at staff gauge 6162565 since 1994. Prior to 1994, water levels were relatively stable at 6 mAHD but have since declined to approximately 5.3 mAHD (Figure 7). Unlike many other wetlands in the Gnangara area, there has been no recent increase in surface water levels associated with the higher rainfall in 2017 and 2018. Mean maximum and minimum seasonal water levels have only declined 0.2 and 0.3 m, respectively from 1994-1999 levels (Table 7). There has been nearly a fourfold increase in seasonal water level variation and waters are generally now in decline for more than 200 days a year. The bore 61611840 is located near the vegetation transects and represents the groundwater levels in the Superficial aquifer that the vegetation at the transect is utilising. There has been a similar decline in groundwater levels at this bore until 2017, although observations have only been recorded since 2008. Therefore surface water levels are used to assess changes in vegetation as surface water is an expression of the Superficial aquifer and shows similar trends (Froend, et al., 2004a). The current Ministerial minimum criteria is 5.9 mAHD while the 2030 proposed threshold is 5.7 mAHD. The lake has been non-compliant with the current criteria since about 2004. The decline in surface waters mirrors what has been observed at Loch McNess although it is not clear whether the same hydrological processes are occurring at Lake Yonderup and Loch McNess (see Loch McNess section for discussion). Slight increases in surface water levels are required to meet the proposed threshold.

Implications of the proposed threshold

Managing the lake at the proposed threshold level may alleviate some of the effects of declining surface waters at Lake Yonderup (Table 8). Like Loch McNess, the remarkably stable surface water levels were a feature of this wetland and have now been compromised by declining water levels and increased seasonal variation (Table 7). There are indications that water quality has begun to shift because of the declining water levels. Nonetheless, if managed to the proposed threshold, it is unlikely the lake will be at risk of acidification given that water levels are projected to be higher than current. The projected higher water levels may also have a positive impact on the nutrient status of the lake and may reverse the current trend of increasing nitrogen in the water.

The projected water levels may also improve the cover abundances of many native plant species; however, it is unknown whether the proposed increases in surface water are sufficient to achieve this. For instance, many natives, including *Banksia attenuata* and *Melaleuca preissiana*, are predicted here to decline further in cover abundance. In fact, *B. attenuata* and *M. preissiana* have already disappeared from the monitoring transect, while stands of *Melaleuca rhaphiophylla* are unhealthy (Figure 6). Managing to the proposed threshold will maintain these key species in a state of stress as they will have to continue surviving towards the maximum depth-to-water levels they can tolerate. As no vegetation transects exist at the lake's margin, it can only be speculated that without any effort to reduce the seasonal variation in surface water levels to the small fluctuations characteristic of the lake before 2004, fringing vegetation will be dominated by sedges capable of surviving periods without surface water.

Managing to the proposed threshold will ensure macroinvertebrate habitat persists and may halt the decline in family richness currently being observed. Although, the increased variability in water levels may change the nature of habitats available to aquatic macroinvertebrates and therefore a shift in assemblage composition may occur. On the other hand, habitat currently unavailable due to low water levels may become available again and restore some of the recently lost diversity.

Figure 6 A vegetation monitoring plot at Lake Yonderup in November 2010 (left) and September 2018 (right). Note the increase in cover of invasive grasses and decline of canopy condition throughout the period. Source (Buller *et al*. 2019).

Table 7 Five-year summaries of surface water level data at Lake Yonderup.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	6.0 (Aug)	5.9 (Sep)	0.07	82
08/1999 – 07/2004	6.0 (Sep)	5.9 (Feb)	0.06	144
08/2004 – 07/2009	5.9 (Apr)	5.9 (Apr)	0.06	130
08/2009 – 07/2014	5.9 (Sep)	5.7 (Apr)	0.19	212
08/2014 – 07/2019	5.8 (Sep)	5.6 (Mar)	0.25	218

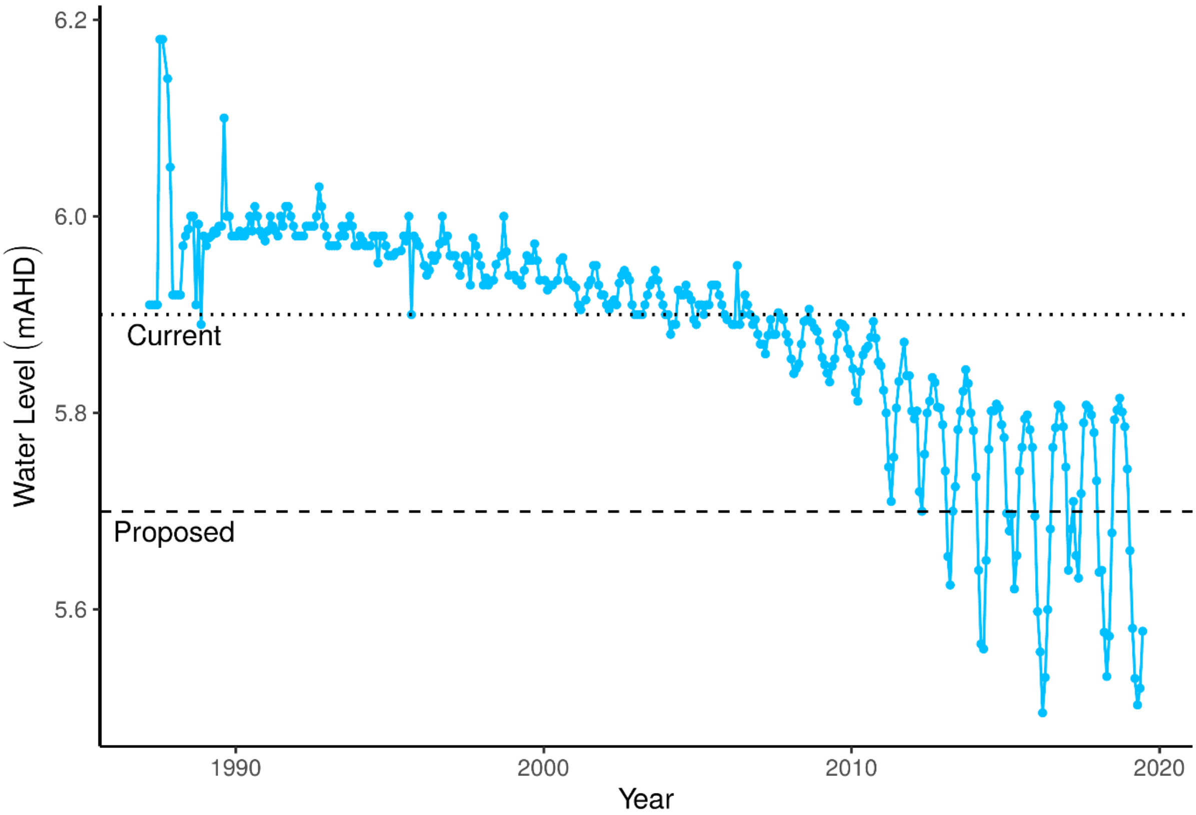


Figure 7 Surface water levels recorded at staff gauge 6162565 for Lake Yonderup. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Table 8 Ecological consequences of proposed minimum threshold (5.7 mAHD) in terms of compliance of stated site values and site management objectives at Lake Yonderup set for the current absolute minimum Ministerial criteria (5.9 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. "Additional values" refers to additional wetland features that were not originally recognized, and that might now be regarded as features worth managing to protect. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 proposed minimum threshold (5.7 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
High ecological values due to undisturbed nature	Terrestrial regions of the site are currently dominated by exotic vegetation, with concerning declines in key native species. Further declines will exacerbate the decline of native vegetation. Native species are unlikely to become more abundant post 2030 if projected higher water levels are achieved based on multivariate modelling (Appendix 2). Continuation of stable water quality and low nutrient state are likely to maintain the current composition of aquatic macroinvertebrates. Managing to the proposed threshold increases the likelihood of maintaining this distinctive community. The stable hydrological regime is unlikely to return.	Unlikely
Rich invertebrate fauna	Higher than present surface waters, combined with maintenance of water quality conditions are likely to have a positive impact on aquatic macroinvertebrate assemblages. There has not been an observed dramatic shift in the assemblage structure in spring monitoring since 1996.	Likely
Excellent water quality	Sustaining surface waters greater than current levels will mean the risk of acidification will remain low. There are indications that nutrient levels may be on the rise and any further declines in water level before 2030 may cause shifts in the ecosystem functioning of the lake.	Likely - dependent on no further declines in water levels before 2030
Undisturbed hydrologic regime and lack of seasonal variation	Seasonal variation has increased with declining water levels. This value can only be maintained if the hydrological controls in the wetland are re-instated as for Loch McNess.	Unlikely

Banksia woodland <8m depth to groundwater	The wetland remains an important *B. littoralis* and *M. rhaphiophyla* woodland. Monitoring suggests these plants are unhealthy due to their ecological water requirements not being met. There are currently few mature *B. littoralis* at the site and only a few, albeit healthy, seedlings in the transect. Mature woodland was destroyed by bushfire in 2004/05 and has not since recovered. Another severe bushfire also recently burnt through the wetland in December 2019 and this will further limit recovery. Other members of this community have disappeared from the wetland, including *Banksia attenuata* and *Melaleuca preissiana*. Achieving water levels higher than current levels will improve, but not guarantee, the chances of recruitment and regeneration. Currently, wetland vegetation is under competition from *Eucalyptus gomphocephala*.	Unlikely - dependent on post- bushfire recruitment
Site management objectives (WAWA, 1995)		
Maintain the environmental quality of the lake	Many exotic vegetation species are likely to persist, particularly if water levels decline further before abstraction is reduced prior to 2030. If nutrient levels remain low, it is likely that the current aquatic invertebrate assemblage will persist.	Likely
Maintain the existing hydrological regime	The hydrological regime has been disrupted since the 2003 declines in surface water levels. In particular, the lack of seasonal variation was a key feature of this wetland that is unlikely to return.	Unlikely
Additional values		
Important habitat for native mammals	Rakali (*Hydromys chrysogaster*) and bush rat (*Rattus fuscipes*) inhabit the Lake Yonderup region. Maintaining fringing vegetation will ensure important habitats remain available. Other measures may need to be considered, including predator control.	Likely
Low nutrient status of waters	Water quality monitoring over the last 20 successive years in spring has revealed consistently low concentrations of dissolved and total phosphorus and nitrogen.	Likely
Proposed site management objectives		
Increase surface area of permanent water for fauna habitat	Although the projected changes are an improvement on the current hydrological state of the lake, they are not sufficient to return to the lake to pre-1990 levels before water levels declined markedly. Managing the lake at the proposed thresholds will ensure permanent water and habitat for aquatic fauna, albeit at a lesser extent to what was once characteristic of the wetland.	Likely

Maintain intact, undisturbed fringing vegetation	There has been a marked decline in *Baumea juncea* and *Lepidosperma gladiatum* which has altered the composition of fringing vegetation. The projected increases in water levels are unlikely to restore this aspect of the vegetation (at least at the monitoring transect). This is particularly true for *M. rhaphiophylla* which will continue to experience water levels approaching the maximum depths that are tolerable for that species. The northern region of the lake is still relatively undisturbed (Buller *et al.* 2019) and the projected changes of water levels may ensure that fringing vegetation remains intact. The recent bushfire in December 2019 may have severely impacted regions of intact vegetation which may facilitate further invasion of exotic species.	Likely – at least for the northern region
Maintain diverse habitat types and excellent water quality	There is evidence that the lower than normal water levels, probably caused by reduced inflow, are causing nutrient levels in the wetland to increase. Under the projected changes to water levels it is possible that nutrient levels will return to normal. Elevated levels of nutrients are currently causing significant shifts in ecological processes and the composition of aquatic faunal communities. Aquatic macroinvertebrate richness is already declining due to low water levels. Nonetheless, sedges are likely to persist, probably at a greater distribution than currently. These sedges will enhance the diversity of habitats available to aquatic fauna and protect water quality by acting as a buffer between run-off and surface water.	Likely

Fringing vegetation and woodland vegetation at Lake Joondalup 2019.

Lake Joondalup

At 611.5 ha, Lake Joondalup is the largest monitored wetland and is managed by the Department of Biodiversity, Conservation and Attractions and the Cities of Joondalup and Wanneroo. The lake is an important habitat and drought refuge for water birds, and in conjunction with Lake Goollelal, is managed to support the full range of avian habitats (Water Authority of Western Australia, 1995). Other management objectives include the conservation of diverse wetland vegetation communities, including sedge beds, fringing woodlands and aquatic macrophytes, and the maintenance or enhancement of aquatic fauna in the lake. Lake Joondalup supports an important population of Pygmy Perch (*Edelia vittata*) and Swan River Goby (*Pseudogobius olorum*) and the fringing woodlands and bushland support a variety of significant mammal species.

Hydrology

Lake Joondalup has remained permanently inundated at the staff gauge since 1986 (Horwitz et al., 2009). However, vast regions of the basin dry most summers and provide habitat for visiting water birds. Recent monitoring of surface water levels at the staff gauge 6162572 remained relatively stable from 2002 but have been increasing from 16.4 mAHD to approximately 17.2 mAHD in 2019 (Figure 8). Five-year summaries of hydrological regimes at Lake Joondalup also reveal the higher mean minimum and maximum surface water levels in the latest period compared to earlier periods, as well as an increase in the number of days to reach seasonal minimum water levels (Table 9). Historically, groundwater levels at monitoring bore 61610661 declined significantly by 1.2 m from 1970 to 2002. Currently, groundwater levels at this bore, as well as bore 61611423 (likely to better reflect lake surface water variation), have been increasing since 2015 to levels like the early 1990s.

Table 9 Five-year summaries of surface water level data at Lake Joondalup

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	17.2 (Sep)	16.2 (Apr)	0.96	213
08/1999 – 07/2004	17.0 (Oct)	16.1 (Apr)	0.92	179
08/2004 – 07/2009	16.9 (Oct)	16.1 (Apr)	0.79	181
08/2009 – 07/2014	16.9 (Oct)	16.1 (Mar)	0.82	173
08/2014 – 07/2019	17.2 (Oct)	16.5 (Apr)	0.68	206

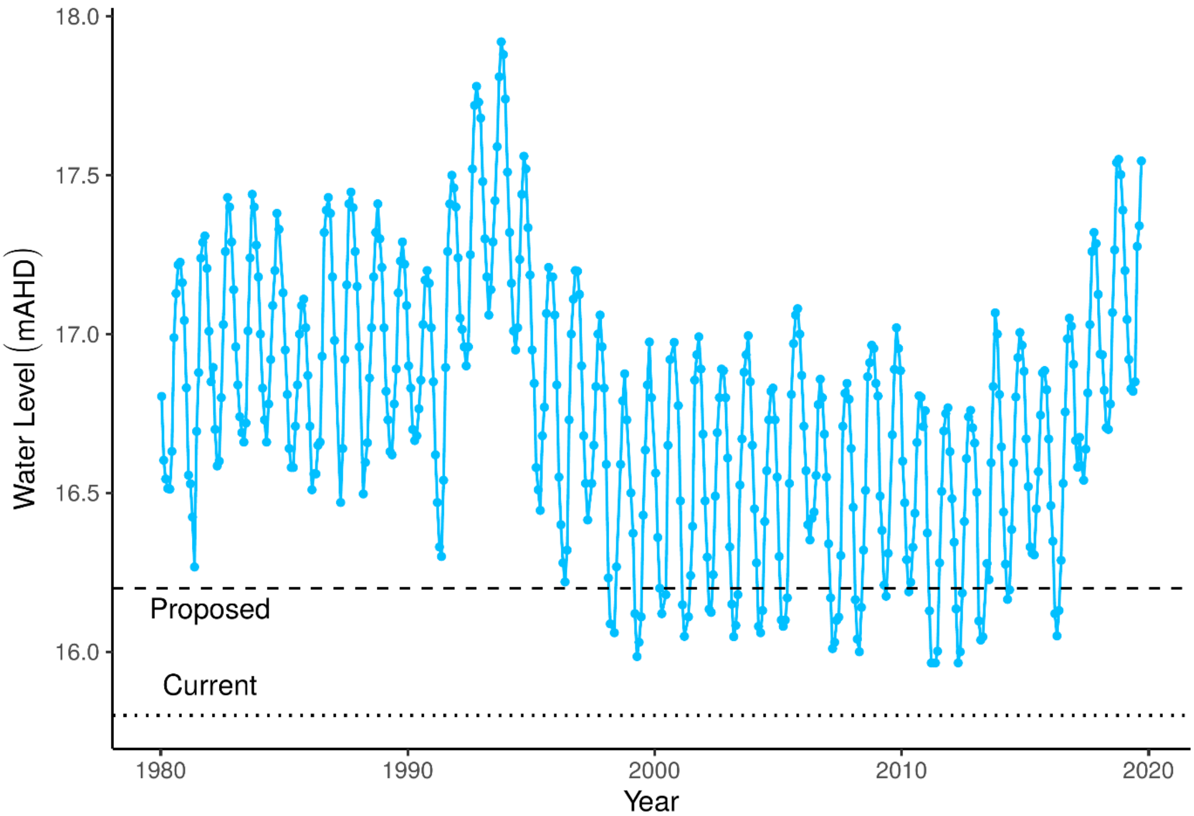


Figure 8 Surface water levels recorded at staff gauge 6162572 for Lake Joondalup. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of the proposed threshold

The water levels in the vicinity of Lake Joondalup are projected to increase up to 2.1 m by 2030 from 2013 levels largely due to land use change and associated changes in groundwater use in East Wanneroo. This increase in water level will continue the rising trend being observed in the lake's surface water levels since 2015. Maintaining surface water levels above 16.2 mAHD at staff 6162572 will ensure permanent water habitat for fauna and flora and the visual amenity of the area (Table 10). The diverse macrophytes inhabiting the lower elevations of the basin are likely to persist and continue to provide a rich habitat for aquatic invertebrates. Although important native macrophytes and wetland species are likely to continue at relatively high cover abundances under the future scenario, there are some native species that are likely to decrease in cover abundance or disappear. This group mainly includes *Acacia* and *Banksia* species which provide important habitat for fauna up-slope of the lake. Further vegetation monitoring is required at these transects to determine vegetation compositional changes since 2015 to understand if the trajectory in compositional change is continuing.

Typhia orientalis stands in Lake Joondalup 2019.

Table 10 Ecological consequences of proposed 2030 minimum threshold (16.2 mAHD) in terms of compliance of stated site values and site management objectives at Lake Joondalup set for the current absolute minimum Ministerial criteria (15.8 mAHD). Assessments of whether the values and objectives will be met under the revised thresholds are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. “Additional values” refers to additional wetland features that were not originally recognized, and that might now be regarded as features worth managing to protect.

	Likely effect of 2030 proposed minimum threshold (16.2 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Water bird habitat and drought refuge	Managing levels to the proposed threshold will ensure the site remains an important water bird habitat. The projected increase in levels will ensure the lake is permanently inundated, which will ensure the lake is a drought refuge for water birds. Seasonal variation in surface water height will also ensure expansive mudflats, an important feeding habitat for many visiting birds, remain.	Very likely
Diverse range of macrophytes	The current diversity of macrophytes, including *B. articulata*, *B. juncea* and *L. longitudinale*, will continue. There is the possibility of these species extending into current terrestrial regions of the lake.	Very likely
Site management objectives (WAWA, 1995)		
Conservation and public enjoyment of natural and modified landscapes	The wetland should retain the current natural and modified assets.	Very likely
Conserve existing wetland vegetation, including sedge beds, fringing woodland and aquatic macrophytes	Managing levels to the proposed threshold will ensure the current wetland at a state similar to 2015. It is possible that the projected increases in groundwater levels will extend the range of these species around the lake by ‘migrating’ up slope.	Very likely
Maintain and if possible, enhance the aquatic fauna of the lake	Aquatic vertebrates, including native fish, are likely to persist in the lake, given that permanent inundation will remain a feature of the lake. Although acidification is unlikely, there are issues around water quality and nutrient enrichment. If nutrients continue to rise, local extinctions of fish populations may occur. There are already unusual trends in macroinvertebrate diversity occurring which may be early warnings of significant ecological shifts that may occur due to nutrient enrichment.	Possible. Eutrophication not linked to water levels may be an issue.

In conjunction with Lake Goollelal, to support the full range of habitats for avian fauna	The maintenance of permanent surface water and wetland vegetation will continue to provide a diverse habitat for different avian species. Extensive mudflats should continue to form during periods of low water level, which are also an important feeding habitat for birds.	Very likely
Ensure the landscape and amenity values of the lake are maintained, except under very low rainfall climatic conditions	The most significant threat to these values is likely to be changes to the water quality. High water levels combined with high temperatures could trigger algal blooms not yet seen at the wetland. Macroinvertebrate assemblages are also changing and a reduction of aquatic insect families in spring sampling suggests an as yet undiagnosed water quality problem.	Unknown
Additional values		
Supports an important population of Pygmy Perch (*Edelia vittata*) and Swan River Goby (*Pseudogobius olorum*)	Maintaining deep and permanent waters will ensure these native fish species remain an important component of Lake Joondalup. Invasive fish, such as *Gambusia holbrooki* and *Cyprinus carpio* remain in the lake and potentially increase competition with the native species for resources and their eradication should be considered.	Likely
Aquatic macroinvertebrates	Healthy populations of the glass shrimp *Palaemonetes australis*.	Likely
Proposed site management objectives		
Maintain permanent water for fauna habitat and for visual amenity	Managing levels to the proposed threshold at Lake Joondalup will ensure permanent water in the basin, protect a diverse array of habitats for aquatic fauna and maintain the visual amenity of the site.	Likely
Maintain diverse aquatic plants and fringing vegetation	It is predicted that the high diversity of aquatic plants and fringing vegetation will persist at the site under the projected changes to water levels. It is likely that the cover abundance of *B. articulata* will remain at the current levels, or even increase, given the projected increases in surface water levels	Likely
Minimise risk of acidification	The projected higher water levels will further reduce the risk of acidification.	Likely

Baumea stands in Lake Mariginiup 2019.

Lake Mariginiup

Lake Mariginiup has a high conservation value as a groundwater dependent wetland (Froend, et al., 2004a). There are several wader birds present at the lake that require the shallow water during the summer for feeding, however, high water levels are required in winter to prevent vegetation encroachment into these habitats. Past declines in surface and groundwater has likely diminished this important component of the system. Sediment processes have been altered as sediments dry and crack and water quality deteriorates due to acidification (Judd and Horwitz, 2019).

Hydrology

Since 1997, Lake Mariginiup has frequently dried or been dry at the staff gauge 6162577 during the summer. Interpretations of seasonal patterns therefore need to be made with caution and perhaps it is more reliable to use groundwater levels at the nearby bore 616100685 as a proxy (Figure 9). Nonetheless, mean seasonal maximum water levels have declined from 42.0 m to 41.4 m since the 1994-1999 period (Table 11). Maximum water levels usually occur in September/October. There has been a recent increase in groundwater level since 2015 which has caused maximum spring surface levels to increase. Land use change and associated changes in local abstraction as the area becomes urbanised are expected to cause an increase in local groundwater levels of up to 3.9 m, according to groundwater modelling results. The expected levels would meet a minimum peak threshold level of 42.1 mAHD and result in levels higher than have been recorded during the ecological monitoring program.

Table 11 Five-year summaries of surface water level data at Lake Mariginiup. Minimum water levels should be treated with caution as the staff gauge 6162577 has frequently been dry since 2000.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	42.0 (Sep)	41.2 (Sep)	0.81	176
08/1999 – 07/2004	41.8 (Oct)	NA	NA	NA
08/2004 – 07/2009	42.5 (Sep)	NA	NA	NA
08/2009 – 07/2014	41.3 (Oct)	NA	NA	NA
08/2014 – 07/2019	41.4 (Sep)	NA	NA	NA

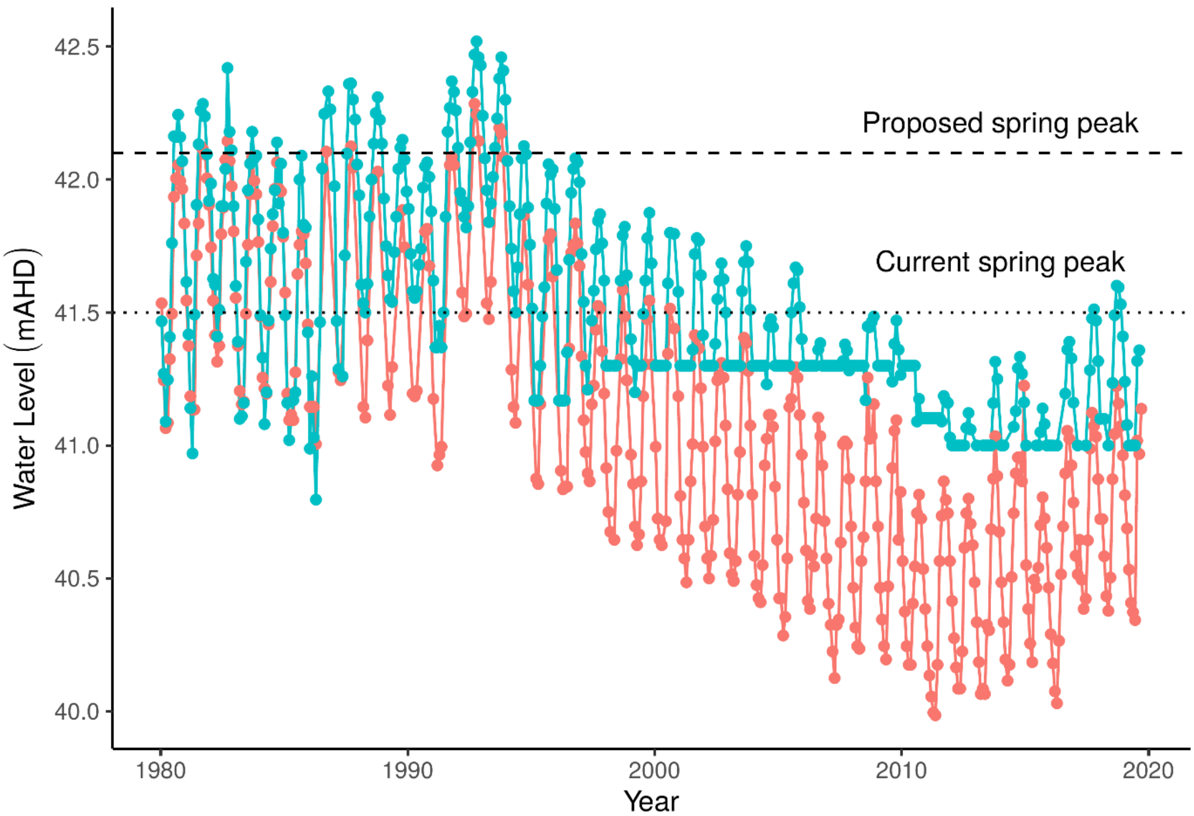


Figure 9 Ground and surface water levels recorded at bore 61610685 (red) and staff gauge 6162577 (blue) that represent changes in water levels at Lake Mariginiup. Dotted line is the current Ministerial spring peak water level criteria. Dashed line is the proposed 2030 spring peak level.

Implications of the proposed threshold

As a result of land use change and reductions in local abstraction, water levels are expected to rise to 2030 and beyond. Adopting a minimum spring peak threshold of 42.1 mAHD will require water levels to rise to levels last recorded in the early 1990s in order to be compliant. Thus, it is difficult to predict the ecological consequences as the lake has never been monitored at those levels (Table 12). It is unlikely that large areas of the wetland will continue to dry during summer if spring levels are managed above 42.1 mAHD. The greater inundation of Lake Mariginiup will likely alleviate acidification issues as sediments are re-wetted and sediment processes return to normal. Artificial augmentation of surface waters at Lake Jandabup has shown that returning a wetland to a 'more' normal hydrological regime can reverse the effects of acidification, although this process is dependent on a number of factors, including whether sufficient buffering capacity of the sediments remain (Sommer and Horwitz, 2009). It is also possible the projected increases in water levels will have a positive impact on the nutrient status of the lake as nutrient concentrations have risen dramatically with declining surface waters. However, nutrient loading may remain high from other anthropogenic sources.

The projected changes in groundwater levels are likely to have a dramatic positive impact on the cover abundances of native species although these projections are beyond the range considered in the modelling. Species likely to increase in cover abundance include *Angianthus* sp., *Epilobium billardierianum*, *Isolepis cernua*, *Juncus* sp., *Lepyrodia muirii*, *Lobelia alata* and *Villarsia capitata*. Other natives, including *Acacia cyclops*, *Acacia saligna* and *E. sparteus*, are likely to decrease in cover abundance as water levels increase. Along with the projected higher water levels, the decline in macroinvertebrate family richness is likely to be reversed as available habitats increase. It is possible that the projected increases in water level may return the macroinvertebrate assemblage composition to something like that observed before 2002. This will require the re-establishment of Amphisopidae, Ceinidae, Chydoridae and Cyprididae in the lake.

The projected changes in water level will require significant migration of fringing plants upslope if they are going to persist at the wetland. Water levels exceeding 42.6 mAHD will cause some mortality of *B. articulata* as their ecological water requirements are exceeded. However, this is unlikely an issue for *B. articulata* which can respond rapidly to seasonal fluctuations in water levels through vegetative regeneration. Achieving the minimum spring peak proposed here will also cause annual submergence of *E. rudis*. Although *E. rudis* can tolerate extended periods of inundation, the health of these individuals in the current distribution will decline and mortality will eventually occur after 3 or more years of continuous inundation. Annual absolute minimum water levels below 41.7 mAHD will ensure that *E. rudis* stands do not become permanently inundated and help ensure they remain healthy and persist at the current distribution. The higher water levels may also reverse the trend of declining health of this stand.

Table 12 Ecological consequences of proposed 2030 minimum peak threshold (42.1 mAHD) in terms of compliance of stated site values and site management objectives at Lake Mariginiup set for the current minimum peak Ministerial criteria (41.5 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 proposed minimum peak threshold (42.1 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Rich aquatic fauna (Swan River Goby, *Pseudogobius olorum*)	Given the declines in water quality and the seasonal drying of the wetland, it is unlikely the lake still provides habitat for *P. olorum*. It is probable the Lake Mariginiup population is now extinct. The lack of compliance is a problem of past management, not linked to managing to the proposed threshold.	Very unlikely
Wading bird habitat	Rising water levels are likely to reverse the terrestrialisation currently occurring at the wetland. Seasonal maximum water levels need to be sufficient to prevent macrophytes growing while seasonal minimums need to be low enough to provide shallow wading habitat. It is likely that these requirements will be met at locations throughout the basin	Likely
Good water quality	Water quality is currently compromised as sediments become dry and are oxidised, causing significant acidification issues. The return of good water quality relies on having the sediments with sufficient buffering capacity remaining to reverse the decline of pH as they are re-wetted.	Possible
Site management objectives (WAWA, 1995)		
Conservation of flora and fauna	The lake has undergone significant shifts in wetland vegetation and aquatic fauna composition. Many native flora species are predicted to increase in cover abundance throughout the wetland under a scenario of rising surface water levels. The significant decline in the health of *E. rudis* is likely to continue, however, rising water levels may reverse this trend. There may still be significant mortality of *E. rudis* before the changes to abstraction occur, which could have a significant impact for the many terrestrial fauna that rely on the trees for habitat. Achieving summer minimum water levels below 41.7 mAHD will facilitate *E. rudis* health by ensuring the trees do not become permanently inundated. The wetland will remain an important site for water birds if the proposed thresholds are achieved. Given the likely extinction of the Lake Mariginiup population of *P. olorum*, it is unlikely this fish will return unless water quality is restored, and the fish is able to immigrate.	Likely Probable extinction of *P. olorum*.

Maintenance of the existing areas of fringing sedge vegetation	Fringing sedge vegetation, including *B. articulata*, is likely to increase in cover abundance as water levels rise. It is likely this habitat will also occur at higher elevations than present and will continue to provide important habitat for macroinvertebrates.	Likely
Maintain invertebrate diversity through some lakebed drying in summer	This management objective is deemed to be inappropriate. Exposing once permanently saturated sediments to drying and rewetting is now regarded to be damaging to the sediments, and a progenitor to acidification.	Not desirable
Maintain and if possible, enhance fringing woodland vegetation	There has been a significant decline in *E. rudis* woodland surrounding Lake Mariginiup. Although elevated water levels will be beneficial to *E. rudis*, the trees are slow growing and will require decades to return. *Acacia* woodland is predicted here to decrease in cover abundance along the transect if water levels increase. Survival of fringing vegetation depends on the rate of inundation being sufficiently slow enough to allow important fringing species to migrate upslope. Although the higher water levels are likely to increase the health status of any remaining *E. rudis* trees, it will be important to ensure absolute minimum water levels reach below 41.7 mAHD to prevent permanent inundation. Prolonged inundation (>3 years) will cause death to *E. rudis*.	Very likely
Proposed site management objectives		
Increase wading bird habitat	See above site value (WAWA, 1995). It is likely that the projected increases in water level will reverse the terrestrialisation of some mud flats and ensure that these areas remain viable feeding habitat for wading birds. Ensuring absolute minimum water levels reach below 41.7 mAHD will enhance wading bird habitat.	Likely
Maintain rich aquatic macroinvertebrate community	The projected increases in water level may be sufficient to restore the aquatic macroinvertebrate community to pre-2000 composition as habitats become increasingly available.	Likely
Reduce lake acidity to beneficial levels for fauna	Acidification events will be at a much lower risk given the projected increases in water levels. Higher waters are also likely to facilitate a return to higher pH levels given that the lake has reasonable alkalinity.	Likely

Lake Jandabup 2019.

Lake Jandabup

Lake Jandabup is a wetland that is supplemented with groundwater pumped into it from the Superficial aquifer. The lake supports the most diverse sedge and macrophyte vegetation communities in the Bassendean Dune wetlands (Judd and Horwitz, 2019). Lake Jandabup has a high conservation value as it is one of the few 'eastern circular wetlands' to not be permanently acidic. Low rainfall and groundwater abstraction impacts are thought to have caused an acidification event in 1998 and 1999; restoration of water levels by supplementation has returned the pH to normal levels (Sommer and Horwitz 2009; Judd and Horwitz, 2019). The lake usually has low levels of nutrients and clear stained waters that support a diverse aquatic invertebrate community. The current trajectory of the macroinvertebrate community suggests the assemblage is transitioning towards a state that will be like the communities of Lake Mariginiup and Melaleuca Park 173, although both wetlands are acidic (the latter has an acidity driven by dissolved organics which is different to the mineral processes at Mariginiup). The abundance of invertebrates and fringing vegetation habitats also allow the wetland to support high numbers of resident and visiting water birds (Bamford and Bamford, 2003).

Hydrology

Surface water levels of Lake Jandabup have only declined slightly since 1980 (Figure 10). Mean maximum seasonal water levels are now 0.2 m lower than in 1994-1999 but mean minimum seasonal water levels are 0.1 m higher than 1994-1999 levels and since 2009, the period of annual maximum to minimum water levels has increased (Table 13). Projected groundwater levels in the vicinity of this wetland are predicted to increase by up to 3.4 m due to land use changes and associated reductions in local abstraction as the area is urbanised. The expected increases in levels mean that the proposed minimum threshold, which is equal to the current Ministerial criteria of 44.3 mAHD can likely be met without the need for ongoing artificial supplementation of the wetland.

Table 13 Five-year summaries of surface water level data at Lake Jandabup

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	44.9 (Oct)	44.1 (Feb)	0.81	156
08/1999 – 07/2004	44.9 (Sep)	44.2 (Mar)	0.64	151
08/2004 – 07/2009	44.8 (Jul)	44.2 (Mar)	0.59	108
08/2009 – 07/2014	44.7 (Oct)	44.2 (Jan)	0.52	164
08/2014 – 07/2019	44.7 (Sep)	44.2 (Mar)	0.51	182

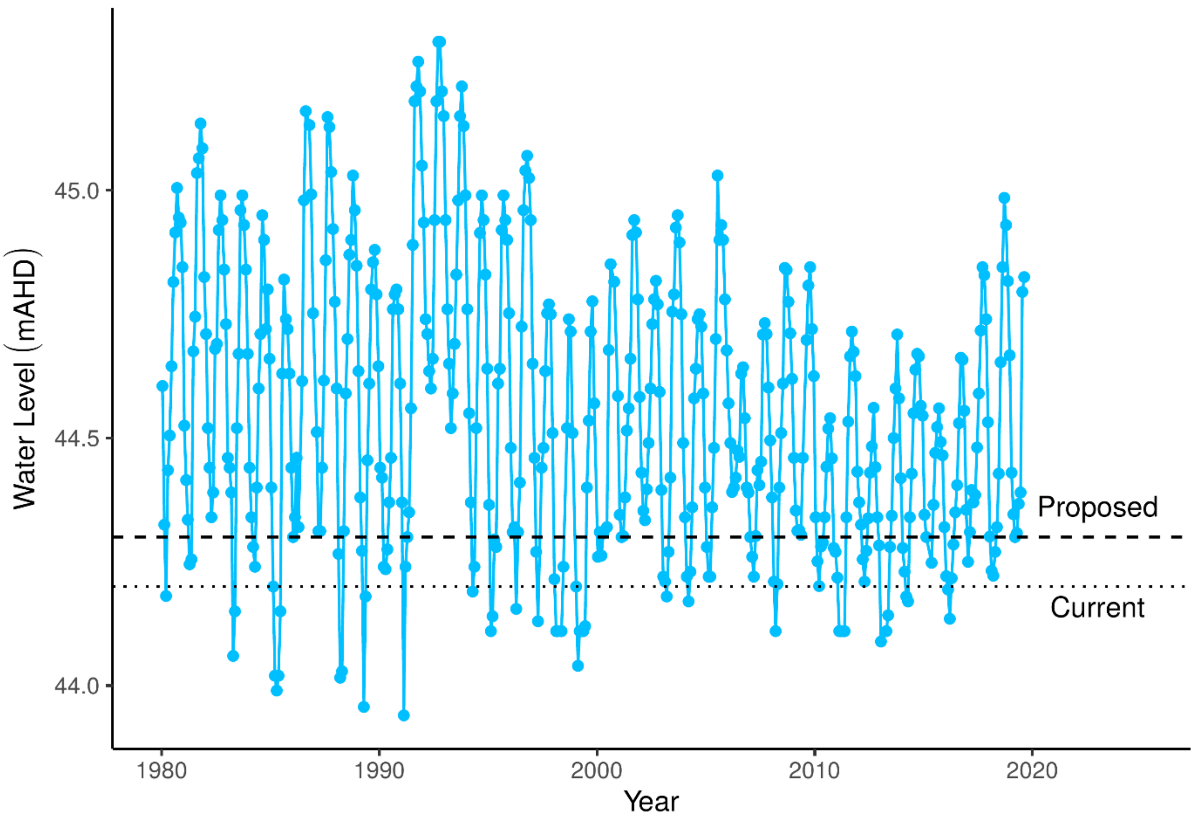


Figure 10 Surface water levels for Lake Jandabup recorded at staff 6162578. Dotted line represents current Ministerial criteria for minimum water levels and dashed line represents the proposed minimum threshold for 2030.

Implications of proposed threshold

Many of the site values of Lake Jandabup are likely to be maintained if water levels are managed above the current minimum water level and the proposed 2030 threshold level (Table 14). The lake is currently susceptible to acidification due to the deterioration of the chloride:sulphate ratio and very low alkalinity. Maintaining surface water levels at the proposed threshold will minimise the risk of further acidification by ensuring sediments remain wet, although acidification events have previously occurred in this wetland at water levels not much lower than the proposed 2030 threshold. Higher water levels in 2030 should also alleviate concern of increased nutrient concentrations although it is difficult to predict whether the wetland will return to a more typical low nutrient state.

It is predicted here that many species of native vegetation are likely to increase in cover abundance given higher water levels. If water levels rise to the point where artificial augmentation is no longer required, restoration of the hydrological regime may facilitate the expansion of wader habitat as seasonal variation in surface water levels increases towards 0.8 m. Under the projected increases in levels, the diverse *Banksia* and *Eucalyptus rudis* overstorey is likely to be maintained at a healthier state than current. The dense and diverse native understory typical of this wetland is also likely to be maintained, and possibly increase in extent, under the projected changes in water levels.

The current low pH of the wetland is driving the aquatic macroinvertebrate community away from pre-2000 compositions and towards one composed of a less diverse, acidophilic community that is likely to also occur at Lake Mariginiup and Melaleuca Park 173. Careful monitoring of nutrient levels is required also as increased nitrogen levels may also be driving the shift in this aquatic community. The projected changes in water level by 2030 are likely to affect the richness and diversity of this assemblage, although these changes will be difficult to predict. The future composition of aquatic macroinvertebrates will be largely determined by the changes in habitat availability driven by sustained higher water levels, whether nutrient levels decrease and if acidification events occur again.

Table 14 Ecological consequences of proposed 2030 minimum level threshold (44.3 mAHD) in terms of compliance of stated site values and site management objectives at Lake Jandabup. Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. "Additional values" refers to additional wetland features that were not originally recognized, and that might now be regarded as features worth managing to protect. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 minimum threshold (44.3 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Most diverse sedge and macrophyte vegetation of all Bassendean dune wetlands, including unusual species	The diverse sedge communities are likely to persist as higher water levels provide additional habitat.	Likely
Supports wide range of waterbirds, especially waders	Provided that seasonal variation in water levels is restored, extensive habitat for waders will continue being a feature of this wetland as seasonal high waters prevent macrophyte encroachment of wader habitat during periods of minimum water levels. Seasonal variation in water levels has decreased from about 0.8 m to 0.5 m. Restoration of hydrological regime is likely to restore seasonal variation to pre-2000 levels and extend feeding habitat for waders.	Likely
Extremely good water quality with low nutrients	Water quality has been compromised by reduced buffering capacity that makes the wetland susceptible to acidification. Sediments need to be prevented from drying to prevent further acidification. Nutrient levels are also rising and may be causing shifts in the aquatic invertebrate assemblages. The projected increase in water levels will minimise the risk of further acidification but elevated nutrient levels will remain a concern.	Possible

Site management objectives (WAWA, 1995)		
Conservation of flora and fauna	Native plant species are predicted to increase in abundance if water levels continue to increase. This will have a beneficial effect for other terrestrial fauna that inhabit the wetland. Wader bird habitat is also likely to remain a feature of this wetland. Elevated nutrient levels and low pH are a concern as the aquatic macroinvertebrate community transitions towards a less diverse, acidophilic composition. Augmentation of water levels appears to have halted further acidification, with recent evidence suggest pH is rising throughout the wetland. Higher pH will prevent further declines in macroinvertebrate richness.	Likely for waders and vegetation. Unlikely for aquatic invertebrate richness unless pH is restored.
Maintenance of the current extent of wading bird habitat	Greater seasonal variation and higher surface water levels are likely to maintain or expand current feeding habitat for waders.	Very likely
No expansion in the areas of sedge vegetation, but maintenance of existing areas	Modelling does not suggest sedge vegetation is likely to increase although higher water levels are likely to provide additional habitat for fringing vegetation.	Likely
Removal of mosquito fish from the lake	This management objective needs to be reworded. *Gambusia holbrooki* should not be referred to in this way because it does not control mosquitoes. The drying that occurred in the wetland in the late 1990s eradicated this species of non-native fish and to our knowledge it has not returned. Vigilance is required to ensure that it does not become established again.	No change
Maintenance of high species richness of aquatic macroinvertebrates, macrophytes and sedge vegetation	The proposed changes will maintain the rich macrophytic and sedge vegetation. The richness of the aquatic macroinvertebrate community has changed, at least partly due to acidification but other factors may be involved.	Likely for macrophytes and sedges. Unlikely for aquatic macroinvertebrates
Additional values		
Aquatic macroinvertebrates	Healthy populations of the baetid mayfly family.	Likely

Proposed site management objectives

Increase wading bird habitat	Wading bird habitat is likely to be maintained under the projected increases to lake water levels. Probably unlikely to increase from current extent. **Suggested change:** The planned changes to groundwater abstraction are likely to maintain the extent of wading bird habitat, therefore it is recommended to change the proposed site management objective to '*Maintain wading bird habitat*'.	Unlikely – see suggested change
Maintain rich aquatic macroinvertebrate community	There have been marked shifts in the composition of aquatic macroinvertebrates since an acidification event. The projected water levels are unlikely to restore the community to pre-acidification composition. Nonetheless, maintaining water levels similar to those currently found at the lake will ensure that further risk of acidification is minimised. A rich consortium of macroinvertebrates is likely to persist at the site, albeit at a lower richness than what has been previously recorded if acidification events are avoided.	Likely (highly dependent on preventing acidification events)
Minimise risk of acidification	The projected increases in water level will minimise the risk of further acidification. However, the lake may have reduced buffering capacity due to previous low water levels and acidification events. Low alkalinity levels mean that the lake will remain at risk of future acidification events despite higher water levels.	Possible

Typha orientalis stands in Lake Nowergup 2019 with fringing Melaleuca rhaphiophylla and Eucalyptus rudis woodland in background.

Lake Nowergup

Lake Nowergup was one of the deepest permanent lakes on the Swan Coastal Plain and has provided a permanent habitat for aquatic invertebrates and fish, as well as an important drought refuge for water birds (Froend, et al., 2004a). Despite the wetland being artificially maintained since 1989, water levels have continued to decline. This decline has altered the fringing vegetation of the lake and reduced the area of permanent water.

Hydrology

Since 2010, surface water levels in the lake have declined significantly to levels that are currently below the minimum reading on the staff gauge 6162567 (Figure 11). Groundwater levels at the nearby bore 61611247 have shown similar trends as surface water levels. Between 2008 and 2014, groundwater levels at the bore declined by more than 1.0 m. A similar decline in surface waters is likely and measurements from this bore have been used in the vegetation analysis. Currently, groundwater levels have increased to above 15 mAHD due to recent rainfall and lake supplementation influencing local Superficial aquifer levels. Mean seasonal maximum groundwater levels from the 1994-1999 period to the 2014-2019 period declined by 1.7 m, while for the mean minimum water levels the decline was 1.5 m (Table 15). Maximum and minimum water levels now tend to occur earlier in the year than previously. Proposed threshold levels will apply to bore 61610601, where under planned reductions in abstraction a threshold at 18.0 mAHD should be achievable. This is likely to correspond to a summer minimum threshold level of 16.0 mAHD at the staff gauge. The current threshold is a spring maximum peak of 16.8 mAHD which hasn’t been achieved since the late 1990’s. The planned reductions in abstraction are likely to significantly raise surface water levels in the lake with peak levels expected to reach 16.5 mAHD, levels not recorded since the late 2000’s.

Table 15 Five-year summaries of surface water level data at Lake Nowergup.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	17.0 (Oct)	16.2 (May)	0.84	115
08/1999 – 07/2004	16.7 (Oct)	16.0 (May)	0.72	20.4
08/2004 – 07/2009	16.8 (Oct)	16.2 (Sep)	0.56	0
08/2009 – 07/2014	NA	NA	NA	NA
08/2014 – 07/2019	NA	NA	NA	NA

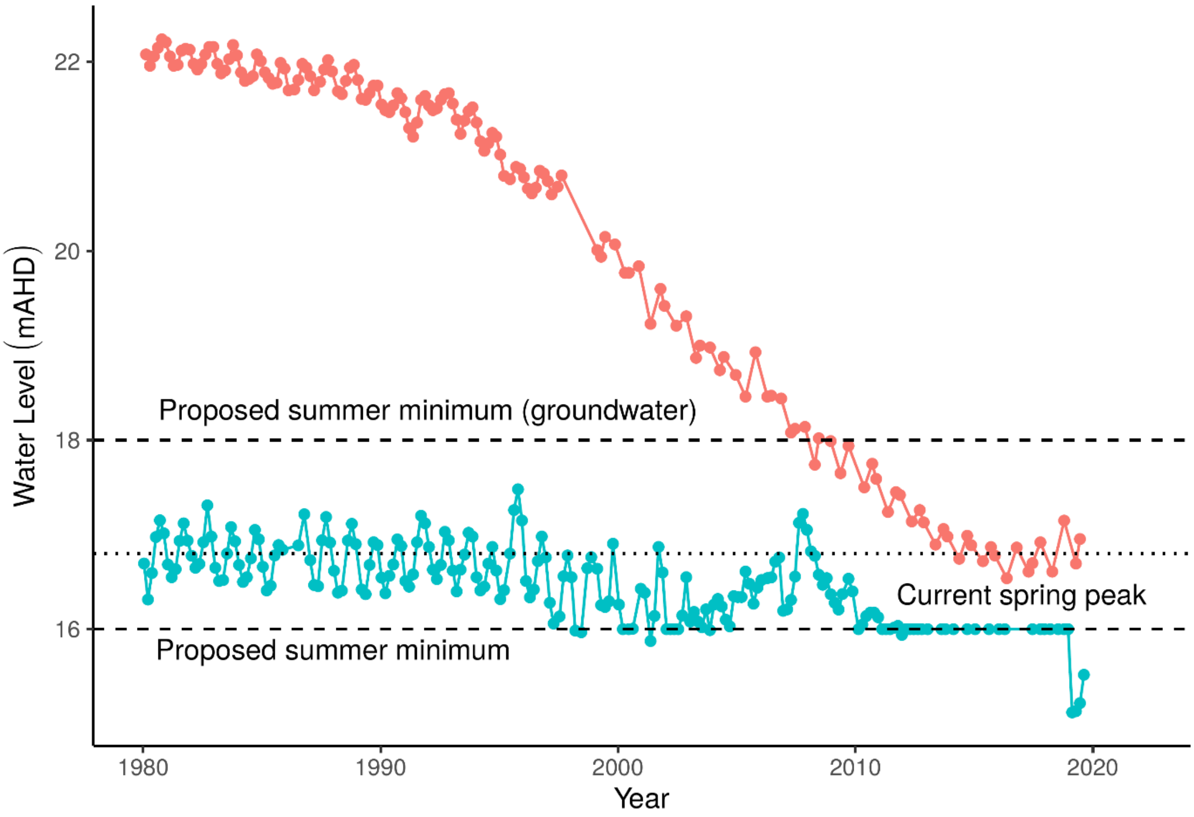


Figure 11 Ground and surface water levels for Lake Nowergup recorded at bore 61610601 (red) and staff gauge 6162567 (blue). The minimum recordable water level for the staff gauge is 16.0 mAHD. Measurements at 16.0 mAHD represent water levels below the minimum level measurable at the staff gauge which has recently been shifted to a lower elevation. Dotted line represents the current Ministerial spring peak water level. The dashed lines represent the proposed minimum water levels for 2030.

Implications of proposed thresholds

The projected changes in groundwater levels by 2030 mean water levels will be higher than current and similar to 2000-2010 levels. Many of the site values of Lake Nowergup are unlikely to be maintained if levels increase to the proposed minimum threshold level of 16.0 mAHD (Table 16). The low water levels have caused a significant decline in macroinvertebrate richness and a shift in assemblage composition away from what was once typical of this wetland. This deterioration of the macroinvertebrate community coincides with increased drying of the wetland and supplementation of surface waters by artificial watering, probably consistent with a decline in the diversity of habitats available. The changes in assemblages are probably driven by a decline in habitat availability for these organisms, although increased nutrient levels may also be facilitating this process. The projected changes in groundwater level to 2030 will return the lake to a similar condition observed in the late 2000's when summer minimums at bore 61610601 were greater than 18.0 mAHD. It is expected that these increases in surface water may reverse the trend of declining macroinvertebrate family richness. It is unlikely some species will return, such as the Sphaeridae bivalve, which will not re-establish unless the natural hydrological regime and water quality are restored and only if a remnant population exists in the lake.

Although many native vegetation species are predicted to increase in cover abundance with increasing water levels, there has been a substantial decline in fringing wetland vegetation and sedges (Figure 12). The projected water levels for 2030 are likely to reverse the terrestrialisation of the vegetation community that has been occurring in recent years in the lower elevations of the basin. This, in turn, will positively impact the macroinvertebrate communities as many of the fringing plant species predicted to increase in cover abundance (e.g. *Baumea articulata* and *Typha orientalis*) provide important habitat for many macroinvertebrate species and reduce the effect of nutrient enrichment. At some regions of the lake, it is possible that *Baumea juncea* will become the dominant sedge species and perhaps prevent further nutrient enrichment of the waters, while *Eucalyptus rudis* will dominate the overstorey. Under the projected water levels, the ecological water requirements for some key wetland species will continue to be met.

Figure 12 There has been substantial loss of sedges at Lake Nowergup between 2010 (left) and 2018 (right). Source Buller *et al.* (2019).

Table 16 Ecological consequences of proposed 2030 minimum threshold (16.0 mAHD) in terms of compliance of stated site values and site management objectives at Lake Nowergup set for the current absolute minimum Ministerial criteria (16.8 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations.

	Likely effect of 2030 revised minimum threshold (16.0 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
As a permanent deep-water wetland acts as a major drought refuge for waterbirds	The lake will retain its deep-water status and continue to act as a drought refuge for birds. Surface waters are likely to be maintained at levels similar to 1990-2010 levels, which will ensure permanent deep water, particularly important for diving water birds.	Very likely
Supports dependent invertebrates and fish species (one native, Swan River Goby (*Pseudogobius olorum*); and one exotic, Mosquito fish (*Gambusia holbrooki*)	Habitat dependent. Invertebrate species, including members of Sphaeridae, Scirtidae and Cordulidae, have been apparently lost from this wetland. It is unknown whether managing levels to the proposed thresholds are likely to bring them back. *Gambusia* should not be regarded as a value and the question is how to remove them, not how to keep them. *Pseudogobius olorum* has not been sighted in the lake for many years, but if it is still present it will benefit from higher water levels that will ensure habitat availability. Maintaining water levels above the proposed threshold should reduce the risk of drying and minimise the risk of further acidification. Reducing the risk of acidification will have a positive impact on the lake's aquatic fauna.	Likely (dependent upon *P. olorum* persisting)
Large areas of sedges minimize impact of nutrient enrichment on aquatic fauna	Likely to be jeopardised with any further decline in water levels. Nonetheless, the proposed increases to water levels will benefit sedges and increase their distribution. Multivariate modelling predicts an increase in *B. articulata* and *T. orientalis* abundance as water levels increase. *B. juncea* may establish in some regions of the lake. The increased abundance of sedges is likely to minimise the impact of nutrient enrichment.	Likely

Site management objectives (WAWA, 1995)		
Wildlife and conservation, scientific study and preservation of features of archaeological, historic or scientific interest	No data to reach conclusion	Unknown
Maintain the existing areas of fringing sedge vegetation	Current terrestrialisation of the lower elevations of the basin is likely to be reversed, although mature *E. rudis* individuals may persist in regions that do not become permanently inundated. The current distribution of *B. articulata* and *T. orientalis* is predicted to also increase due to the planned reductions in groundwater abstraction. These fringing plant species are likely to respond rapidly to increased surface water levels by vegetative spread upslope.	Very likely
Maintain deep, permanent water as a bird habitat and drought refuge and to protect aquatic invertebrates and fish dependent on permanent water	The increase of surface water levels will expand the areas of deep water and improve the habitat available to birds and fish. The function of the lake as a drought refuge for particular birds (diving birds) will continue.	Likely
Maintain the existing extent of *Baumea* fringe between *Typha* stands and the fringing woodland	Multivariate modelling (Appendix 2) predicts *B. articulata* and *T. orientalis* to increase from the current distribution. Existing stands are likely to become inundated and will need to establish further up-slope. The extent of these stands will increase. These species usually rely on vegetative regeneration to establish in regions up-slope of their current distribution. They are likely to rapidly respond to the increase in surface water levels.	Very likely
Provide some area of wading bird habitat at the end of summer, although it is recognized that this is limited by the shape of the wetland.	Depends on seasonal variation allowing areas of mudflats suitable for waders to establish. Maintaining seasonal variation in surface waters between 0.7 – 0.8 m should allow suitable habitat for wading birds as these levels will peak high enough to prevent fringing vegetation from establishing, while reaching minimum levels sufficient to allow feeding by wading birds.	Possible if seasonal variation of between 0.7 – 0.8 m is achieved.

Proposed site management objectives		
Increase area of permanent deep-water habitat for fauna	The projected changes represent an increase in the extent of permanent water (deeper than 1.5 m) throughout the basin to levels typical of the lake in the late 1990's. Managing water levels above the proposed 2030 minimum threshold will ensure permanent deep water remains a feature of this wetland and could have beneficial consequences like helping to reverse the declining trend in aquatic macroinvertebrate richness and reducing phosphate levels.	Likely
Maintain fringing vegetation to support macroinvertebrate diversity and nutrient retention	The projected changes in water levels will extend the distribution of fringing vegetation habitats available for aquatic macroinvertebrates. However, it is likely to remain dominated by *T. orientalis*. A remnant patch of *B. articulata* is also found along the margin of the lake. The distribution of *B. articulata* and *T. orientalis* sedge are likely to increase, particularly in regions upslope of the current distributions.	Likely

Deceased wetland vegetation at Lake Wilgarup with Eucalyptus gomphocephala individuals in the background (2019).

Lake Wilgarup

Lake Wilgarup is a high conservation, once seasonally inundated dampland located in the southern area of Yanchep National Park. The basin covers an area of 16 ha in a limestone depression that used to experience discharge from groundwater. There are extensive peat deposits in the lakebed that suggest the sediments were saturated for a long period. Surface waters have not been recorded in the basin since 1998 and peats have been burnt significantly in the 2004/5 fire, and remaining peats are dry and vulnerable to combustion.

Hydrology

Groundwater levels have been recorded at the nearby bore 61618500 since 1997 (Figure 13). There has been a significant decline in groundwater levels throughout this monitoring period from 4.75 to 3.25 mAHD. Maximum and minimum seasonal groundwater levels have decreased by 1.6 and 1.2 m, respectively (Table 17). Maximum water levels have consistently occurred during September-October, but minimum water levels are now occurring later in the year with the site experiencing a longer period of drying. The wetland has been non-compliant with Ministerial criteria for most of the monitoring period. A proposed threshold at 0.5 m lower than the current criteria is likely to be achievable under planned reductions in abstraction by 2030. These changes in abstraction are projected to cause an increase in groundwater levels, but it is unlikely to be sufficient to restore the natural hydrological regime.

Table 17 Five-year summaries of ground water level data at Lake Wilgarup

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	5.2 (Oct)	4.3 (Sep)	0.91	184
08/1999 – 07/2004	4.7 (Oct)	4.0 (Feb)	0.73	193
08/2004 – 07/2009	4.3 (Sep)	3.7 (Apr)	0.62	150
08/2009 – 07/2014	3.8 (Oct)	3.2 (Apr)	0.59	190
08/2014 – 07/2019	3.6 (Oct)	3.1 (Mar)	0.55	212

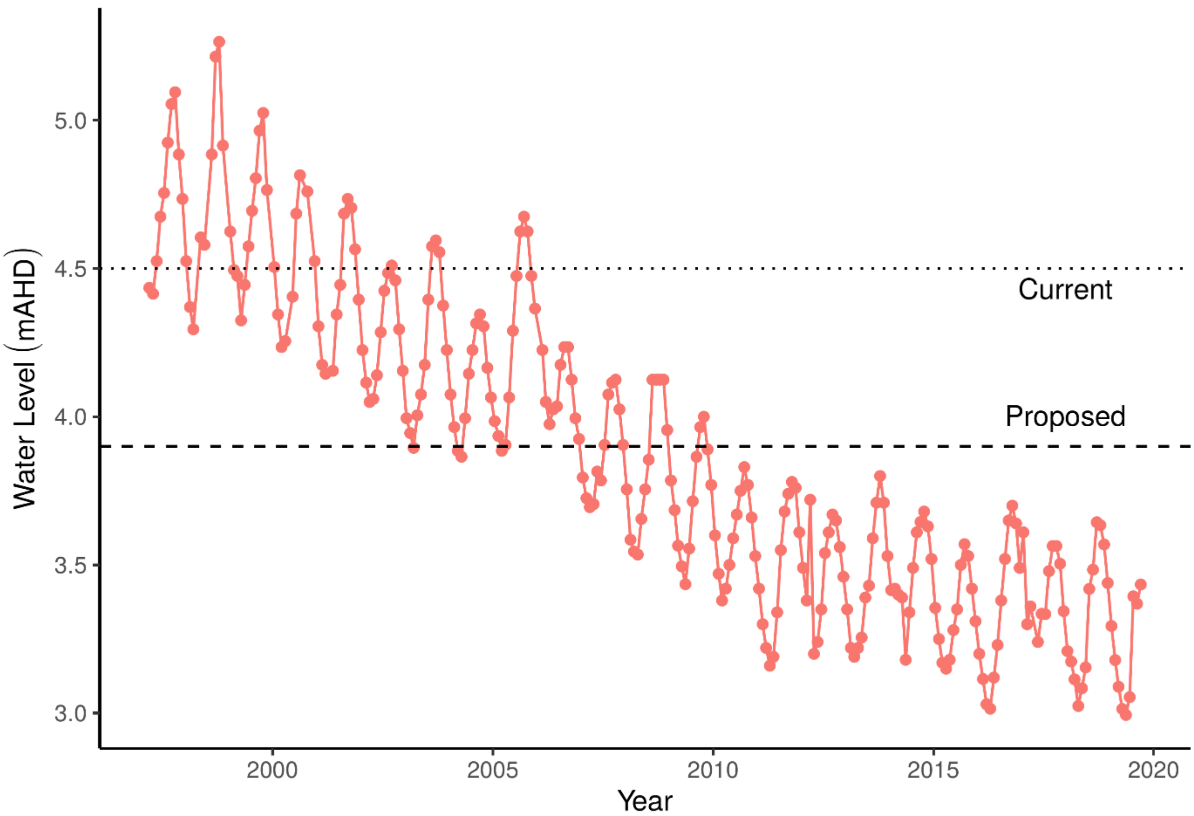


Figure 13 Groundwater levels recorded at bore 61618500 in the vicinity of Lake Wilgarup. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of proposed thresholds

The site values of Lake Wilgarup are unlikely to be maintained if levels are managed to meet the proposed threshold level (Table 18) despite water levels returning to pre-2005 levels. Vegetation composition has shifted from one dominated by wetland species, such as *B. articulata*, to a terrestrial community dominated by *Eucalyptus gomphocephala*. Increases in groundwater are unlikely to have an impact on the vegetation unless seasonal inundation of the basin can be restored. For instance, the ecological water requirements for *M. rhaphiophylla* are unlikely to be met given the proposed minimum threshold. Even if the hydrological regime begins to resemble that of a dampland, the significant losses of peat sediments due to bushfire events mean that any re-establishment of wetland vegetation, particularly *Baumea* species, is unlikely to resemble the site's natural state. Furthermore, the re-establishment of wetland vegetation will need to compete with the woodland vegetation that now inhabits the basin.

Table 18 Ecological consequences of proposed 2030 minimum threshold (3.9 mAHD) in terms of compliance of stated site values and site management objectives at Lake Wilgarup set for the current absolute minimum Ministerial criteria (4.5 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (3.9 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
One of few remaining undisturbed wetlands within the region	Declining groundwater and fire render this wetland highly disturbed. The vegetation composition no longer reflects that of a wetland as the site has become highly terrestrialised.	Extremely unlikely
Rich and unusual vegetation (dense monospecific stands of sedges)	These sedges are locally extinct and terrestrial plants are establishing in the basin. Peat sediments, which are important for native sedges, have been destroyed by fire.	Extremely unlikely
Likely to support diverse fauna	A rich woodland fauna likely exists at the site; however, this assemblage would not reflect the rich wetland fauna that would have once occupied the site. Aquatic species that are no longer a feature of the site include a native crayfish species and the rare fish *Galaxiella nigrostriata*.	Extremely unlikely
Site management objectives (WAWA, 1995)		
Maintain the environmental quality of Lake Wilgarup	The quality of Lake Wilgarup as a Swan Coastal Plain wetland has been permanently compromised. As it is extremely unlikely that permanent water will become a feature of Lake Wilgarup in the future, the site will not retain its environmental quality.	Extremely unlikely
Maintain the existing extent and variety of wetland vegetation	Wetland vegetation has probably been permanently destroyed by declining water levels and fire. The terrestrial woodlands that now inhabit the site are unlikely to facilitate the return of wetland vegetation unless permanent water is restored to the site.	Extremely unlikely

Proposed site management objectives		
Maintain soil moisture and minimise risk of acidification	The projected changes in groundwater levels will not restore inundation of the site. However, the soils will increase in moisture and be at a reduced likelihood of acidification. Peats have probably been destroyed by fire events, so even under the proposed scenario which resemble conditions prior to 2005, it is unlikely the diverse *Baumea* stands will return. Without further increases in groundwater levels, the basin is likely to remain dominated by *E. gomphocephala*. Nonetheless, future management of this site should aim to maintain wetland sediment processes in order to restore current and new habitats.	Likely

View of Pipidinny Swamp showing stands of wetland vegetation (2019).

Pipidinny Swamp

Vegetation at Pipidinny Swamp was damaged by a fire in 2005. Macroinvertebrate and water quality monitoring occurred in the 2000s but ceased in 2011 as the wetland was atypical and had little water. A single vegetation survey has been conducted in September 2019 and the results are presented here.

Hydrology

There has been at least a 2 m decline in surface water levels at Pipidinny Swamp since the mid-1990s, although measurements at the staff gauge were frequently below the minimum recordable level in the mid-late 2000s to 2019 despite the gauge being moved in 2010 (Figure 14). Mean maximum seasonal surface waters are at least 1.2 m lower now than in the 1994-1999 seasons. Records of minimum levels are difficult to interpret due to the water levels frequently being below the staff gauge. Groundwater levels at the nearby bore 61611872 suggest that water levels at the swamp are no longer in decline.

It is likely that water levels in Yanchep National Park will increase under the planned changes in groundwater abstraction. The proposed threshold level of 1.1 m at bore 61611872 is likely to slightly increase or stabilise surface water levels in Pipidinny Swamp.

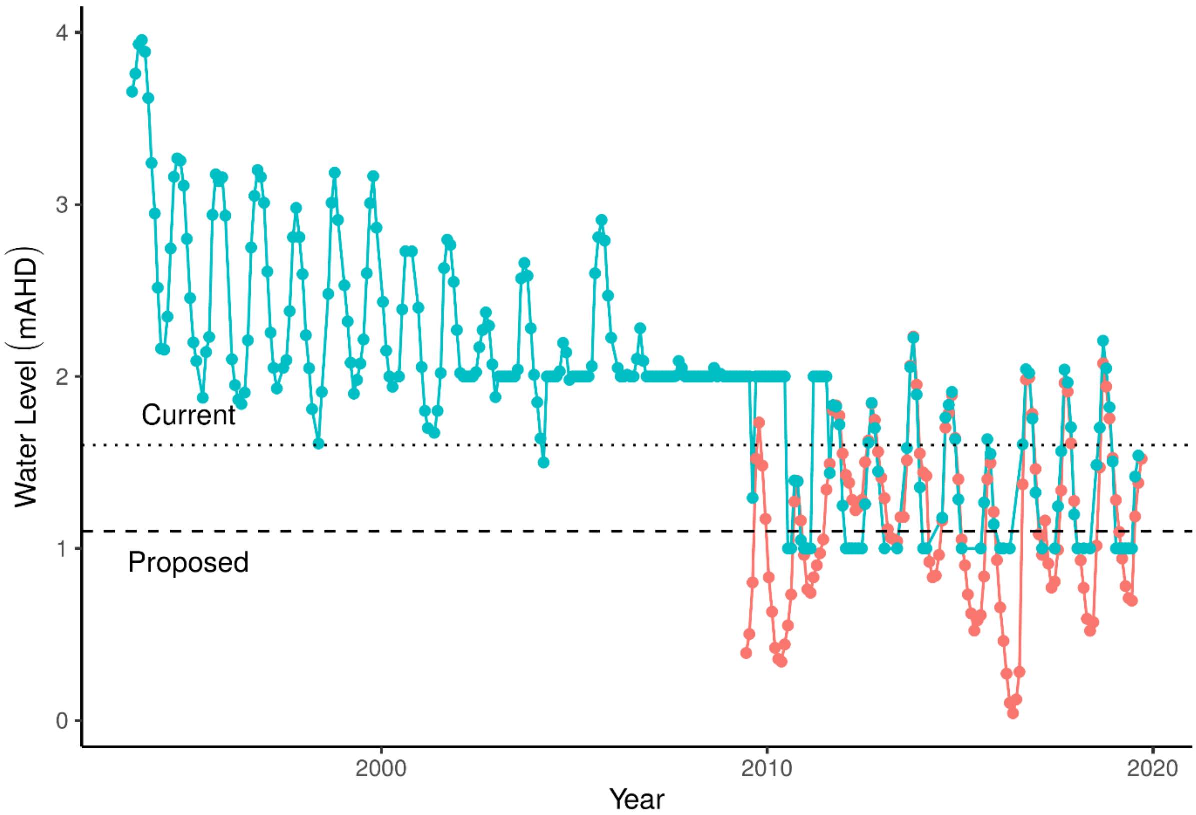


Figure 14 Ground and surface water levels recorded at bore 61611872 (red) and staff gauge 6162624 (blue) that represent fluctuations in water levels at Pipidinny Swamp. Surface water levels were initially only recordable above 2 mAHD and later above 1 mAHD.

Implications of proposed thresholds

The planned reductions to abstraction are not likely to restore surface water levels to pre-2000 levels at Pipidinny Swamp which will affect the capacity to maintain the site values (Table 19). Features that characterised this wetland before the significant decline in water levels are unlikely to return given water levels will be maintained at levels lower than was once typical of the wetland. However, the water levels are predicted to be slightly higher than current levels, which will have a beneficial effect on fringing vegetation health. Given the location of this swamp in an increasingly urbanised region and the altered hydrological regime, it is likely that exotic vegetation species will remain a feature of this swamp. Exotic species that are likely to remain abundant at the site include *Bromus diandrus* and *Ehrharta longiflora*.

The swamp was once an important habitat for a variety of resident and non-resident waterbirds such as White-faced Heron, Pacific Black Duck, Dusky Moorhen, Purple Swamphen, Australian Reed Warbler, Maned Duck, Grey Teal and the Little Pied Cormorant (Boucher 2000). Water bird richness was consistently between 16 and 29 species between 1984 and 1993 but very dramatically reduced to less than 5 by 2000 (Boucher 2000). Similar declines of water bird abundance have been recorded and are likely caused by the declines in water levels that occurred during that period. Given the further declines in water levels since 2000, the value of the site for water bird habitat has been seriously degraded.

Table 19 Ecological consequences of proposed 2030 minimum threshold (1.1 mAHD) in terms of compliance of stated site values and site management objectives at Pipidinny Swamp set for the current absolute minimum Ministerial criteria (1.6 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (1.1 mAHD)	Values and objectives maintained in future
Site management objectives (WAWA, 1995)		
Maintain and enhance wetland vegetation	Water levels are currently more than 1 m lower than pre-2000 levels. Planned changes to abstraction are unlikely to restore levels at the swamp to pre-2000 levels but are likely to maintain slightly higher levels than currently exist. The slightly deeper waters will provide additional habitat for aquatic fauna than currently exists. Fringing vegetation is likely to persist with higher surface water levels, although this prediction is not based on empirical data. If fringing *B. articulata* and *T. orientalis* continue to occur, additional habitat for aquatic macroinvertebrates may become available.	Possible
Protect and enhance water bird habitats	The value of the wetland to waterbirds has been seriously compromised by low water levels. The richness and abundance of waterbirds found at the swamp in the 1980s has been reduced because of declining water levels. Under the proposed changes, it is unlikely that this aspect of the wetland will return.	Very unlikely
Proposed site management objectives		
Increase area of permanent deep-water habitat for fauna	It is probable that the extent of permanent water will increase given the projected increases in water levels. These levels will not be sufficient to reach pre-2000 coverage nor support large numbers of fauna (such as water birds).	Unlikely
Maintain fringing vegetation to support a range of habitat types for macroinvertebrates	Any increase in water levels will support fringing vegetation. It is unlikely that the proposed changes will drastically alter the extent nor the diversity of fringing vegetation. Currently the only data for macroinvertebrates does not come from the swamp itself only from the constructed wetlands. Here fringing vegetation will remain an important habitat for macroinvertebrates.	Likely

Mature Melaleuca preissiana at the nearby Lexia 86 wetland (2019).

Lexia 186

The Lexia 186 wetland has a high conservation value because it consists of a largely undisturbed Sumpland habitat with a diverse vegetation community that provides significant habitat for fauna (Froend, et al., 2004a). The Lexia system of wetlands is composed of a series of separate wetlands including Lexia 86, Lexia 94 and Lexia 186. These three wetlands were chosen as representative and were given Ministerial water level criteria in the report for the East Gnangara (Lexia) borefield (EPA 1998). Lexia 186 was previously a seasonally waterlogged basin, however, prolonged decline of groundwater levels mean water levels are now below the level of the basin all year. There have been dramatic shifts in fringing vegetation health and composition as the basin sediments dry and oxidise.

Hydrology

There was a significant decline in groundwater levels at Lexia 186 from 1996 to 2015 of approximately 1 m. Since 2015 water levels have risen by 0.5 m (Figure 15). Nonetheless, current mean maximum and minimum water levels are 1.1 and 0.6 m below 1994-1999 levels and seasonal minima are occurring earlier in the year (Table 20). Groundwater levels at Lexia 186 have been non-compliant since 2000. Planned reductions in groundwater abstraction are not projected to increase water levels in the dampland, therefore a threshold 0.7 m below the current criteria has been proposed for 2030. Managing levels to this threshold will maintain groundwater levels at similar levels to the period between 2010-2015.

Table 20 Five-year summaries of surface water level data at Lexia 186

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	48.2 (Sep)	47.2 (May)	1.02	233
08/1999 – 07/2004	47.9 (Oct)	47.1 (Apr)	0.86	212
08/2004 – 07/2009	47.7 (Sep)	46.9 (Jun)	0.77	241
08/2009 – 07/2014	47.2 (Oct)	46.6 (May)	056	219
08/2014 – 07/2019	47.1 (Oct)	46.6 (Apr)	0.54	224

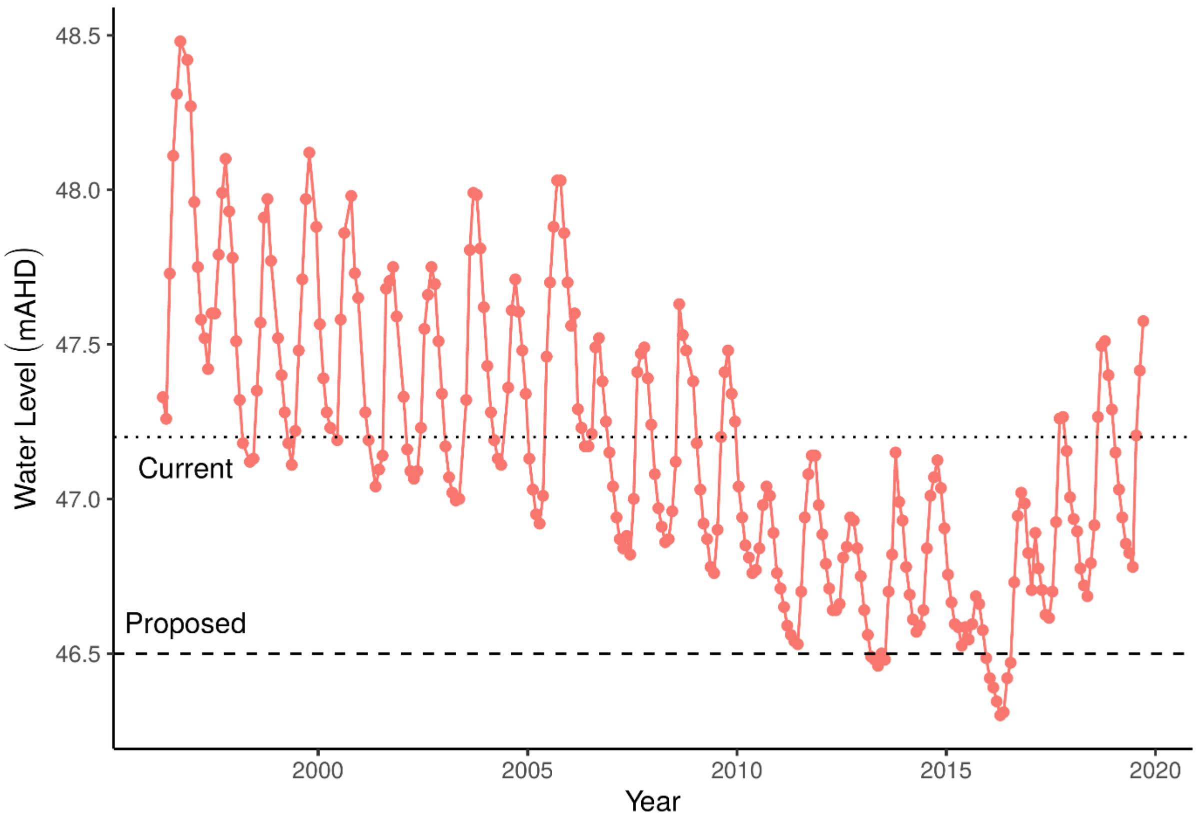


Figure 15 Groundwater levels recorded at bore 61613214 that represent water level fluctuations at Lexia 186. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of proposed thresholds

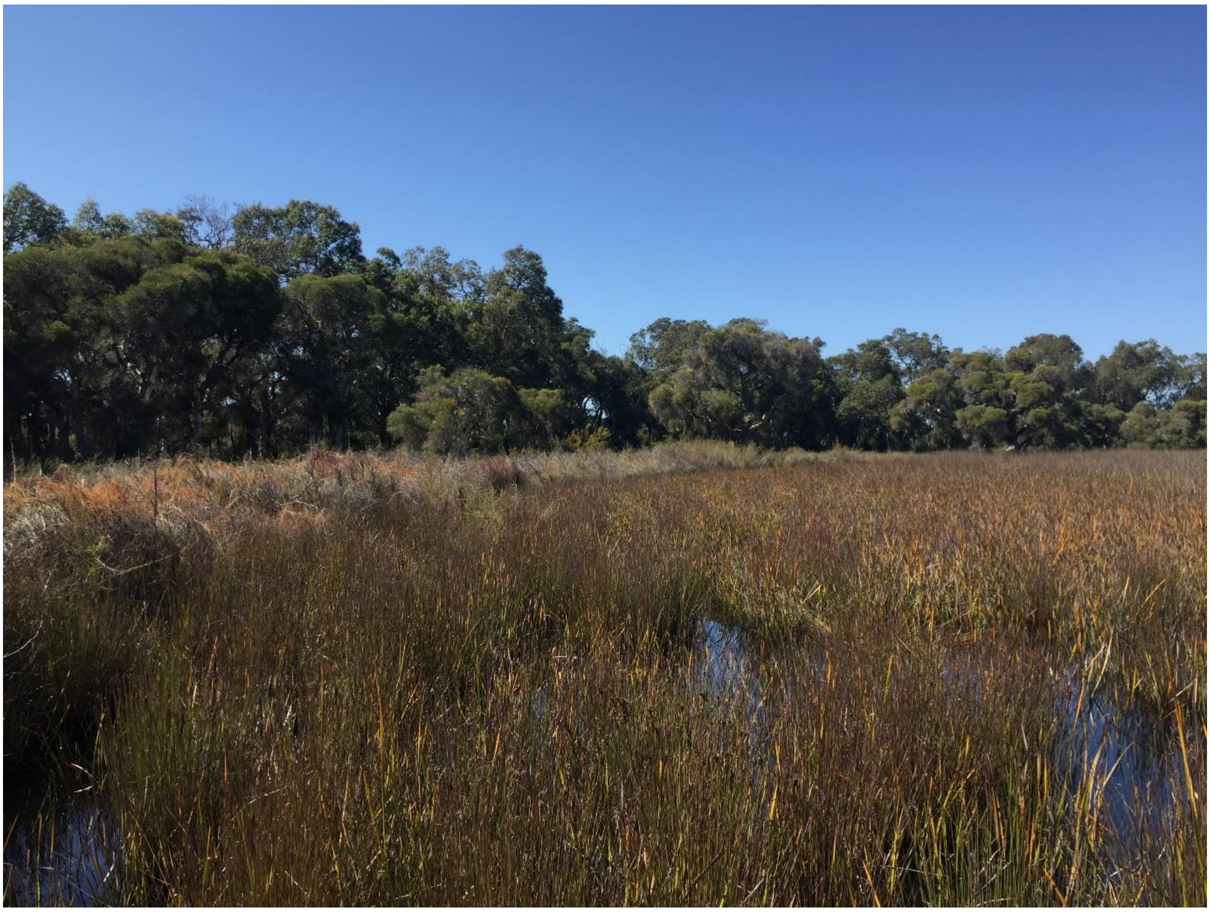
The site values of the Lexia 186 wetland are unlikely to be maintained under the planned changes to groundwater abstraction (Table 21). There has been a significant shift from a seasonally waterlogged basin to a system that is now permanently dry. The planned reductions in abstraction are not going to restore this important characteristic of the wetland. Instead, predicted changes in water level suggest maintenance of conditions similar to what the site has experienced since 2011. It is likely that vegetation will undergo further shifts in composition as some species (in particular *A. scoparia*, *M. preissiana* and *P. ellipticum*) will be exposed to extended periods where their ecological water requirements are not met during summer minimum water levels (Figure 16). Nonetheless, further monitoring will provide additional information as to whether the vegetation is likely to continue to change further.

Figure 16 Vegetation changes at the vegetation monitoring transect at Lexia 186 in October 2013 (left) and October 2018 (right) showing a gradual loss of ground cover. Source Buller *et al.* (2019).

Table 21 Ecological consequences of proposed 2030 minimum threshold (46.5 mAHD) in terms of compliance of stated site values and site management objectives at Lexia 186 set for the current absolute minimum Ministerial criteria (47.2 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (46.5 mAHD)	Values and objectives maintained in future
Site values (WRC, 1997)		
Undisturbed by typical impacts	Extensive native vegetation remains a feature of this site despite the significant shifts in composition during the monitoring period. Multivariate modelling (Appendix 2) suggests these shifts in vegetation species composition are not attributed to changes in groundwater levels. There has been a general trend of increasing native richness and cover abundance during the monitoring period.	Likely
Supports diverse vegetation	Managing levels to the proposed threshold is likely to maintain the high richness of native vegetation of the site, although it is markedly different to 1997 baseline conditions. There has been a general trend of increasing native richness and cover abundance during the monitoring period.	Very likely
Significant fauna habitat	The continued diverse native vegetation will continue to provide a rich habitat for (terrestrial) fauna.	Very likely
Site management objectives (1997)		
Conserve ecological values	Despite the altered hydrological regime, the site has maintained many of the ecological values that make this site important. These values are likely to persist given the proposed changes to the threshold level. Nonetheless, the site has been fundamentally altered as it is no longer a seasonally waterlogged dampland and altered sediment processes are likely contributing to the shift in vegetation community being observed.	Possible
Protect vegetation assemblages in and fringing the wetland	Fringing vegetation has been lost at the wetland as the site is no longer inundated. The planned changes to abstraction are not going to cause inundation and therefore fringing vegetation will continue to remain absent from the site.	Extremely unlikely

Protect invertebrate communities dependent on the wetland	Given the likely persistence of native vegetation at the site, terrestrial invertebrates will continue to inhabit the site, although this prediction is not based on any empirical evidence. Invertebrates typical of damplands are likely to have been affected by the declining groundwater levels. Aquatic macroinvertebrates have been lost since inundation no longer occurs. This situation will persist given the planned changes to abstraction.	Extremely unlikely
Proposed site management objectives		
Maintain fringing and wetland vegetation to support a range of habitat types	The projected water levels are not going to support fringing vegetation that rely on surface water. Some wetland vegetation, such as *Melaleuca preissiana* and *Banksia ilicifolia* will be sustained. This vegetation supports a variety of habitat for terrestrial fauna. **Suggested change:** As there is currently no fringing vegetation at the site, it is proposed here to alter the proposed objective to '*Maintain groundwater dependent vegetation to support a range of habitat types*'. A minimum water criteria set at 47.0 mAHD would reduce the risk of water stress to *M. preissiana.*	Unlikely – see suggested change



Inundation of Melaleuca Park 173 during spring peak levels.

Melaleuca Park 173

Melaleuca Park 173 (EPP 173) is located within the Bassendean North Vegetation Complex and represents a regionally significant wetland (Hill et al., 1996). It appears to be a remnant of a larger wetland, and is fed from a series of springs along the western margin of the basin (WRC, 1999; Froend, et al., 2004a; Judd and Horwitz, 2019), and has a creek running from its north-eastern end. The highly coloured waters supported a rich macroinvertebrate community and an endemic (and most northern) population of the black-striped minnow (*Galaxiella nigrostriata*). It was likely to have contained open water for about half the year, probably to a maximum depth of around 0.5m, and then it dried for the summer months, leaving only some surface water (up to 30cm) in its western margins due to the presence of the springs (WRC, 1999). There have been dramatic decreases in surface and groundwater levels in recent decades, to the point where there is now little or no surface water at all in the wetland over the summer months. Declining water levels are thought to have caused the local extinction of the black-striped minnow and degradation of fringing vegetation.

Hydrology

There has been a prolonged decline in surface water levels since 1990 that show similar trends with fluctuations in groundwater levels (bore 61613213; Figure 17). The readings at the staff gauge show the wetland is mostly now dry at the gauge. Since 2011, groundwater levels have been stable. Mean maximum and minimum water levels have decreased by 0.8 m and 0.5 m, respectively, since 1994 (Table 22). The latest 5-year period (2014-2019) suggests that groundwater is reaching an annual minimum earlier in the year than in previous seasons. Groundwater levels have been non-compliant during the monitoring period. The proposed threshold level of 48.5 mAHD is 1.7 m lower than the current threshold. Managing the wetland to these levels may result in further declines in water levels, though not to the record lows seen in 2016.

Table 22 Five-year summaries of surface water level data at Melaleuca Park 173. Data is based on data from bore 61613213 as many readings for the surface water staff 6162628 are below the minimum reading of 50.4 mAHD.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	50.9 (Sep)	49.2 (May)	1.73	242
08/1999 – 07/2004	50.8 (Sep)	49.1 (May)	1.66	220
08/2004 – 07/2009	50.6 (Sep)	49.0 (May)	1.59	168
08/2009 – 07/2014	50.0 (Oct)	48.7 (Jun)	1.27	224
08/2014 – 07/2019	50.1 (Sep)	48.7 (Apr)	1.38	225

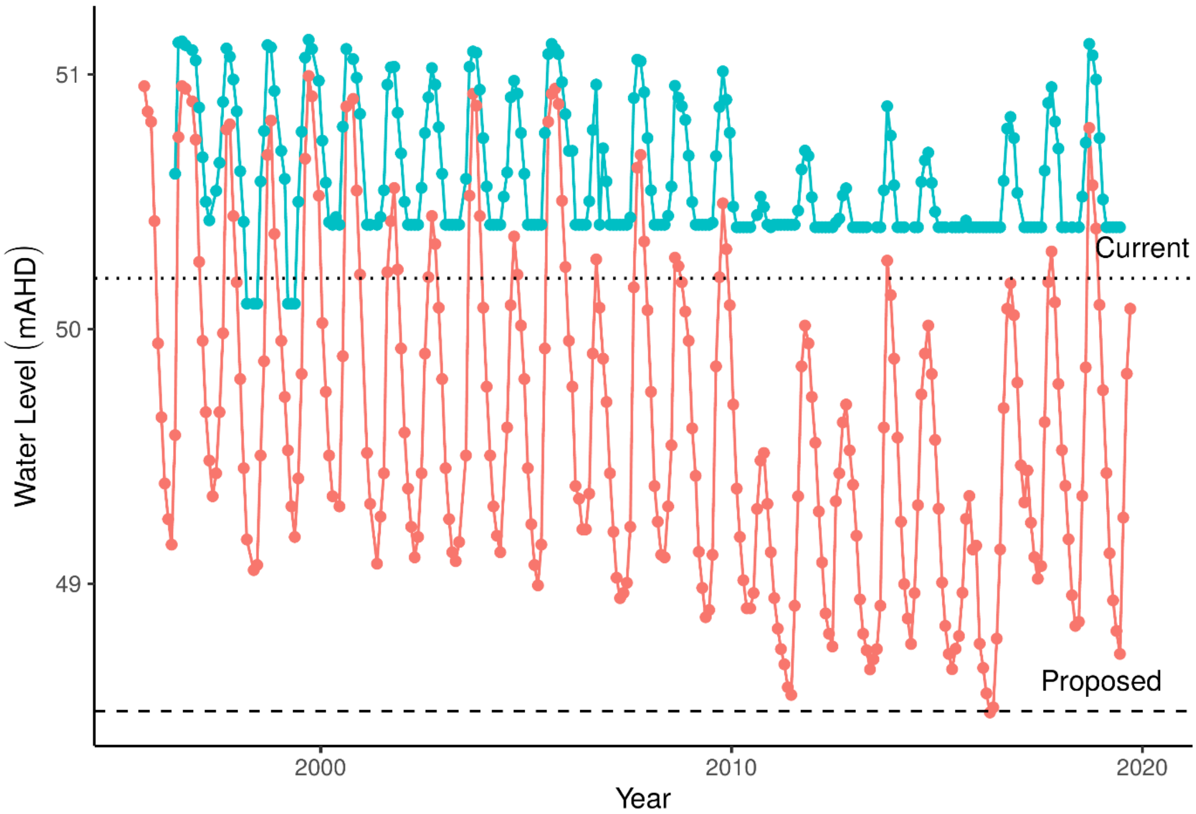


Figure 17 Ground and surface water levels for Melaleuca Park 173 recorded at bore 61613213 (red) and staff 6162628 (blue). The minimum recordable water level for the staff gauge is 50.4 mAHD. Records at 50.4 mAHD represent water levels below the minimum level measurable by the staff. Dotted line is the current Ministerial absolute minimum water level criteria for groundwater. Dashed line is the proposed 2030 minimum threshold level for groundwater.

Implications of proposed thresholds

It is unlikely that maintenance of many of the site values of the Melaleuca Park 173 wetland will be achievable given that the low groundwater levels and loss of surface water since 2000 are projected to continue (Figure 18 and Table 23). The vegetation modelling presented here suggests that vegetation from higher elevations of the basin are likely to migrate down-slope as water levels remain at the current low levels. The health of the important overstorey species, *Melaleuca preissiana*, is likely to continue to decline whilst terrestrial species, such as *Corymbia calophylla*, *Dielsia stenostachya* and *Xanthorrhoea preissii*, are likely to increase in abundance. It is unlikely that the ecological water requirements for important wetland species found at Melaleuca Park 173 will be met when maintaining water levels at the proposed thresholds.

The macroinvertebrate assemblage at Melaleuca Park 173 is displaying similar shifts as the other wetlands that have low pH, such as Lake Jandabup and Lake Mariginiup, which are experiencing declining richness. The projected water levels for 2030 are not likely to restore the high richness recorded at the site prior to 2008 as habitat availability continues to be diminished by low water levels and the low pH excludes non-acidophilic species.

Figure 18 Declining groundwater levels have dried a spring which once fed a permanently inundated body of water at Melaleuca Park 173. Vegetation monitoring has documented a shift in vegetation composition at this site from September 2005 (left) to October 2018 (right).

Table 23 Ecological consequences of proposed 2030 minimum threshold (48.5 mAHD) in terms of compliance of stated site values and site management objectives at Melaleuca Park 173 set for the current absolute minimum Ministerial criteria (50.2 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. "Additional values" refers to additional wetland features that were not originally recognized, and that might now be regarded as features worth managing to protect. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (48.5 mAHD)	Values and objectives maintained in future
Site values (WRC, 1997)		
An important example of the coastal vegetation type characteristic of the Bassendean North Complex	The site is rather distinct from other sites in terms of vegetation composition. There are healthy stands of *Melaleuca preissiana* which is an important canopy forming species. There has been an increase in abundance of *Corymbia calophylla* (Marri) at the site, suggesting low groundwater levels are facilitating terrestrialisation of the vegetation community. A higher minimum water level similar to pre-2009 levels (49.0 mAHD) would ensure seasonal inundation and play an important role in reversing further terrestrialisation of the site.	Very unlikely
High vertebrate and macro invertebrate species richness	Aquatic vertebrate and invertebrate richness have declined significantly. Native fish species are probably no longer at the wetland and macroinvertebrate surveys show a clear decline in richness of taxa. Proposed water level changes are not sufficient to reinstate permanent water from the spring and reverse this loss of diversity. The wetland now has surface waters during winter and spring months. The proposed threshold of 48.5 m will facilitate the ongoing transformation of the site into a seasonally inundated wetland, although surface water is unlikely to occur every year.	Very unlikely
Contains most northern population of black stripe minnow (*Galaxiella nigrostriata*), supported by permanent water sustained by a nearby spring.	Probably locally extinct from the wetland due to loss of permanent water maintained by spring.	Very unlikely

Site management objectives (WRC, 1997)		
Maintain wildlife and landscape values of the wetlands	The functioning of this wetland has changed markedly from a permanently inundated wetland to a seasonally inundated dampland. This has had a significant effect on the flora and fauna of the site. Nonetheless, the high native vegetation richness of the site is likely to persist and provide habitat for wildlife. *Galaxiella nigrostriatal* is locally extinct due to loss of permanent water and the value of this site as a permanently inundated wetland is unlikely to be recovered.	Unlikely
Maintain the existing areas of wetland and stream vegetation they support	Permanent water is unlikely to be a feature of this wetland under the revised abstraction plan. Seasonal inundation is likely to continue and will maintain many of the components of existing wetland vegetation. However, water levels are sufficiently low enough that surface waters do not form every year. Terrestrialisation of the vegetation community is occurring, and likely to continue under the current conditions.	Unlikely to halt terrestrialisation of vegetation
To protect invertebrate communities dependent on the wetland and stream	Declining waters are attributed to the marked decline in aquatic macroinvertebrate richness. The planned changes to abstraction are unlikely to reverse this trend.	Unlikely
To protect the fish species, *Galaxiella nigrostriata*	The projected levels under the planned reductions to abstraction suggest the wetland will not become permanently inundated, a necessity for fish. Because surface waters will continue to disappear seasonally, the wetland will not provide the habitat required for any fish species. *G. nigrostriata* is likely to be(come) locally extinct from this wetland.	Extremely unlikely
Additional values		
Aquatic macroinvertebrates	Only monitored wetland to have Perthiidae amphipods.	Likely
Proposed site management objectives		
Limit declines in health of fringing and wetland vegetation to support a range of habitat types	The planned changes to abstraction are likely to maintain water levels similar to the current conditions. The loss of permanent water is significant; however, the wetland should remain as a seasonally inundated sumpland. Managing the water levels above the proposed minimum threshold is likely to maintain fringing and wetland vegetation at a similar state to present and continue to support the current consortium of habitats. A higher minimum water criterion of 49.0 mAHD would likely halt, or reverse, terrestrialisation of the vegetation at this site by ensuring surface waters occur every year.	Possible. Likely if minimum threshold is raised to 49.0 mAHD

Mature Melaleuca preissiana woodland at the nearby Melaleuca Park 173 site.

Melaleuca Park 78

Melaleuca Park 78 (also referred to as Dampland 78) is located north-west of the Lexia wetlands in the southern area of Melaleuca Park. The site is approximately 6.7 ha in area and represents a regionally significant wetland (Hill et al., 1996). Melaleuca Park 78 is classified as a dampland habitat, meaning the basin has seasonally waterlogged soils that are not often inundated with surface waters (Semeniuk and Semeniuk, 1996). The site is an important habitat for a unique assemblage of phreatophytic vegetation which provides important habitat for native populations of fauna.

Hydrology

Monitoring of groundwater levels in the Melaleuca Park since the mid-1970s show a steady decline in water levels. Water levels at the Melaleuca Park 78 site declined from the beginning of monitoring in 1999 up until 2014, although absolute minimum levels were recorded in 2016. Bore 61613231 indicates that groundwater in the dampland may have declined by about 1.3 m since 1999, although there has been a recent increase in groundwater levels since 2016 (Figure 19). Current 5 year mean maximum and minimum groundwater levels in the bore are about 1 m lower than when monitoring began in 1999, with peak levels occurring in October/November and minimums occurring between April-May (Table 24).

Groundwater levels have mostly been non-compliant since 2012 after a significant decline from 2009 levels. The effects of reduced abstraction are unlikely to arrest the decline in groundwater levels at this wetland. The proposed threshold is 0.4 m lower than the current criteria. Further declines in groundwater levels are expected by 2030 under a drying climate scenario.

Table 24 Five-year summaries of ground water level data Melaleuca Park 78 recorded at bore 61613231.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1999 – 07/2004	66.2 (Oct)	65.8 (May)	0.40	235
08/2004 – 07/2009	66.0 (Nov)	65.6 (Apr)	0.36	228
08/2009 – 07/2014	65.4 (Oct)	65.1 (July)	0.31	213
08/2014 – 07/2019	65.2 (Nov)	64.9 (May)	0.29	170

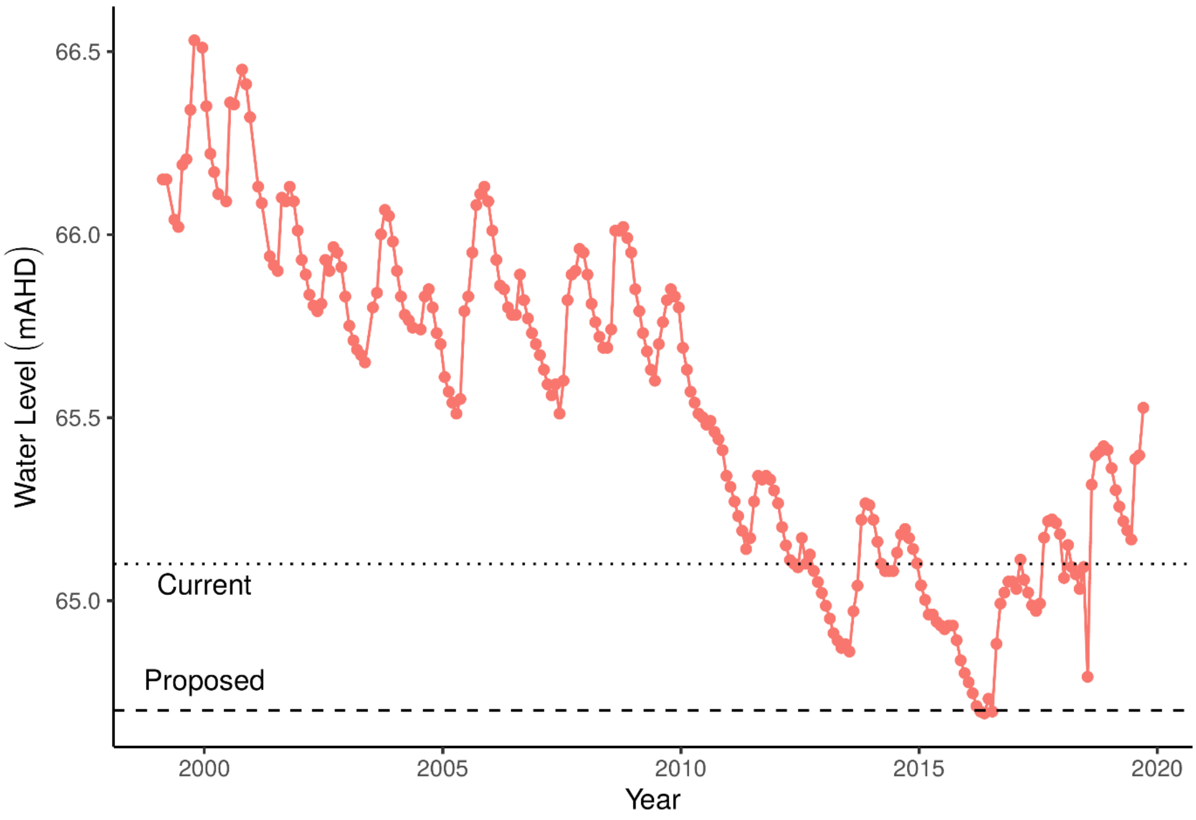


Figure 19 Groundwater levels recorded at bore 61613231 in the vicinity of the Melaleuca Park 78 wetland. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of proposed thresholds

The current site values are likely to be maintained despite the projected decreases in groundwater levels at Melaleuca Park 78 by 2030 (Table 25). The site will continue to contain a rich native consortium of vegetation that will provide habitat for fauna and important wetland species, such as *Banksia attenuata* and *Melaleuca preissiana*. There is evidence that the site has recovered substantially from past bushfire events and the ecological water requirements of *M. preissiana* will be met under the proposed changes, at least for individuals in the lower elevations. Evidence suggests that the trend of declining health of *M. preissiana* in upper elevations of the wetland will continue as the projected changes to groundwater levels are likely to put these plants into stress when annual minimum water levels are reached. Evidence suggests *M. preissiana* at higher elevations of the site do not meet their ecological water requirements when ground water levels are below 65.5 mAHD.

Table 25 Ecological consequences of proposed 2030 minimum threshold (64.7 mAHD) in terms of compliance of stated site values and site management objectives at Melaleuca Park 78 set for the current absolute minimum Ministerial criteria (65.1 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (64.7 mAHD)	Values and objectives maintained in future
Site values (WRC, 1997)		
Supports wetland vegetation	The site is composed of *Banksia* woodland and many groundwater dependent plant species typical of dampland habitats. Monitoring suggests that the community is relatively stable and has recovered from past fire events. There is evidence of declining *M. preissiana* health in the upper elevations of the wetland. Given the planned changes in abstraction, it is likely that these species will continue to persist, and the rich native consortium of vegetation will also persist.	Very likely. *M. preissiana* unlikely to be supported at upper elevations
Site management objectives (WRC, 1997)		
Maintain wildlife and landscape values of the wetlands	The site will retain the *Banksia* woodlands as a feature and continue to provide habitat to wildlife. It is possible that sustained low water will ultimately kill *M. preissiana* individuals located at higher elevations of the basin.	Very likely
Maintain the existing areas of wetlands and wetland vegetation	Some deep-rooted wetland species, such as *Adenanthos cygnorum,* which are susceptible to groundwater declines, are predicted to increase in cover abundance given a scenario of low ground water levels. It is likely that the site will retain many of key wetland species, but it is unlikely *B. articulata* will return. There is a risk that some wetland vegetation will disappear in the higher elevations of the basin, including *M. preissiana*.	Likely although *M. preissiana* distribution may decrease

Proposed site management objectives		
Limit declines in health of wetland vegetation	There is evidence that the proposed low water levels are sufficient to maintain the health of *Banksia* vegetation, however, *M. preissiana* health has been declining in the upper elevations of the site. The site has experienced very dry conditions similar to the projected water levels since 2010 and the continued decline in health of these *M. preissiana* individuals is likely. Annual minimum groundwater levels are likely to continue putting *M. preissiana* individuals at upper elevations for the site under water stress as water levels reach their absolute minimum ecological water requirements. Achieving spring peak water levels of 65.5 mAHD will ensure that *M. preissiana* individuals located along the entire elevational distribution achieve their minimum ecological water requirements periodically. This may reverse the trend of declining health of these individuals at upper elevations.	Likely (loss of *M. preissiana* is likely at upper elevations of the basin)

Banksia woodland at Whiteman Park East.

MM59B - Whiteman Park East

Hydrology

Groundwater levels at Whiteman Park East have been declining since 1980, although this decline seems to have stabilised since 2010 (Figure 20). Current 5-year mean maximum and minimum water levels are 0.9 and 0.6 m lower than 1994-1999 levels, respectively (Table 26). Minimum water levels occur in June, while maximums are usually reached in October.

Table 26 Five-year summaries of surface water level data at Whiteman Park East.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	37.2 (Oct)	36.2 (Jun)	1.08	229
08/1999 – 07/2004	37.2 (Oct)	36.1 (Jun)	1.11	244
08/2004 – 07/2009	36.6 (Sep)	35.8 (Jun)	0.86	244
08/2009 – 07/2014	36.2 (Oct)	35.5 (Jun)	0.72	249
08/2014 – 07/2019	36.3 (Oct)	35.6 (Jun)	0.69	249

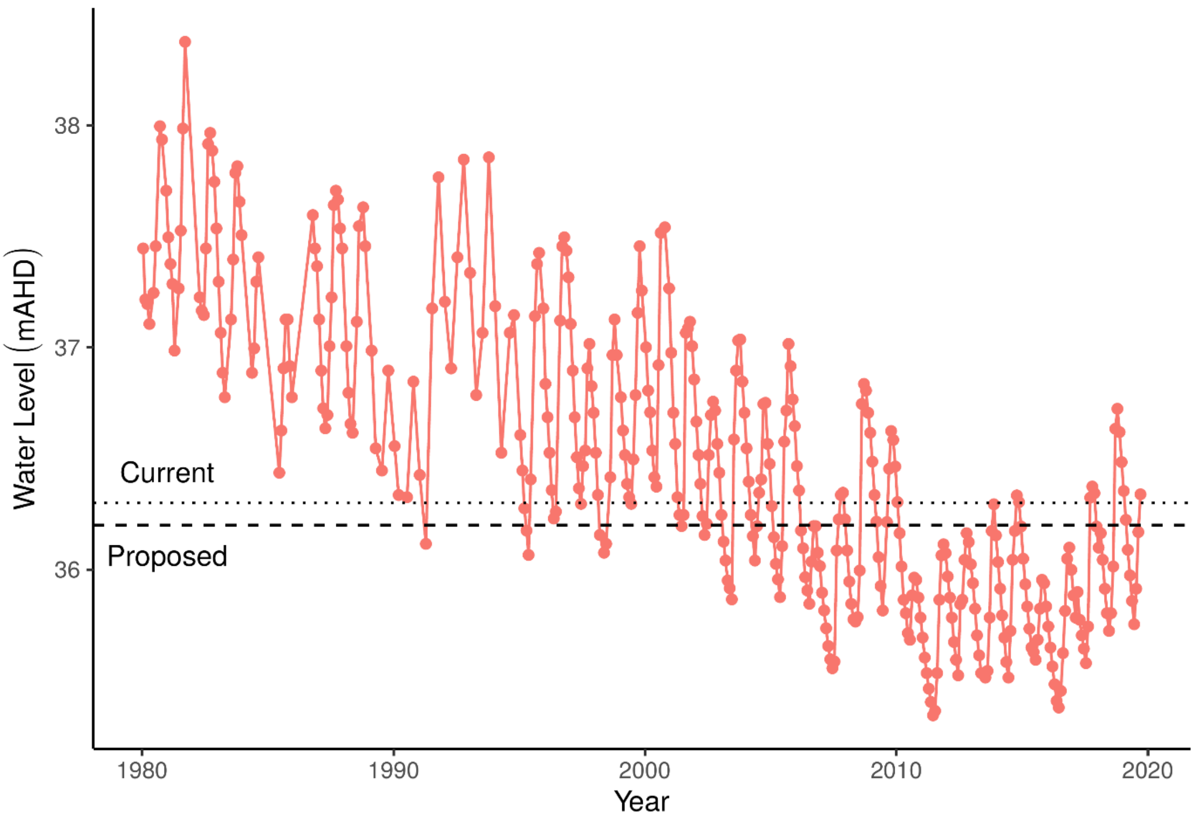


Figure 20 Groundwater levels recorded at bore 61610661 in the vicinity of MM59B. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of proposed thresholds

The site contains a fairly sparse understory and open mixed woodland canopy consisting of *Banksia* spp., *Allocasuarina fraseriana*, *Nuytsia floribunda* and *Eucalyptus todtiana*. *Banksia* species found at the site include *B. attenuata*, *B. ilicifolia* and *B. menziesii*. Vegetation is slightly degraded with signs of rabbits evident. Species richness and diversity are notably less than some of the other Pinjar sites and more exotic species, such as *Ursinia anthemoides*, are present at high cover abundances. Predominant native understory species include *Scholtzia involucrata*, *Calytrix* spp. and *Patersonia occidentalis*. *Banksia* spp. health was mostly good, although some *B. attenuata* appeared to be approaching senescence, and a number of dead *Banksia* are also present. Recruitment was present but low.

The projected increases in groundwater level are likely to have a positive impact on the health of the *Banksia* stands as groundwater becomes more readily available. However, such predictions are speculative as there has been no vegetation monitoring at this site and the shifts associated with groundwater decline are unknown. Nonetheless, the projected increases in groundwater levels at this site will ensure the *Banksia* woodland remains within 5 m of groundwater throughout the year (assuming a ground elevation of 41.2 mAHD). This will allow the woodland to be somewhat dependent upon groundwater and enhance the health of *Banksia* individuals.

Table 27 Ecological consequences of proposed 2030 minimum threshold (36.2 mAHD) in terms of compliance of stated site values and site management objectives at MM59B (Whiteman Park East) set for the current absolute minimum Ministerial criteria (36.3 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (36.2 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Selected to represent water levels over area of undisturbed phreatophytic vegetation	The site contains some important wetland species, including *Banksia* species, *E. todtiana*, *N. floribunda*, *S. involucrate* and *Calytrix* sp. However, the site is compromised by predation from rabbits and high abundance of exotic species. The revised minimum threshold is unlikely to affect the composition of the vegetation as groundwater levels will remain within 8 m of the surface. However, sustained predation from rabbits make it unlikely this site will continue to represent an undisturbed example of phreatophytic vegetation.	Unlikely
Banksia woodland <8m depth to groundwater	*Banksia* woodland appears in good health current low groundwater levels are not causing water stress. Given the proposed threshold will require groundwater levels to be higher than current levels, it is likely that *Banksia* woodland will remain healthy.	Likely
Site management objectives (WAWA, 1995)		
To protect terrestrial vegetation	The high predation from rabbits probably pose the greatest threat to the vegetation currently found at the site.	Possible
Proposed site management objectives		
Improve groundwater levels to improve the condition of dependent vegetation and potential *Banksia* woodland threatened community	Low groundwater levels and predation by rabbits appears to be affecting the health of the *Banksia* woodland at this site. Managing water levels above the proposed minimum threshold are likely to be sufficient to improve the health of the *Banksia* stands as the projected increases represent maintenance of groundwater levels within 5 m of the surface.	Likely

PM9 - Pinjar North

Hydrology

Groundwater at PM9 have almost continually been in decline since 1980 from approximately 59 mAHD to 2016 levels around 53 mAHD (Figure 21). The most significant rate of decline has been occurring since 1995 to 2016. Maximum and minimal seasonal water levels are 4 and 5 m lower now than in the 1994-1999 period, respectively (Table 28). Since 2016, no measurements at bore 61610804 have been made due to the operation of a nearby rifle range. It is unknown if groundwater levels have continued to decline since 2016 because no measurements have been recorded due to safety concerns regarding access to the bore. If the observed decline has continued, groundwater levels at the site may currently be below 52 mAHD, representing more than a 7 m decline since 1980.

Table 28 Five-year summaries of surface water level data at Pinjar North. The final period is based on data up to 2016 only.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	58.4 (Nov)	57.7 (Jun)	0.73	252
08/1999 – 07/2004	57.5 (Sep)	56.8 (Jul)	0.68	201
08/2004 – 07/2009	56.5 (Oct)	56.0 (Jul)	0.49	257
08/2009 – 07/2014	55.2 (Nov)	54.7 (Sep)	0.44	207
08/2014 – 07/2016	54.4 (Dec)	52.8 (May)	1.55	242

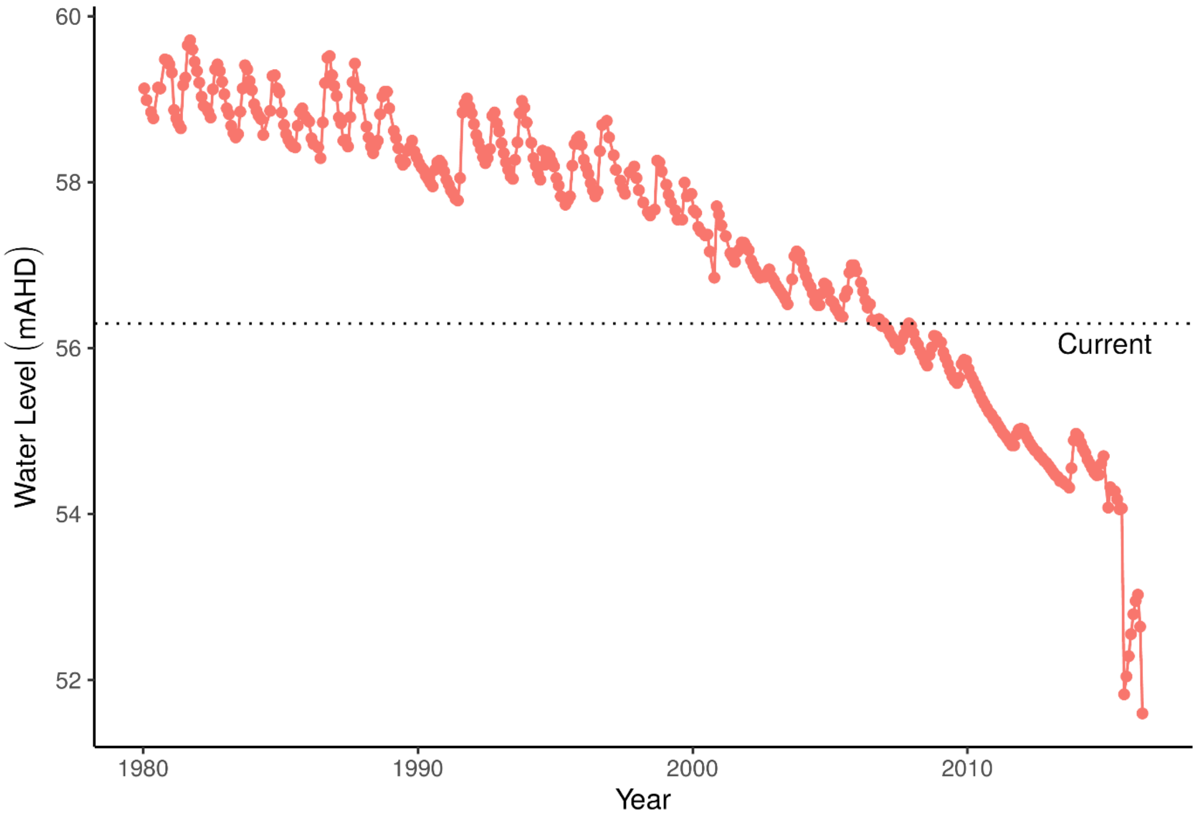


Figure 21 Groundwater levels recorded at bore 61610804 in the vicinity of PM9. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of proposed thresholds

The significant declines in groundwater levels at this site currently mean the water table is 12 m below the surface. Vegetation at this site is therefore no longer groundwater dependent. It is likely vegetation at this site has experienced significant shifts since 2008 as water levels declined to more than 8 m below the surface. Projected changes to groundwater suggest that further declines are likely. Therefore, the site will not recover any lost groundwater dependent values and maintaining a minimum water level threshold at the site is redundant.

Banksia woodland surrounding WM1 bore (2019).

WM1 - Pinjar

WM1 is located east of Lake Pinjar in the Chitty Road Bushland within the Bassendean north vegetation complex. Water levels at WM1 have been non-compliant with current Ministerial water level criteria since 2001. The site was visited in October 2019 and a baseline survey completed.

Hydrology

Groundwater levels at WM1 have declined up to 4.0 m since 1980, although levels have increased from 54.4 to 55.5 mAHD since 2015 (Figure 22). Current mean maximum and minimum water levels are 2.0 and 1.7 m lower than 1994-1999 levels (Table 29). Maximum water levels generally occur in October and minimum water levels are now occurring later in the year than previously.

Table 29 Five-year summaries of surface water level data at Pinjar (WM1).

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	57.1 (Nov)	56.2 (Apr)	0.95	217
08/1999 – 07/2004	56.5 (Oct)	55.6 (Jun)	0.86	246
08/2004 – 07/2009	55.9 (Oct)	55.1 (Jul)	0.81	200
08/2009 – 07/2014	54.9 (Oct)	54.3 (Aug)	0.54	204
08/2014 – 07/2019	55.1 (Oct)	54.5 (Aug)	0.57	110

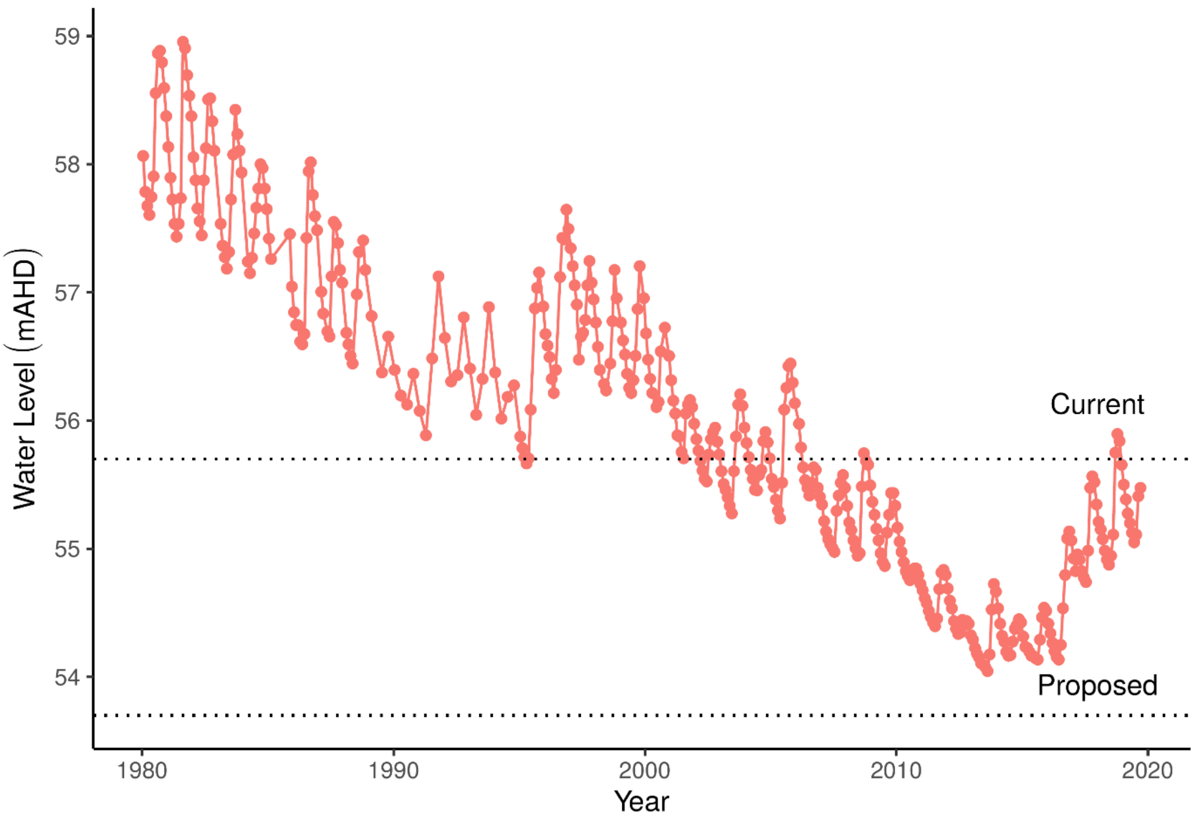


Figure 22 Groundwater levels recorded at bore 61610833 in the vicinity of WM1. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of proposed thresholds

The area has been affected by fire in the past (sometime between early Jan 2015 and late February 2015) and some of the older *Banksias* on the transect have old fire scars. Vegetation structure and community composition of the site is typical *Banksia* woodland, consisting of overstorey species *B. attenuata*, *B. menziesii* and *B. ilicifolia* and a typically diverse dry land understory of *Acacia pulchella*, *Adenanthos cygnorum*, *Jacksonia* spp and *Xanthorrhoea preissii*. Although not recorded in the transect, *Melaleuca preissiana* has been noted nearby. In general, *Banksia* health appears good despite several individuals having significant insect damage and yellow leaves. Previous reports have document the decline of vegetation at this site due to declining groundwater levels (Department of Water, 2008; Water and Rivers Commission, 2004). The trends included a general thinning of the understory, *B. attenuata* deaths, declining condition of *B. ilicifolia* and *B. menziessi*. *Eucalyptus todtiana* and *Corymbia calophylla* have also been reported to be declining in health in 2008 (Department of Water, 2008).

The projected decline of groundwater levels to 2030 may result in levels lower than what has previously observed at this site. This decline would hasten the decline of canopy health of species dependent on groundwater, including *B. attenuata*. Terrestrial species, such as *Acacia* species and *Xanthorrhoea preissii* are likely to become more abundant at the site, although these predictions are speculative because no long-term vegetation monitoring has occurred at the site. Despite these predicted low groundwater levels, the decline should arrest and be maintained to minimum levels that are less than 6.9 m below the surface levels (assuming ground level at 60.6 mAHD). Individuals that are located more than 6 m above the groundwater are likely to be less groundwater dependent and instead rely more on rainfall.

Table 30 Ecological consequences of proposed 2030 minimum threshold (53.7 mAHD) in terms of compliance of stated site values and site management objectives at WM1 set for the current absolute minimum Ministerial criteria (55.7 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (53.7 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Selected to represent water levels over area of undisturbed phreatophytic vegetation.	Phreatophytic vegetation at this site has already undergone changes associated with the declining groundwater level. This site still represents typical *Banksia* woodland although the understory has likely shifted to one dominated by dryland species. Given the low groundwater levels, it is possible that fire disturbance could shift the composition of the woodland dramatically. Water levels are likely to be below 6 m, and up to 7 m below the surface. Therefore, the vegetation is less likely to be as dependent on groundwater.	Unlikely given continued low groundwater levels
Banksia woodland <8m depth to groundwater.	The projected changes in water level should maintain the groundwaters within 6.9 m of the surface level (assuming ground elevation of (60.6 mAHD)	Likely
Site management objectives (WAWA, 1995)		
To protect terrestrial vegetation.	Terrestrial vegetation will persist at the site but may be less dependent on groundwater.	Likely
Maintain the existing extent and variety of wetland vegetation.	It is likely that the vegetation will be less groundwater dependent as groundwater levels will frequently be below 6 m from the surface. Further mortality of remaining groundwater dependent vegetation may continue.	Unlikely
Proposed site management objectives		
To avoid significant impacts to the habitat values of the *Banksia* woodland community as it transitions from groundwater-dependent to non-groundwater dependent vegetation.	Much of the groundwater dependent vegetation has already been lost from the site. Further losses are likely although it is possible that remaining *Banksia* individuals can rely solely on rainfall and persist into the future.	Likely as changes may have already occurred

Banksia woodland surrounding WM2 bore (2019).

WM2 - Melaleuca Park North

Located in Melaleuca Park in the Bassendean North vegetation complex, the area represents an area of undisturbed phreatophytic vegetation, including *Banksia* woodlands. The site was visited in October 2019 and a baseline survey completed.

Hydrology

There have been periods of significant decline in groundwater levels from 68.8 mAHD in 1980 to 66.4 mAHD in 2014 (Figure 23). The projected declines in groundwater levels at this site are significant and represent changes up to 1 m below levels ever recorded for the site. Since 2015, there has been an increase in groundwater to slightly above 67 mAHD. Mean maximum and minimum seasonal water levels are now 1.5 and 0.9 m lower than the period 1994-1999. Maximum levels have consistently been reached in October, on average (Table 31).

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Table 31 Five-year summaries of surface water level data at Melaleuca Park North (WM2).

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	68.5 (Nov)	67.6 (Sep)	0.94	216
08/1999 – 07/2004	68.1 (Oct)	67.4 (Feb)	0.68	246
08/2004 – 07/2009	67.7 (Oct)	67.1 (Apr)	0.62	205
08/2009 – 07/2014	66.8 (Oct)	66.4 (Apr)	0.46	210
08/2014 – 07/2019	67.0 (Oct)	66.5 (Mar)	0.52	79

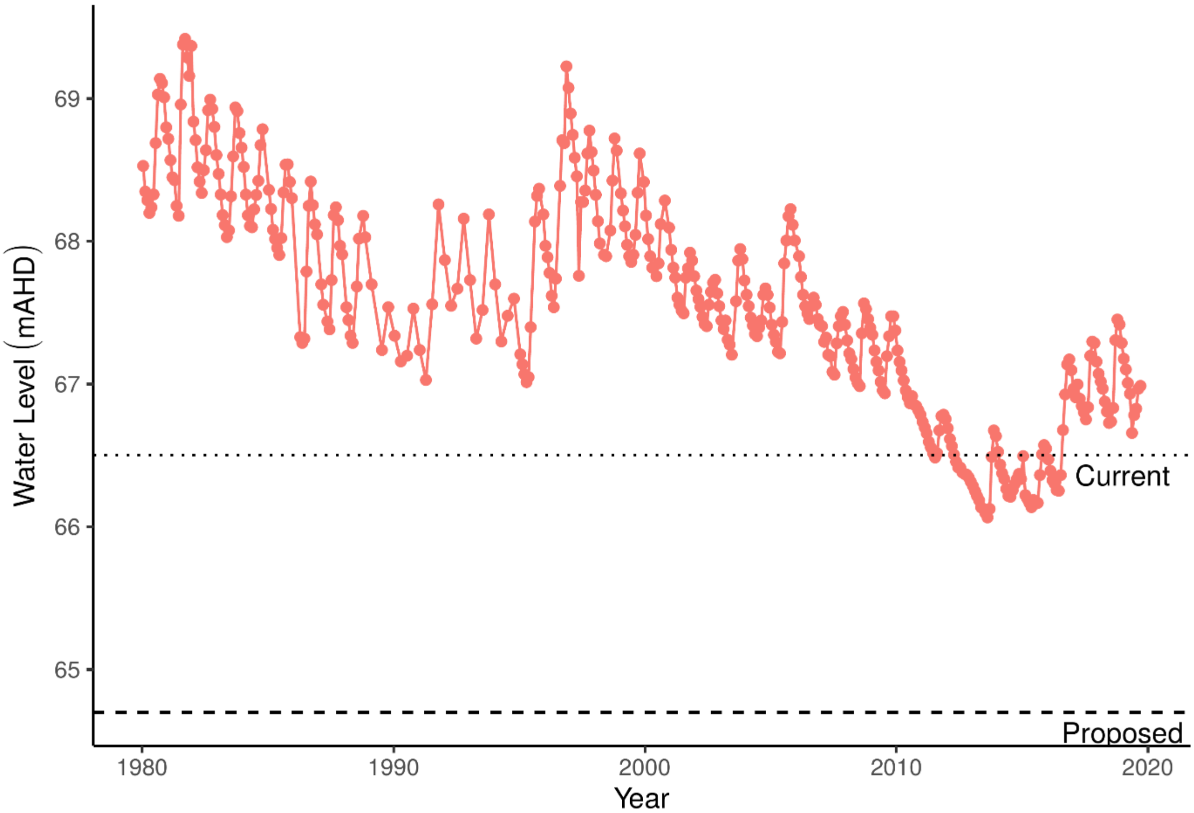

Figure 23 Groundwater levels recorded at bore 61610908 in the vicinity of WM2 Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of proposed thresholds

The vegetation around monitoring bore WM2 has similar vegetation composition to WM1. The vegetation also appears to have been affected by fire in the summer of 2014/2015. The understory is highly diverse, with *Acacia pulchella*, *Adenanthos cygnorum* and *Xanthorrhoea preissii* common. Canopy cover is quite open, with several mature *Banksias* present. Most *Banksias* were resprouts and/or young trees between 1 and 3 m tall. Several mature trees bore significant epicormic growth. New *Banksia* recruitment (mainly very small seedlings) for *Banksia attenuata* and *Banksia menziessi* have been observed.

The projected declines in groundwater at this site are likely to have a serious impact on groundwater dependent trees such as *Banksia attenuata* and *Banksia menziessi*. The health of these trees is likely to decline as groundwater approaches 65.0 mAHD as the groundwater is expected to reach more than 7 m below the surface. The diverse understory is likely to continue to be composed of terrestrial species such as *Acacia pulchella* and *Xanthorrhoea preissii*. Long term monitoring at this site is likely to capture significant shifts in vegetation composition if groundwater declines to the projected levels by 2030.

Table 32 Ecological consequences of proposed 2030 minimum threshold (64.7 mAHD) in terms of compliance of stated site values and site management objectives at WM2 set for the current absolute minimum Ministerial criteria (66.5 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (64.7 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Selected to represent water levels over area of undisturbed phreatophytic vegetation	Declining groundwater levels have reduced the site's value as an example of undisturbed phreatophytic vegetation. Vegetation at the site is likely to be less dependent on groundwater as groundwater levels are predicted to be more than 7 m below the surface.	Unlikely
Banksia woodland <8m depth to groundwater	Water levels should not decline past 7.2 m below the surface.	Likely
Site management objectives (WAWA, 1995)		
To protect terrestrial vegetation	Vegetation is likely to shift to one dominated by dryland species. Some wetland species, such as *Banksia* may persist and intermittently access groundwater when levels are high. The current consortium of groundwater dependent vegetation will deteriorate in condition as groundwater declines approach 8 m below the surface.	Unlikely
Maintain the existing extent and variety of wetland vegetation	As above. Vegetation is likely to be less groundwater dependent given the projected declines.	Unlikely
Proposed site management objectives		
To avoid significant impacts to the habitat values of the *Banksia* woodland community as it transitions from groundwater-dependent to non-groundwater dependent vegetation	Much of the groundwater dependent vegetation has already been lost from the site. Further losses are likely although it is possible that remaining *Banksia* individuals can rely solely on rainfall and intermittent access to groundwater and will therefore persist into the future.	Likely as changes may have already occurred

Banksia woodland surrounding WM8 bore (2019).

WM8 - Melaleuca Park

The WM8 monitoring bore is in Melaleuca Park within the Bassendean north vegetation complex and represents native vegetation that may be affected by abstraction from the Lexia groundwater scheme. There has been no reported change in vegetation at the site as no vegetation monitoring occurs here. The site was visited in October 2019 and a baseline survey completed.

Hydrology

Groundwater levels began to decline in 2000 at WM8 from approximately 66.0 mAHD to 64.6 mAHD in 2015 (Figure 24). Since 2015, there has been an increase in groundwater levels to approximately 65.5 mAHD. Mean maximum and minimum seasonal water levels have declined by 1.3 and 1.0 m, respectively (Table 33). Maximum levels are generally reached in December while minimum levels are reached in July.

Table 33 Five-year summaries of surface water level data at Melaleuca Park (WM8).

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	66.3 (Oct)	65.7 (Jul)	0.65	230
08/1999 – 07/2004	66.0 (Dec)	65.5 (Jun)	0.53	180
08/2004 – 07/2009	65.6 (Nov)	65.2 (Jul)	0.40	256
08/2009 – 07/2014	65.0 (Nov)	64.7 (Aug)	0.36	200
08/2014 – 07/2019	65.0 (Dec)	64.7 (Jul)	0.33	30

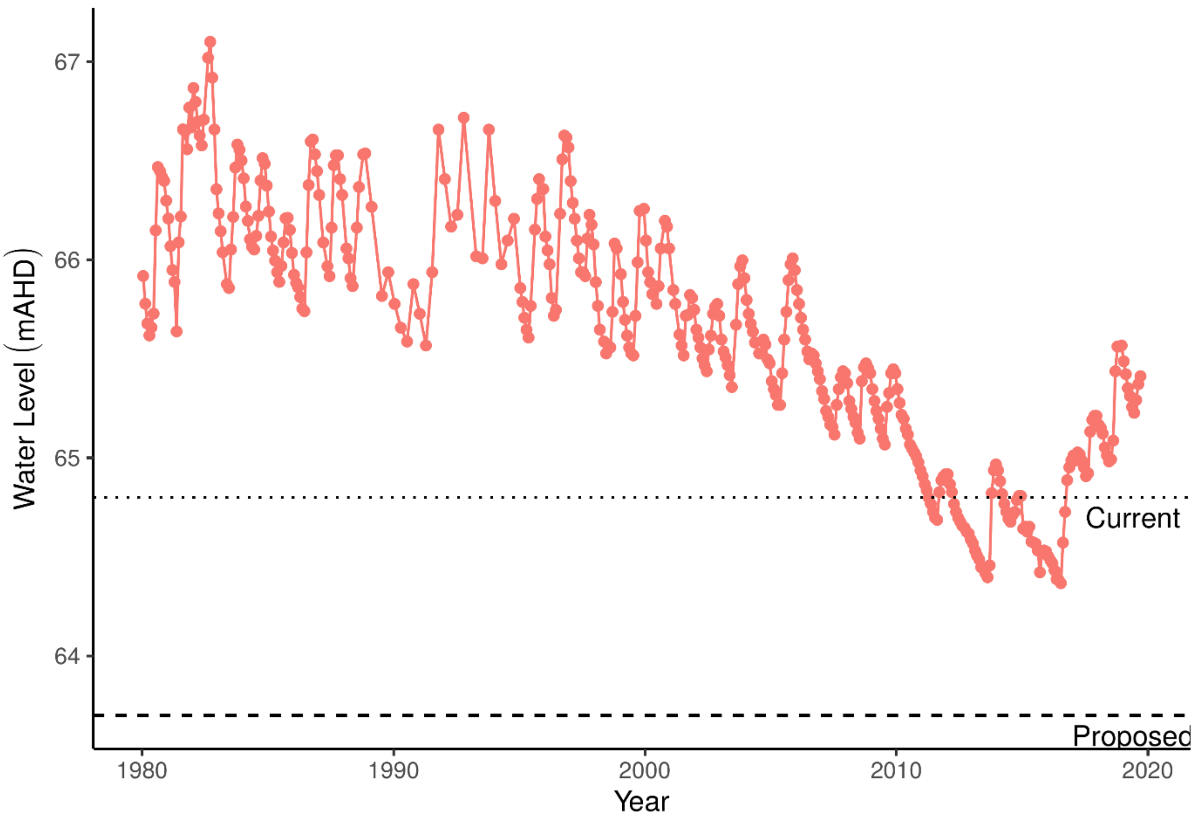

Figure 24 Groundwater levels recorded at bore 61610983 in the vicinity of WM8. Dotted line is the current Ministerial absolute minimum water level criteria. Dashed line is the proposed 2030 minimum threshold level.

Implications of proposed thresholds

The vegetation community at WM8 is typical of *Banksia* woodland. There is a sparse understory composed predominately of *Lyginia barbata*, *Scholtzia involucrata* and *Eremaea pauciflora*. The canopy is open and consists predominately of *Banksia attenuata* and *B. menziesii*. Tree health at the site was good although several dead mature *Banksias* were present. There is evidence of recent *Banksia attenuata* recruitment, mainly in the form of small seedlings. *Jacksonia floribunda* in notably poorer health than at the other Pinjar sites (WM1 and WM2).

Like the other Pinjar sites, the projected decline in groundwater by 2030 is very likely to have a detrimental effect on species that access the groundwater. Groundwater levels are projected to decline to 7.2 m below the surface. The site will therefore transition away from groundwater dependence. The understory is likely to remain dominated by dryland species. Some wetland species may persist. These species include the important canopy forming *Banksia attenuata*. Long term monitoring of the site will likely detect the shift of the *Banksia* woodland to a community dominated by terrestrial species by 2030 if groundwater levels decline as projected.

Table 34 Ecological consequences of proposed 2030 minimum threshold (63.7 mAHD) in terms of compliance of stated site values and site management objectives at WM8 set for the current absolute minimum Ministerial criteria (64.8 mAHD). Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations. Red shading indicates site values that have been lost (not currently characteristic of the site) and management objectives that are not currently being achieved.

	Likely effect of 2030 revised minimum threshold (63.7 mAHD)	Values and objectives maintained in future
Site values (WAWA, 1995)		
Selected to represent water levels over area of undisturbed phreatophytic vegetation	Declining groundwater levels have reduced the site's value as undisturbed phreatophytic vegetation. The site is less likely to be dependent on groundwater if levels are more than 7 m below the surface.	Unlikely
Banksia woodland <8m depth to groundwater	Water levels should not decline past 7.2 m below the surface.	Likely
Site management objectives (WAWA, 1995)		
To protect terrestrial vegetation	Vegetation is likely to shift to one dominated by dryland species. Some wetland species, such as *Banksia* may persist and intermittently access groundwater when levels are high. The current consortium of groundwater dependent vegetation will deteriorate in condition as groundwater declines approach 8 m below the surface.	Unlikely
Maintain the existing extent and variety of wetland vegetation	As above. Vegetation is less likely to be groundwater dependent given the projected declines.	Unlikely
Proposed site management objectives		
To avoid significant impacts to the habitat values of the *Banksia* woodland community as it transitions from groundwater-dependent to non-groundwater dependent vegetation	Much of the groundwater dependent vegetation has already been lost from the site. Further losses are likely although it is possible that remaining *Banksia* individuals can rely solely on rainfall and persist into the future.	Likely as changes may have already occurred

Task 4: East Wanneroo maximum threshold revisions

It is projected that a number of Spearwood/East Wanneroo lakes could experience a substantial increase in water levels due to increased recharge from urban development and associated local decreases in abstraction. Surrounding groundwater levels at Lake Goollelal are projected to increase by 0.4 m while groundwater levels surrounding Lake Mariginiup may increase by up to 3.9 m from 2013 levels (Table 35). Revised maximum thresholds are proposed here that maintain the current ecological values of the wetlands. However, these revisions are based on a series of generalisations outlined below.

Table 35 Summary of water level changes for four lakes which are likely to experience increased water levels (by 2030 compared to 2013 levels) under the likely changes land use and local groundwater abstraction.

Wetland	Current minimum criteria(mAHD)	Proposed minimum threshold (mAHD)	Current maximum criteria (mAHD)	Projected increase of surrounding groundwater (m)	Proposed maximum thresholds (m)
Lake Goollelal	26.0	26.4	27.5	0.4	No change
Lake Joondalup	15.8	16.2	17.6	2.1	18.0
Lake Mariginiup	41.5	42.1	42.6	3.9	No change
Lake Jandabup	44.2	44.3	46.1	3.4	46.2

The maximum thresholds proposed here represent increases that match the proposed increases of minimum water levels except that they are limited by the maximum ecological water requirements for the emergent fringing vegetation found at each wetland as determined by Froend et al., (2004b). For example, if the proposed minimum threshold represents an increase of 0.4 m, a maximum threshold is proposed here that also represents a 0.4 m rise. The threshold was qualified in two ways. First, if this rise exceeds the maximum water requirements for emergent vegetation the maximum threshold was reassessed to ensure maximum water levels do not exceed their physiological requirements. Second, the effect on fringing tree species was considered and, if necessary, the maximum threshold was revised further down if the maximum water requirements for tree species was exceeded for a wetland. These proposed maximum thresholds are therefore conservative, ensuring emergent vegetation and fringing tree species will persist at the very least at current highest elevation of their distributions in each wetland. These proposed maximum thresholds will guard against local extinctions of fringing trees from wetlands. Reasons to base maximum thresholds on the ecological water requirements of emergent vegetation include:

1. ***Continuity of wetland vegetation (preserving the hydrological gradient)***

Fringing vegetation can respond rapidly to changing water levels. Vegetative (asexual) spread of *Baumea* species and *Typha orientalis* is likely to be the main mechanism that allows establishment of populations further upslope under a scenario of increasing surface water levels. This is because seedling establishment is more likely to occur on moist sediments when water levels fall, rather than facilitate an upslope migration. However, for vegetative spread, the rate of surface water increase (rate of inundation) requires consideration because if the rate of inundation is too fast, local extinctions of emergent vegetation can occur as species may be unable to respond to the rapidly increasing water levels. Under an extreme scenario where rate of inundation exceeds a species' ability to migrate upslope, extinction of that wetland population will occur. Alongside maximum water levels, rate of inundation also needs to be considered when attempting to manage current emergent macrophytes. Here we assume that the rate of inundation rise is slow enough to allow emergent vegetation to migrate upslope, however this assumption might not hold for some species (particularly *E. rudis* and *M. rhaphiophylla*).

2. Maintaining Invertebrate habitat

Loss of emergent vegetation or a change in the species composition of emergent vegetation has been demonstrated to cause shifts in macroinvertebrate diversity and community composition (Judd and Horwitz, 2019). Here we use emergent vegetation health as a surrogate for macroinvertebrate diversity. It is therefore fundamental to maintain the existing diversity of macroinvertebrates and emergent vegetation to preserve taxonomic diversity throughout the Swan Coastal Plain (see Appendix 1). The maximum thresholds presented here aim to prevent loss of emergent vegetation and hence preserve the current macroinvertebrate diversity and maintain the ecological values stated for the wetlands (WAWA, 1995; WRC, 1997).

3. Maintaining water quality

Fringing vegetation contributes to the maintenance of water quality by providing a buffer between the wetland and surrounding land use where run-off and shallow groundwater flow might be influential.

Vegetation response to rising water levels

Fringing vegetation species found in the Swan Coastal Plain have absolute maximum water depth ranges between 0.43 m (*Banksia littoralis*) to 1.03 m (*Eucalyptus rudis* and *Melaleuca rhaphiophylla*). When water depth exceeds a species maximum water depth range, it is likely that the plant's physiological requirements will not be met (such as oxygenation of rhizosphere) and the plant will die. Furthermore, the duration of inundation can affect plant health and increase mortality. For example, emergent vegetation, such as *B. articulata* and *T. orientalis*, can cope with 12 months of inundation per year (Froend et al., 2004b), but other fringing species, such as *B. littoralis,* can only cope with a maximum of 2.8 months of inundation per year (Froend et al., 2004b). Although *E. rudis* occurs in locations along the Swan Coastal Plain where it can be inundated for up to 12 months of a year, it is highly unlikely that plants that remain inundated for a number of consecutive years will survive or be able to reproduce.

Due to the geomorphological similarities the East Wanneroo Interdunal wetlands of Lake Jandabup and Lake Mariginiup are likely to be impacted similarly by the projected increases in water levels. At both wetlands, as water levels rise, emergent vegetation will have to migrate larger horizontal distances, and into expansive and distal areas of the wetland basin; these expansions are more likely to be dependent on wetland bathymetry, and occur on flatter (less steep slopes) wetland extremities. In such cases expansions are likely to encroach upon regions of leached organically poorer quartz sands, pushing sediment saturation beyond the current organic sediments and in doing so extend the areal extent of the formation of these sediments within each wetland. This projection is based on the assumption that the organic material produced by *B. articulata* (and to a lesser extend *T. orientalis* and other emergent sedges) will accumulate as sediment under saturated conditions.

At Lakes Goollelal and Joondalup where the basin bathymetry around the wetland is steeper, emergent vegetation will only be able to expand over smaller horizontal distances. At these wetlands there is a greater likelihood of increased competition from already established fringing trees preventing colonization by emergent species.

Of further relevance is the issue of 'urban squeeze'. The projected increases in water levels may cause the preferred hydrological regime of some of the fringing vegetation species to shift into regions that are otherwise unsuitable habitat due to lawns, parkland, buildings and roads. For example, at the Urban Spearwood Dunal wetlands, Lake Goollelal and Lake Joondalup, emergent macrophytes may be prevented from migrating to 'higher' elevations because of maintained grasslands/lawns. Similarly, at the terrestrial end of the hydrological gradient, species may be prevented from moving upslope because of urban development. This 'squeezing' of vegetation may cause the loss of significant regions of emergent macrophytes which will have additional consequences for other elements of wetland flora and fauna. Additionally, longer lived tree species may not persist as they are unable to successfully migrate into more favourable hydrological conditions because of urban development.

The effect of 'urban squeezing' itself on the vegetation is not considered here. To do so would require a detailed analysis of the bathymetry of each wetland, the distribution of habitats and the likely distributional changes in water levels. Consideration of these factors will enhance our understanding of the potential changes in vegetation distributions and the likelihood of species being lost from wetlands and provide a much more comprehensive analysis of the effect of rising surface waters.

Below we consider the current distributions of key wetland vegetation species to determine the effects of maximum water levels to propose maximum thresholds that will maintain the current consortium of species of each wetland. Species maximum ecological water requirements, periodicity of inundation and their historical elevation distributions are considered for each wetland. The aim is to propose maximum thresholds for Lake Goollelal, Lake Joondalup, Lake Mariginiup and Lake Joondalup that will preserve the current diversity of emergent and fringing vegetation and comply with the site management objectives and ecological values as stated in WAWA (1995) and WRC (1997).

Lake Goollelal

Recording the elevational distributions of some key wetland species (*Baumea articulata, Eucalyptus rudis, Lepidosperma longitudinale, Melaleuca rhaphiophylla* and *Typha orientalis*) forms part of the vegetation monitoring survey at Lake Goollelal. Absolute maximum water depths for *B. articulata*, *E. rudis* and *M. rhaphiophylla* at Lake Goollelal have also been proposed by Froend et al. (2004b). These estimates are used here to determine the maximum surface water levels that can be reached before loss of vegetation will occur.

Baumea articulata has the lowest theoretical maximum threshold that is required to maintain the historical distribution. Surface water levels exceeding 27.55 mAHD are likely to cause mortality of current *B. articulata* stands and the distribution may shift upslope if the abiotic and biotic conditions allow. Surface water levels that reach 28.05 mAHD for prolonged periods over consecutive years are likely to reduce the health or cause death of *E. rudis* and *M. rhaphiophylla*. Migration of these fringing tree species upslope will not be as rapid as emergent vegetation and complete loss of these species is more likely if the conditions of their entire distributions become unfavorable.

Maintaining maximum water levels below 27.5 mAHD will prevent prolonged inundation of fringing trees and prevent the maximum inundation depths being reached (Table 36). A maximum surface water threshold of 27.5 mAHD will maintain the current distribution of *B. articulata* while causing periodic flooding of fringing trees. It is proposed here to not revise the maximum threshold water level for Lake Goollelal and to retain the current maximum threshold of 27.5 mAHD.

Table 36: Maximum inundation surface water levels for key species inhabiting Lake Goollelal and analysis of the ecological effect of adopting a maximum threshold of 27.5 mAHD. Elevation distribution data is from Buller et al. (2019) while maximum ecological water requirements are from Froend et al. (2004b). Species theoretical maximum thresholds are determined by summing their absolute maximum elevation and absolute maximum ecological water requirements.

Species	Absolute minimum elevation (mAHD)	Mean minimum elevation (mAHD)	Mean maximum elevation (mAHD)	Absolute maximum elevation (mAHD)	Absolute maximum ecological water requirement	Species theoretical maximum threshold (mAHD)	Effect of maximum threshold of 27.5 mAHD
Baumea articulata	26.6	26.6	26.71	26.74	0.81	27.55	Inundation exceeding the maximum depth is extremely unlikely. Stands are likely to persist within the historical distribution.
Eucalyptus rudis	26.76	26.77	27.01	27.02	1.03	28.05	Inundation exceeding the maximum depth is extremely unlikely. Stands are likely to persist within the historical distribution.
Lepidosperma longitudinale	26.65	26.65	26.78	26.78			Plants are likely to be inundated frequently, similar to historical events.
Melaleuca rhaphiophylla	26.6	26.6	27.02	27.02	1.03	28.05	Inundation exceeding the maximum depth is unlikely. Stands are likely to persist within the historical distribution.
Typha orientalis	26.6	26.6	26.65	26.65			Plants are likely to be inundated frequently, similar to historical events.

Lake Joondalup

Recording the elevational distributions of some key wetland species (*Baumea articulata, Baumea juncea, Lepidosperma longitudinale* and, *Melaleuca rhaphiophylla*) forms part of the vegetation monitoring survey at Lake Joondalup. Absolute maximum water depths for *B. articulata*, *B. juncea* and *M. rhaphiophylla* at Lake Joondalup have also been proposed by Froend et al. (2004b). These estimates are used here to determine the maximum surface water levels that can be reached before loss of vegetation will occur.

Baumea articulata has the lowest theoretical maximum threshold that is required to maintain the historical distribution. Surface water levels exceeding 19.91 mAHD are likely to cause mortality of current *B. articulata* stands and the distribution may shift upslope if the abiotic and biotic conditions allow. Surface water levels that reach 21.86 mAHD for prolonged periods over consecutive years are likely to reduce the health or cause death of *M. rhaphiophylla*. Migration of *M. rhaphiophylla* upslope will not be as rapid as emergent vegetation and complete loss of these species is more likely if the conditions of their entire distributions become unfavorable.

Maintaining maximum water levels below 18.0 mAHD will prevent prolonged inundation of fringing trees and prevent the maximum inundation depths being reached (Table 37). A maximum surface water threshold of 18.0 mAHD will maintain the current distribution of *B. articulata* while causing periodic flooding of fringing trees. It is proposed here to revise the maximum threshold water level for Lake Joondalup from 17.6 to 18.0 mAHD.

Table 37: Maximum inundation surface water levels for key species inhabiting Lake Joondalup and analysis of the ecological effect of adopting a maximum threshold of 18.0 mAHD. Elevation distribution data is from Buller et al. (2019) while maximum ecological water requirements are from Froend et al. (2004b). Species theoretical maximum thresholds are determined by summing their absolute maximum elevation and absolute maximum ecological water requirements.

Species	Absolute minimum elevation (mAHD)	Mean minimum elevation (mAHD)	Mean maximum elevation (mAHD)	Absolute maximum elevation (mAHD)	Absolute maximum ecological water requirement	Species theoretical maximum threshold (mAHD)	Effect of maximum threshold of 18.0 mAHD
Baumea articulata	16.7	17.02	18.1	19.1	0.81	19.91	Not likely to significantly affect the current distribution
Baumea juncea	17.24	17.78	19.0	19.2	1.03	20.23	Not likely to significantly affect the current distribution
Lepidosperma longitudinale	18.14	18.45	18.97	19.2			Not likely to significantly affect the current distribution
Melaleuca rhaphiophylla	16.7	16.84	19.23	20.83	1.03	21.86	Not likely to significantly affect the current distribution

Lake Mariginiup

Recording the elevational distributions of some key wetland species (*Baumea articulata* and *Eucalyptus rudis*) forms part of the vegetation monitoring survey at Lake Mariginiup. Absolute maximum water depths for *B. articulata* and *E. rudis* at Lake Mariginiup have also been proposed by Froend et al. (2004b). These estimates are used here to determine the maximum surface water levels that can be reached before loss of vegetation will occur.

Baumea articulata has the lowest theoretical maximum threshold that is required to maintain the historical distribution. Surface water levels exceeding 42.64 mAHD are likely to cause mortality of current *B. articulata* stands and the distribution may shift upslope if the abiotic and biotic conditions allow.

Maintaining maximum water levels below 42.6 mAHD will prevent prolonged inundation of fringing trees and prevent the maximum inundation depths being reached (Table 38). A maximum surface water threshold of 42.6 mAHD will maintain the current distribution of *B. articulata* while causing periodic flooding of fringing trees. It is proposed here to not revise the maximum threshold water level for Lake Mariginiup and to retain the current maximum threshold of 42.6 mAHD.

Table 38: Maximum inundation surface water levels for key species inhabiting Lake Mariginiup and analysis of the ecological effect of adopting a maximum threshold of 42.6 mAHD. Elevation distribution data is from Buller et al. (2019) while maximum ecological water requirements are from Froend et al. (2004b). Species theoretical maximum thresholds are determined by summing their absolute maximum elevation and absolute maximum ecological water requirements.

Species	Absolute minimum elevation (mAHD)	Mean minimum elevation (mAHD)	Mean maximum elevation (mAHD)	Absolute maximum elevation (mAHD)	Absolute maximum ecological water requirement	Species theoretical maximum threshold (mAHD)	Effect of maximum threshold of 42.6 mAHD
Baumea articulata	41.55	41.55	41.83	41.83	0.81	42.64	Maximum water levels that reach 42.6 mAHD will maintain the current distribution of *B. articulata*. Frequent inundation to this depth may cause some migration of stand upslope.
Eucalyptus rudis	41.55	41.73	41.84	41.86	1.03	42.89	Maintaining water levels below 42.6 m AHD will maintain the current distribution of *E. rudis*. However, prolonged inundation above 41.86 mAHD, especially over consecutive years, may cause mortality of current trees.

Lake Jandabup

Recording the elevational distributions of some key wetland species (*Artemisia scoparia, Banksia ilicifolia, Eucalyptus rudis, Hypocalymma angustifolium, Melaleuca preissiana* and *Pericalymma ellipticum*) forms part of the vegetation monitoring survey at Lake Jandabup. Absolute maximum water depths for these species at Lake Jandabup have also been proposed by Froend et al. (2004b). These estimates are used here to determine the maximum surface water levels that can be reached before loss of vegetation will occur.

Pericalymma ellipticum has the lowest theoretical maximum threshold that is required to maintain the historical distribution. Surface water levels exceeding 46.98 mAHD are likely to cause mortality of current *P. ellipticum* stands and the distribution may shift upslope if the abiotic and biotic conditions allow. Surface water levels that reach 48.9 mAHD for prolonged periods over consecutive years are likely to reduce the health or cause death of *E. rudis* and *M. preissiana*. Migration of these fringing tree species upslope will not be as rapid as emergent vegetation and complete loss of these species is more likely if the conditions of their entire distributions become unfavorable.

Maintaining maximum water levels below 46.2 mAHD will prevent prolonged inundation of fringing trees and prevent the maximum inundation depths being reached (Table 39). A maximum surface water threshold of 46.2 mAHD will maintain the current distribution of *P. ellipticum*. The existing maximum criterion is 46.1m AHD. It is proposed here to revise the maximum threshold water level for Lake Jandabup to 46.2 mAHD.

Table 39: Maximum inundation surface water levels for key species inhabiting Lake Jandabup and analysis of the ecological effect of adopting a maximum threshold of 46.2 mAHD. Elevation distribution data is from Buller et al. (2019) while maximum ecological water requirements are from Froend et al. (2004b). Negative ecological water requirements indicate depth below the surface. Species theoretical maximum thresholds are determined by summing their absolute maximum elevation and absolute maximum ecological water requirements.

Species	Absolute minimum elevation (mAHD)	Mean minimum elevation (mAHD)	Mean maximum elevation (mAHD)	Absolute maximum elevation (mAHD)	Absolute maximum ecological water requirement	Species theoretical maximum threshold (mAHD)	Effect of maximum threshold of 46.2 mAHD
Artemisia scoparia	46.5	46.5	48.33	48.53	1.03	49.56	Not likely to significantly affect the current distribution
Banksia ilicifolia	47.9	48.02	47.90	47.9	0.43	48.33	Not likely to significantly affect the current distribution
Eucalyptus rudis	47.9	48.04	48.04	47.9	1.03	48.93	Not likely to significantly affect the current distribution
Hypocalymma angustifolium	46.5	46.5	48.34	48.55	-0.16	48.39	Not likely to significantly affect the current distribution
Melaleuca preissiana	46.5	46.5	47.94	48.02	1.03	49.05	Not likely to significantly affect the current distribution
Pericalymma ellipticum	46.77	46.88	46.94	46.98	0.0	46.98	Not likely to significantly affect the current distribution

Task 5: Review of Lake Gwelup management

Lake Gwelup is a shallow groundwater system located in the highly urbanised area of Gwelup/Karrinyup. The lake was once permanently inundated with surface water and its surface levels are dependent on groundwater. These hydrological conditions made the lake an important habitat to a variety of fauna and fringing vegetation. Between 2001 and 2016, the lake dried during the summer, however levels have increased in recent years and the lake currently contains surface water year-round.

The wetland does not currently have Ministerial water level criteria. Proposed minimum and maximum thresholds are provided here to facilitate the development of management objectives. It is projected that groundwater levels in the surrounding area will rise by about 0.6 m from 2013 levels, probably resembling current conditions somewhat.

Hydrology

Lake water levels were first monitored in 1960, but regular monitoring has occurred between 1967 and 1988, and from 1999 until the present. Lake levels in the 1970s and 1980s were 1m to 2m higher than in the 2000s (Figure 25). They have risen again since 2013 and levels are currently similar to levels in the 1980s and 1990s (Table 40). The nearby bore 61610032 has been monitored since 1972. Water levels at the bore have declined by around 4 meters since the start of monitoring. Levels have been reasonably stable since the early 2000s and have trended slightly upwards since 2011.

Table 40 Five-year summaries of surface water level data at Lake Gwelup.

Period	Mean max seasonal level (mAHD)	Mean min seasonal level (mAHD)	Mean seasonal change (m)	Mean max to min (days)
08/1994 – 07/1999	7.5 (Sep)	5.7 (Apr)	1.85	239
08/1999 – 07/2004	6.7 (Oct)	5.1 (Apr)	1.52	172
08/2004 – 07/2009	6.3 (Sep)	5.0 (Dec)	1.32	14
08/2009 – 07/2014	6.1 (Oct)	5.0 (Jan)	1.17	138
08/2014 – 07/2019	7.3 (Oct)	5.6 (Apr)	1.66	222

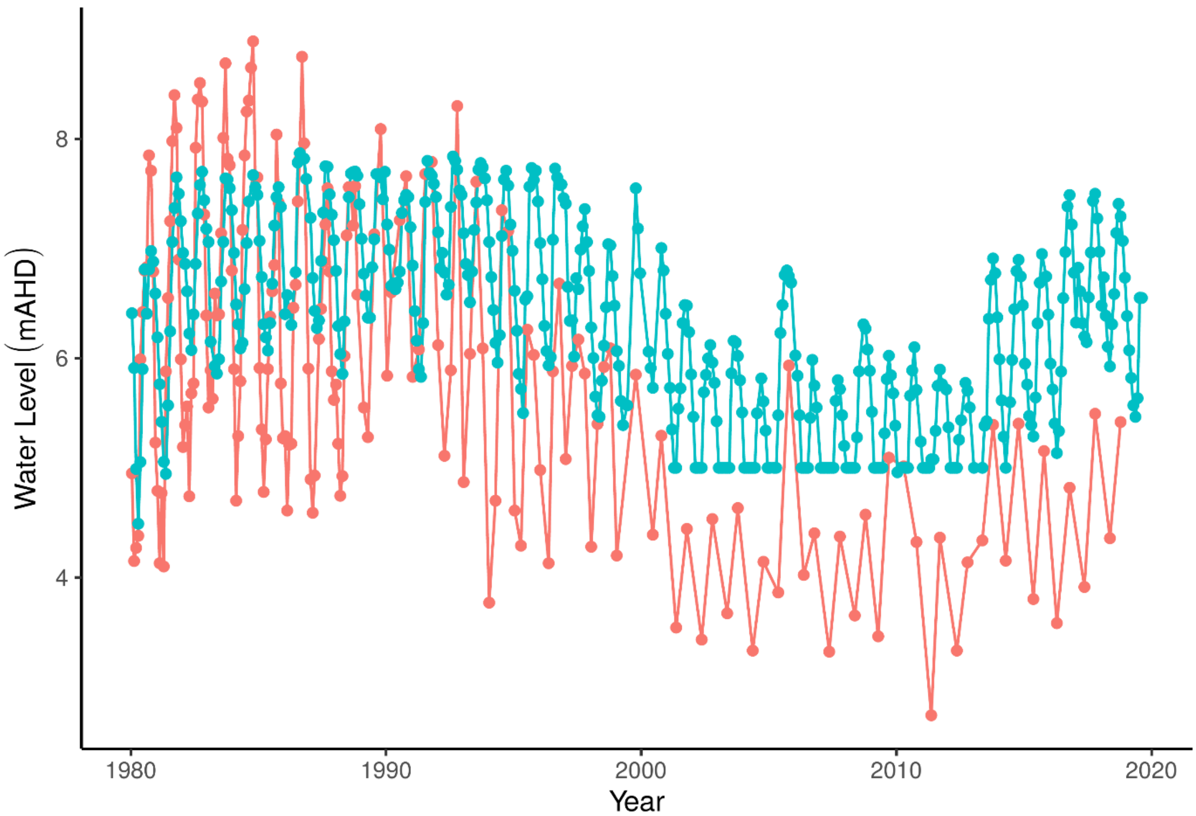

Figure 25 Ground and surface water levels for Lake Gwelup recorded at bore 61610032 (red) and staff 6162504 (blue). The minimum recordable water level for the staff gauge is 5.0 mAHD. Blue dots at 5.0 mAHD represent water levels below the minimum level measurable by the staff.

Proposed thresholds

The key wetland vegetation species at Lake Gwelup include *Melaleuca rhaphiophylla* and *Eucalyptus rudis* (Buller et al., 2018). The important bullrush species, *Typha orientalis*, has also been recorded at the lake but is absent from monitoring transects (Buller et al., 2018; Froend et al., 2009b). There is no information regarding aquatic macroinvertebrate trends at Lake Gwelup, but due to the importance of fringing and emergent vegetation providing habitat, proposed thresholds that aim to protect the surrounding vegetation can be considered a surrogate for the ecological water requirements for aquatic macroinvertebrates. However, increased inflow from stormwater needs to be monitored as pollution, primarily nutrient enrichment, may have a detrimental effect on macroinvertebrate assemblages. Because of the permanent surface water that typically occurs, the site is an important habitat for waterbirds. Shallow water is required by wader species in summer to facilitate feeding and high waters in winter to prevent the spread of vegetation throughout the basin.

Froend et al., (2004b) suggest that absolute minimum ecological water requirements for *M. rhaphiophylla*, *E. rudis* and *T. orientalis* are 2.14, 3.26 and 0.95 m below surface levels, respectively. Clohessy (2012) determined, that based on the lowest elevation occurrence of individuals at Lake Gwelup, the ecological water requirements at this site may be 4.24 and 3.86 mAHD for *M. rhaphiophylla* and *E. rudis*, respectively.

However, as the proposed management objectives for Lake Gwelup include the maintenance of permanent surface water, a minimum threshold needs to ensure that minimum water levels do not fall below the surface of the lake (approximately 5.0 mAHD). Considering the projected local rises in groundwater levels of 0.6 m from 2013 levels, maintaining surface water levels at the staff gauge that resemble the 1990-2000 hydrological regime could be met. Therefore, a minimum threshold of 5.4 mAHD at staff gauge 6162504 is recommended.

This threshold will ensure permanent water exists in the lake, enough variation in water levels for water bird feeding habitat, absolute minimum ecological water requirements for fringing vegetation are met and that maximum water levels prevent loss of important fringing vegetation (*M. rhaphiophylla* and *E. rudis*). An assessment of the proposed management objectives for the proposed thresholds is provided in Table 41.

Table 41 Ecological consequences of proposed minimum threshold of 5.4 mAHD at staff gauge 6162504 in terms of compliance of proposed site management objectives at Lake Gwelup. Future compliance assessments are based on current understandings of the hydrological influences on flora and fauna. They do not include future exogenous factors (like pollution events, introduction of exotic plants or animals) that might or might not occur in the future and affect these compliance estimations.

	Likely effect of proposed minimum threshold (5.4 mAHD)	Future Compliance
To maintain permanent water for fauna habitat and for visual amenity	Managing surface water levels above 5.4 mAHD will ensure permanent water remains a feature of Lake Gwelup. Seasonal minimum surface water levels greater than 5.4 mAHD will ensure habitat for aquatic fauna and flora. Permanent surface water will also enhance the visual amenity of the lake. Seasonal variation in surface water levels should be sufficient to provided feeding habitat for visiting and resident water birds.	Very likely
To maintain permanent water for fringing vegetation	The minimum and maximum thresholds provided here will ensure that fringing vegetation of *E. rudis*, *M. rhaphiophylla* and *T. orientalis* are maintained. The occurrence of surface water will ensure the ecological water requirements for these key species, while the maximum threshold will prevent the death of fringing vegetation when maximum water levels occur.	Very likely

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Appendices

Appendix 1: Trends across wetlands on the Gnangara groundwater system

Each wetland monitored in the Gnangara groundwater system vegetation surveys represent unique assemblages of native vegetation, particularly wetlands such as Melaleuca Park 173, Lake Jandabup and Loch McNess (Figure 26). Generally, the wetlands occurring in the Bassendean Dunes are distinct from those of the Spearwood Dunal System. However, annual monitoring reveals shifts in the composition of these assemblages, with evidence of some wetlands becoming increasingly similar to each other over time, probably in response to changing hydrological regimes. Lexia 186, Melaleuca Park 78 and Quin Brook appear to have vegetation communities with similar shifts in composition, suggesting the drying of these wetlands is a having a common influence on their vegetation structure. Similarly, Lake Mariginiup and Lake Wilgarup, both of which are now experiencing seasonal dry periods, are experiencing dramatic shifts in composition. It is likely that the temporary drying of these once permanent bodies of water is driving similar changes in vegetation composition.

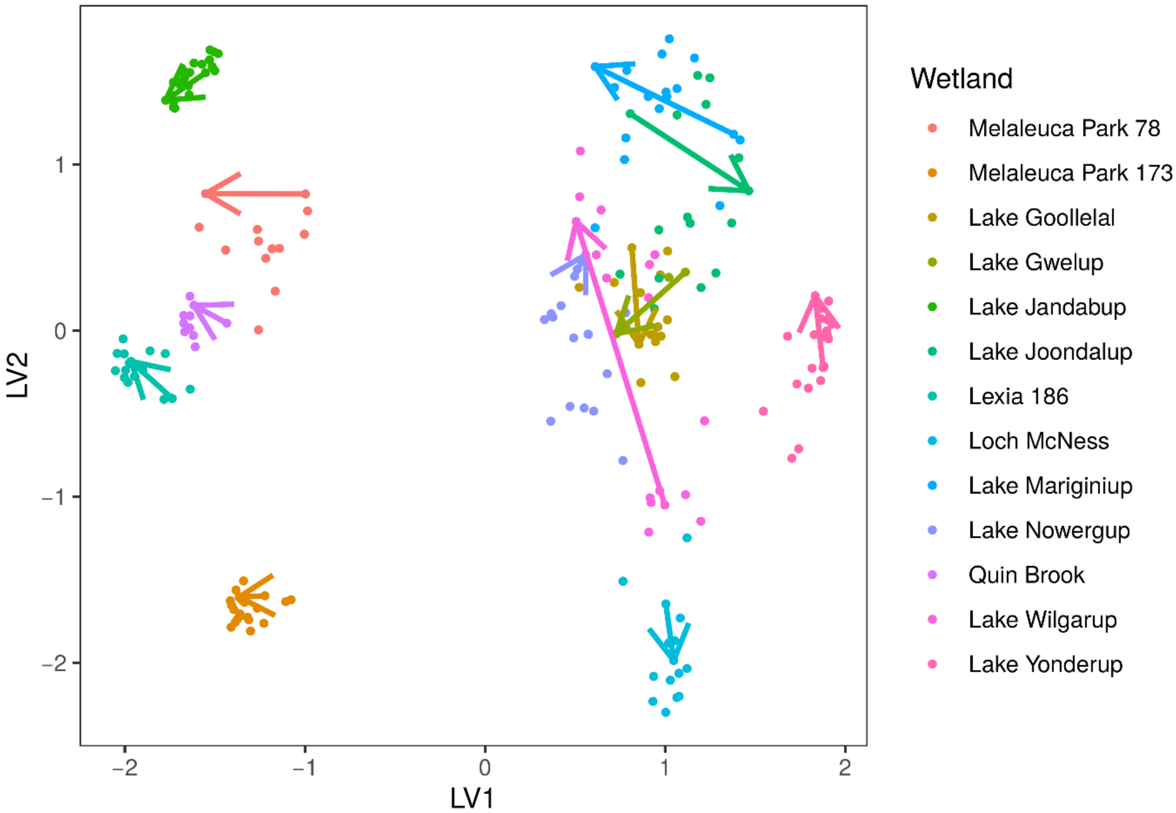

Figure 26 Unconstrained ordination plot of vegetation at each wetland site during the survey period (1996-2018). Arrows represent change from first survey to last survey. Vegetation ordination includes native vegetation only.

The aquatic invertebrate assemblages form three distinct groups based on the dunal system of the wetland (Figure 27). The Spearwood Dunes (Lake Goollelal, Lake Joondalup, Loch McNess, Lake Nowergup and Lake Yonderup) form the most diverse group, while the Bassendean Dunes Wetlands (Melaleuca Park 173) and East Wanneroo Interdunal Wetlands (Lake Jandabup and Lake Mariginiup) have different assemblages to each other. Generally, the Bassendean Dunes and East Wanneroo Interdunal wetlands are becoming more similar to each other, although such conclusions are based on a very limited set of wetlands. The Spearwood Dunes contain wetlands with two distinct trajectories, those migrating towards initial Lake Joondalup compositions (Loch McNess, Lake Goollelal and Lake Nowergup), and those migrating towards initial Loch McNess compositions (Lake Joondalup and Lake Yonderup). Although each wetland has a distinct assemblage of macroinvertebrates, aquatic macroinvertebrate communities have shifted during the monitoring period. Recent monitoring suggests that Loch McNess and Melaleuca Park 173 are becoming more similar to other wetlands. For instance, Loch McNess has shifted dramatically towards early Lake Joondalup composition. Lake Goollelal has displayed a similar, although not as dramatic, shift in composition. During the monitoring period, it is becoming apparent that Melaleuca Park 173, Lake Jandabup and Lake Mariginiup are converging in terms of macroinvertebrate assemblages. The communities at Lake Joondalup and Lake Yonderup have been shifting towards the early communities of Loch McNess. Lake Nowergup has shown some variation in community composition, but the current trajectory shows little change to the 1996 assemblage.

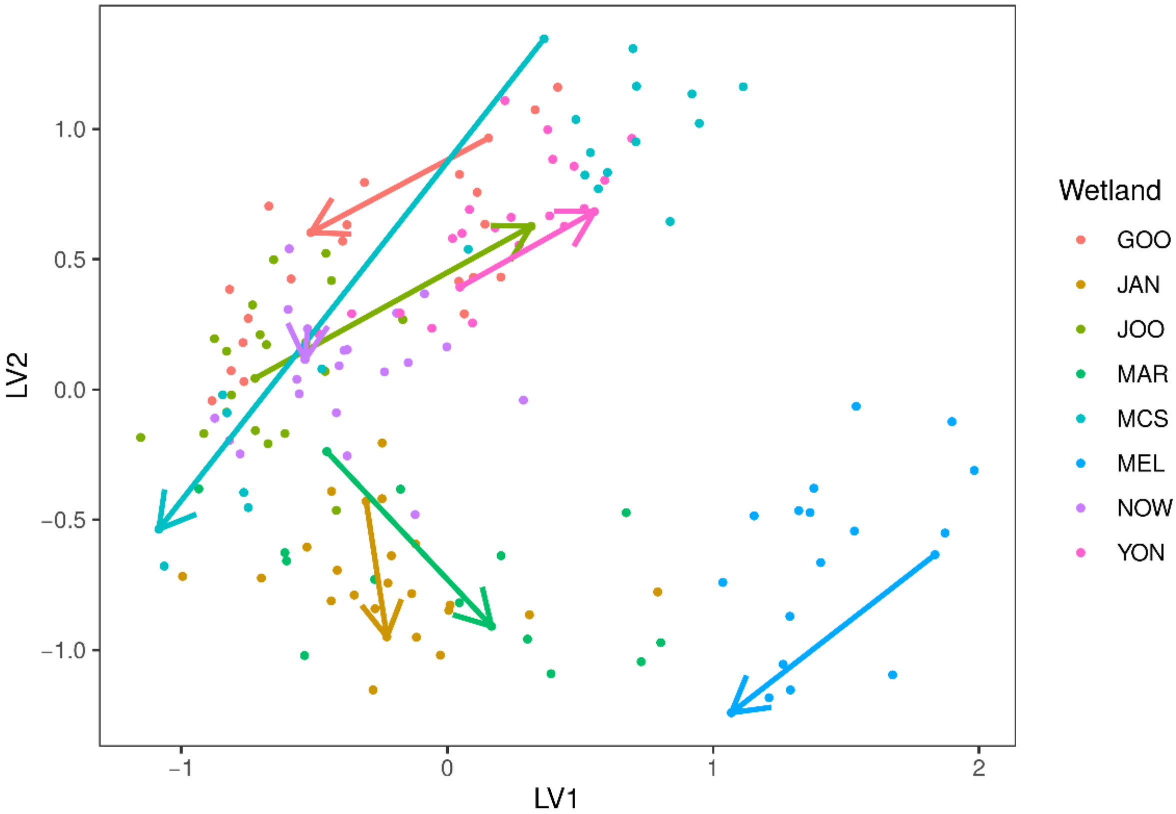

Figure 27 Unconstrained ordination plot of aquatic invertebrates at each wetland site during the survey period (1996-2018). Arrows represent change from first survey to last survey. Vegetation ordination includes native vegetation only. Wetlands included in invertebrate analysis include Lake Goollelal (GOO), Lake Jandabup (JAN), Lake Joondalup (JOO), Lake Mariginiup (MAR), Loch McNess (MCS), Melaleuca Park 173 (MEL), Lake Nowergup (NOW) and Lake Yonderup (YON).

Patterns of changing assemblages and declining richness are complemented by an analysis of monitoring data for macroinvertebrates (Table 42). The limitations of these data are that they are only once-off sampling for the season of spring each year, and only at usually three sites representing three different habitats, so the presence of taxa is a more reliable indicator than the absence of taxa. Nevertheless, patterns are discernible and if repeated over a sequence of years, and if they can be shown at more than one wetland, then they warrant closer attention. For the dataset examined, two patterns were determined. Some taxa were regularly present in the samples, in most years in the early period of monitoring (between 1996 and 2006) but have since become less frequently observed and are now actually absent in the samples in the last 5-15 years). Other taxa were extremely common in the early period of monitoring (between 1996 and 2006) but have since become much rarer or absent in the samples in the last 5-15 years).

Lakes Nowergup, Yonderup and Loch McNess have many taxa in one of these two groups (8, 9 and 10 taxa overall, respectively). Two insect groups have shown the same pattern of decline – Scirtidae beetles (from 4 of the six wetlands) and the Cordulidae damsel flies (also from 4 of the six wetlands). The insects, Corduliidae (Odonata), Ecnomidae (Trichoptera), Haliplidae (Coleoptera) and Mesoveliidae (Hemiptera) are all species with widespread distributions in the Swan Coastal Plain (Sommer et al., 2008), but are now not found in the monitored wetlands reported here.

Table 42 Taxa that have gone from regularly rare to absent and taxa that have gone from common to rare or absent during spring monitoring. Years represent the last time they were recorded in a wetland.

Lake	Taxa that have gone from regularly rare to absent	Taxa that have gone from common to rare or absent
Lake Goollelal	Scirtidae (beetle) 2004	Hydrophilidae (beetle) 2014
Lake Joondalup	Cordulidae (damsel fly) 2011	
	Haliplidae (beetle) 2010	
	Scirtidae (beetle) 2010	
Lake Nowergup	Sphaeridae (bivalve) 2002	Ceinidae (amphipod) 2007
	Arrenuridae (mite) 2007	Notodromadidae (ostracod) 2005
	Limnesiidae (mite) 2007	
	Cordulidae (damsel fly) spring 2011	
	Scirtidae (beetle) spring – 2004	
	Chydoridae (Cladoceran) 2011	
Lake Yonderup	Hirudinea (Leech) 2003	
	Ancylidae (limpet) 2011	
	Physidae (snail) 2012	
	Cordulidae (damsel fly) spring 2008	
	Lestidae (damsel fly) spring 2006	
	Libellulidae (damsel fly) spring 2005	
	Mesovelidae (bug) 2006	
	Dytiscidae (beetle) 2014	
	Macrothricidae (cladoceran) 2013	
Loch McNess	Limnesiidae (mite) 2007	Palaemonidae (shrimp) 2010
	Oxiidae (mite) 2008	Hydroptilidae (purse caddis) 2014
	Unioncolidae (mite) 2006	
	Parastacidae (crayfish) 2003	
	Caenidae (mayfly) 2010	
	Simuliidae (blackfly) 2003	
	Calanoida (zoopl.) 2009	
	Macrothricidae (cladoceran) 2007	

Appendix 2: Data analysis for each wetland

Lake Goollelal

Water quality

Lake Goollelal has stable water quality (Judd and Horwitz, 2019). Water pH, normally around 7.5, has only been recorded below 7 in 2007 while the current risk of acidification remains low due to declining chloride:sulphate ratios. Currently, the lake has low phosphorous, but is experiencing increasing levels of nitrogen, although levels are still below long-term averages.

Vegetation dynamics

The composition of vegetation at Lake Goollelal has been assessed 15 times between 1997 and 2019 at four plots along an established transect. Plot A represents fringing *Melaleuca rhaphiophylla*/*Eucalyptus rudis* vegetation and a stable community of the native sedges, *Baumea articulata* and *Lepidosperma gladiatum*. The *M. rhaphiophylla*/*E. rudis* complex continues throughout the transect, which has also remained relatively stable in terms of cover abundance since 2002. There is a high richness of exotic vegetation species present at the lake. Generally, these exotic species have increased in abundance during the survey period. The projected changes in surface water levels are likely to maintain the ecological water requirements of key wetland species, including *B. articulata*, *E. rudis* and *M. rhaphiophylla* (Figure 28).

Ordination reveals that Plot A has a distinct assemblage to the other plots but has displayed similar shifts in vegetation composition during the monitoring period (Figure 29). All plots show minor shifts in composition during the monitoring period, with each plot distinct from the others. Plot D displays a different pattern, probably due to the recorded presence of *B. articulata* in 1997 and the high cover abundance of exotic species. Bayesian regression analysis predicts many exotic species to increase in cover abundance with declining surface water levels (Figure 30).

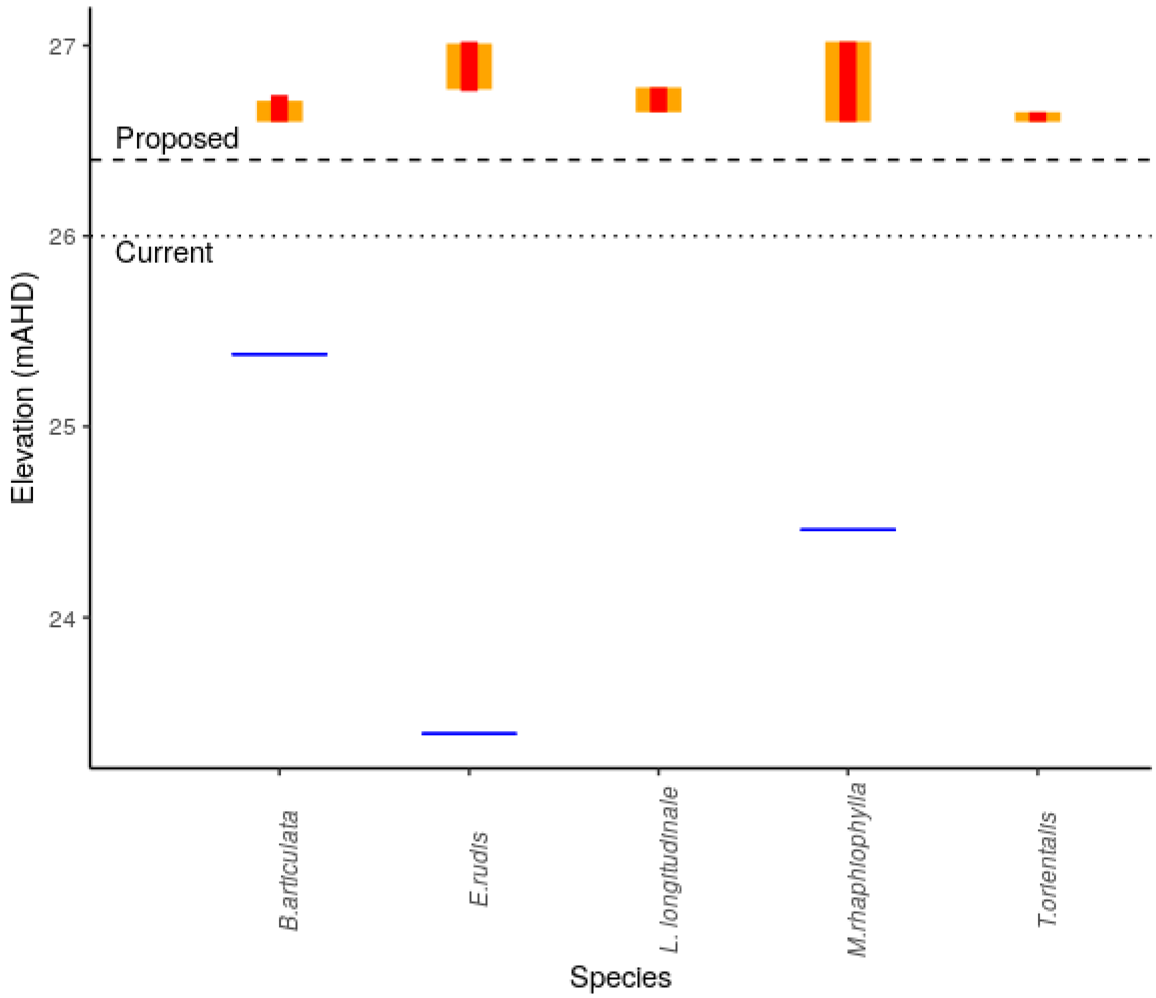

Figure 28 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2014 and 2019 at Lake Goollelal. *Lepidosperma longitudinale* only occurred in the transect in 2014 and *T. orientalis* in 2001. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line.

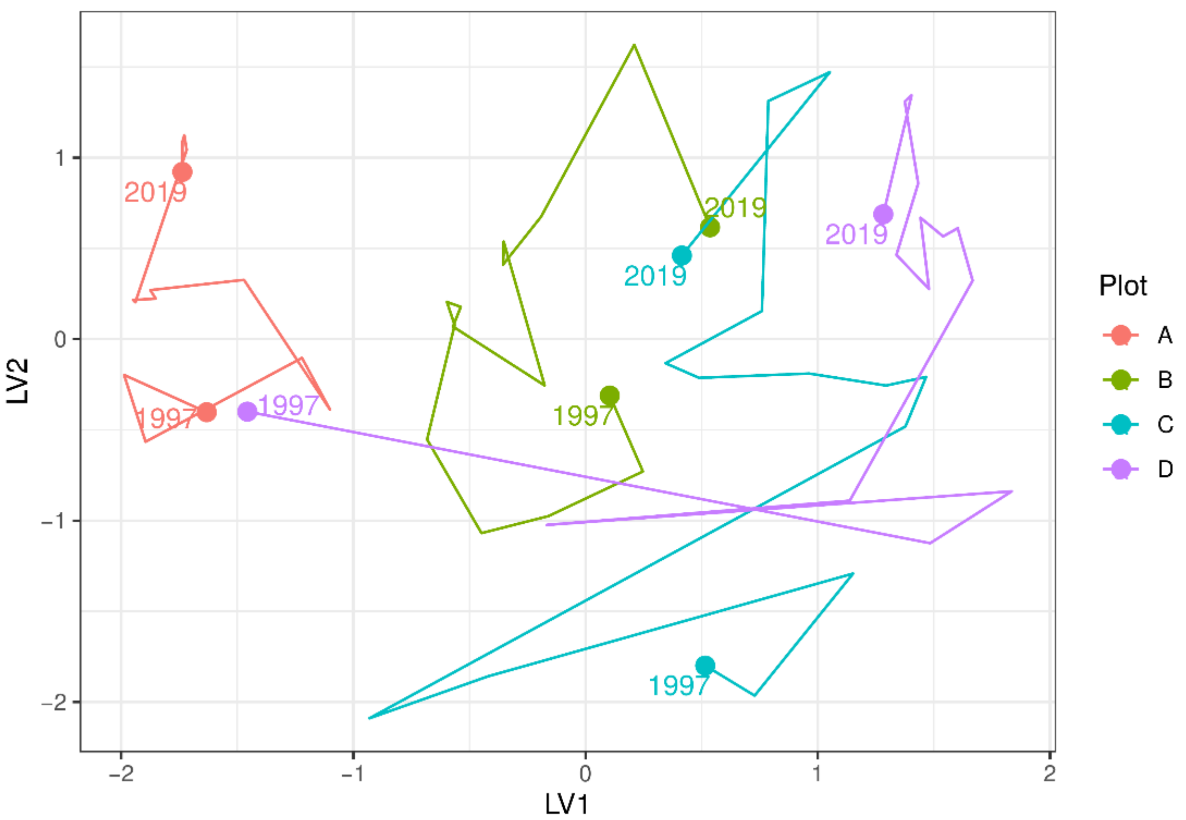

Figure 29 Unconstrained ordination based on vegetation data for each surveyed year for Lake Goollelal. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

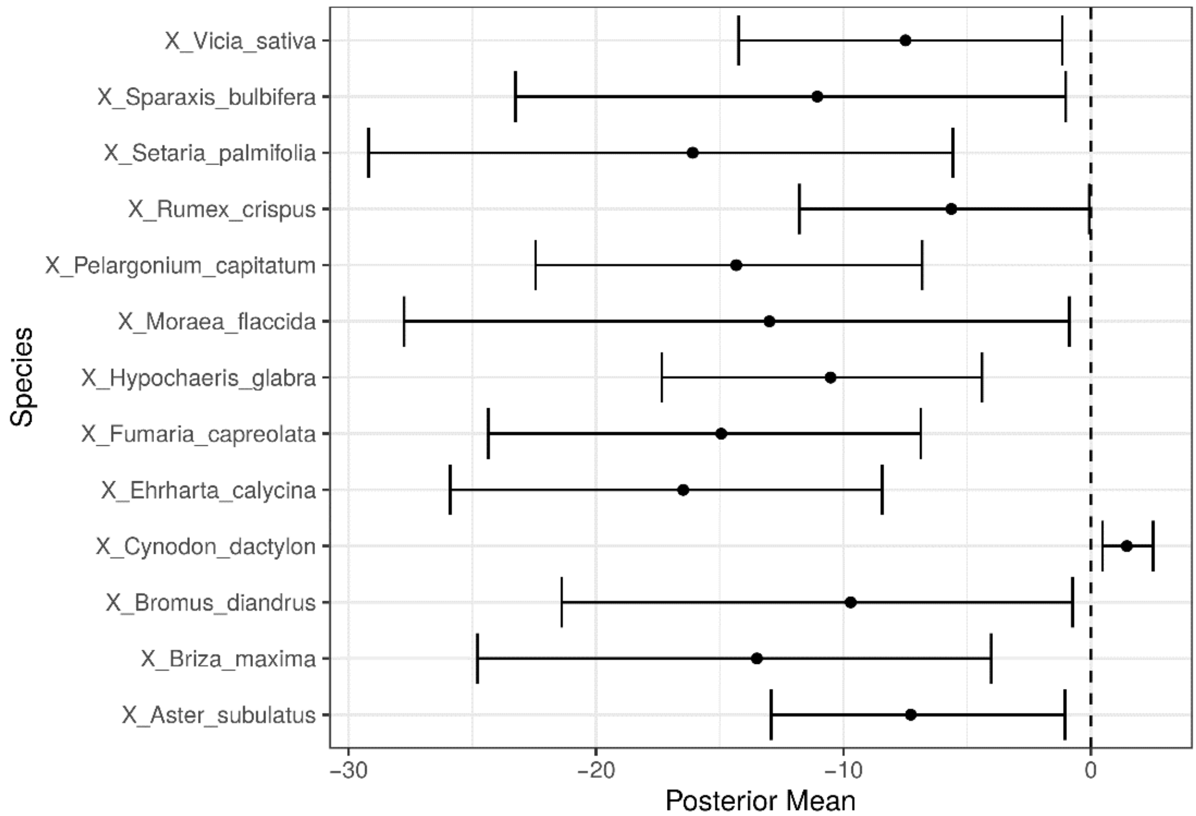

Figure 30 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at Lake Goollelal on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline while species with positive posterior values are likely to increase in cover abundance with increasing water levels. Only those species with coefficients significantly different to zero are shown. Invasive species are identified by the pre-text 'X'.

Aquatic invertebrates

The mean spring family richness of aquatic invertebrates is 22 for Lake Goollelal (Figure 31). Since 2008, family richness has mostly been stable and above the long-term average. There are stable populations of Amphisopidae, Calanoida, Ceinidae, Chironominae, Corixidae, and Cyprididae at the lake. The current absence of the Chydoridae (Cladocera) is notable given the abundance in early monitoring years. Also, the beetle family Scirtidae has not been found at the wetland since 2004. Other taxa showing recent absences in the lake include Ceratopogonidae, Chydoridae, Oligochaeta and Pionidae. There was a major shift in the assemblage composition in 2006-2007, with ordination revealing two main groups of annual data; those collected pre 2007, and those collected post 2007 (Figure 32). However, recent high-water levels and low nutrients appear to be shifting the assemblages back towards pre-2007 compositions (see Judd and Horwitz 2019).

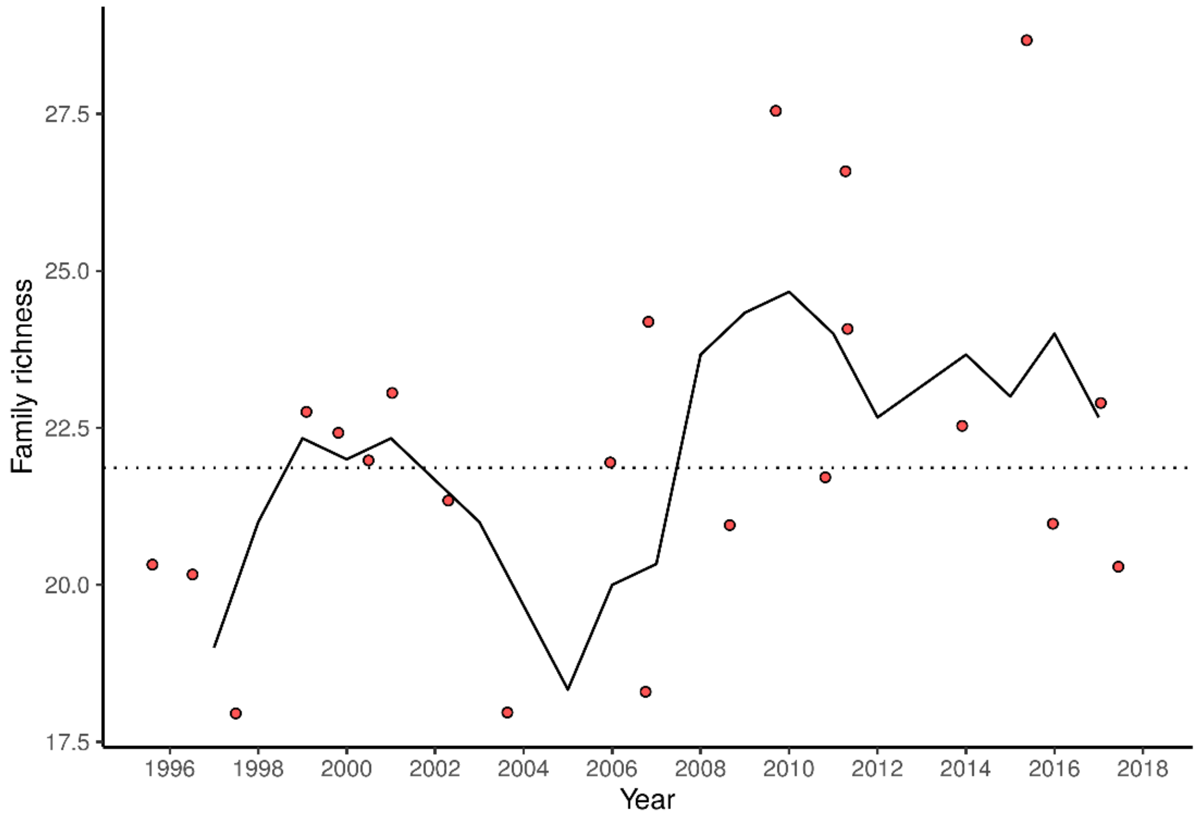

Figure 31 Richness of aquatic invertebrate families for each year at Lake Goollelal. Line is a moving 3-year average.

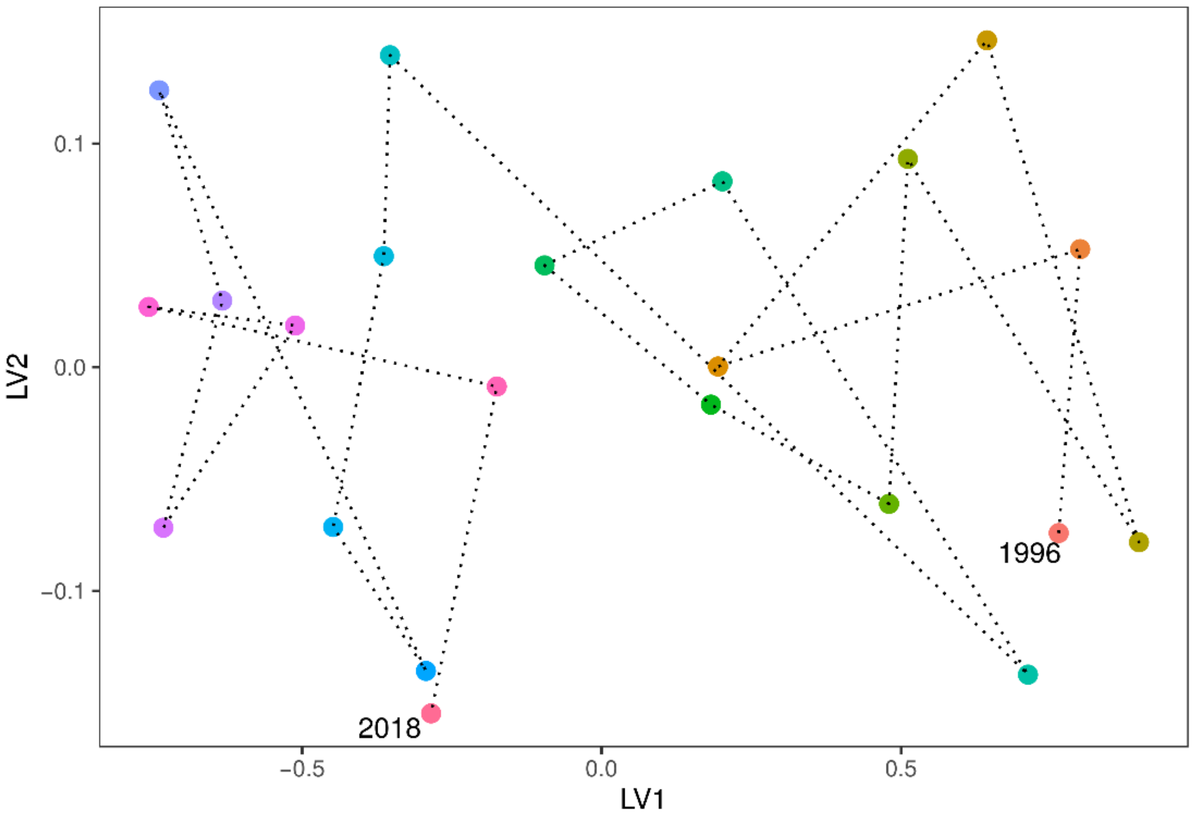

Figure 32 Unconstrained ordination based on invertebrate data for each surveyed year for Lake Goollelal. Consecutive years are joined by a line with first and last survey years labeled.

Loch McNess

Water quality

Water quality at Loch McNess appears to have stabilised in the past couple of years. Normal pH is thought to be over 8.0 but has been below 8.0 since 2010. Current monitoring suggests a pH of 7.8, the highest since 2010 (Judd and Horwitz, 2019). Chloride:sulphate and alkalinity observations suggest that acidification is not a current concern at Loch McNess South; but the same cannot be said for Loch McNess North. In Loch McNess South there has been a trend of increasing nitrogen levels in the wetland since 2010, current levels are double those recorded in 1997-2007 levels. Current phosphate levels are an order of magnitude greater than 1999-2004 levels and require close monitoring. These changes are probably due to exposure of unconsolidated sediments to a drying-rewetting regime.

Vegetation dynamics

A vegetation monitoring transect was established in 2004 with three plots (A, B, and C) plus an additional up-slope plot in 2009 (Plot D) and a plot down-slope of Plot A in 2010 (Plot E). The fringing vegetation is largely comprised of a *Melaleuca rhaphiophylla*/*Eucalyptus rudis* complex. Most trees are in average to good health (Buller et al., 2019). *Baumea juncea* is found in Plots A - D at relatively constant cover abundances. *Baumea articulata*, however, disappeared from Plot A in 2005 and was present in the new down-slope plot (Plot E) until 2014. Currently, *B. articulata* is probably not present at the site (Buller 2019 - personal observation) and the disappearance is likely due to a combination of a fire in 2009 and declining water.

The proposed minimum threshold is likely to cause added hydrological stress to some key wetland species found at Loch McNess (Figure 33). Nonetheless, the projected lower water levels are unlikely to reduce water levels below the ecological water requirements for *B. juncea*, *E. rudis* and *M. rhaphiophylla*. There may be migration of some of these species downslope overtime as preferred hydrological regimes for each species maintained.

Plots A and B have shifted in community composition dramatically during the monitoring period as the vegetation responds to lower surface water levels in the lake and the impact of fire in 2004 and 2009 (Buller et al. (2019); Figure 34). Regression analysis reveals that the exotic *Avena barbata* and the native *Tricoryne elatior* will increase the most in cover abundance as water levels in the lake remain low or decline further (Figure 35). The natives, *Carex fascicularis*, *Triglochin centrocarpa* and *M. rhaphiophylla* are most likely to decline dramatically at the wetland under a scenario of continued low water levels.

Aquatic macroinvertebrates

Loch McNess is the most taxonomically rich of the Spearwood Dune wetlands, with about 27 macroinvertebrate families regularly found there in spring seasonal monitoring (Figure 36). However, the composition of the community is shifting (Figure 37). The communities were relatively stable in terms of composition until 2008 after water levels had begun to decline significantly. The current trajectory suggests the dissimilarity between pre-2008 and contemporary communities will continue. The site is now dominated by common taxa of the Swan Coastal Plain such as Amphisopidae, Chironomidae larvae, Corixidae, Culicidae larvae, Cyclopoida (*Daphnia*), Dytiscidae, Notonectidae and Pionidae. Some of these, namely Chironomidae and Culicidae larvae, are considered nuisance species. The Amphipod, Ceinidae, has not been collected in the lake since 2014 and the shrimp *Palamonetes australis* not recorded since 2010 – both of these taxa were once abundant. Nine families of invertebrates that were once regularly detected in the spring monitoring events, are no longer so. This shift in macroinvertebrate assemblage indicates serious changes in ecological processes as the wetland transitions towards a nutrient enriched shallow lake.

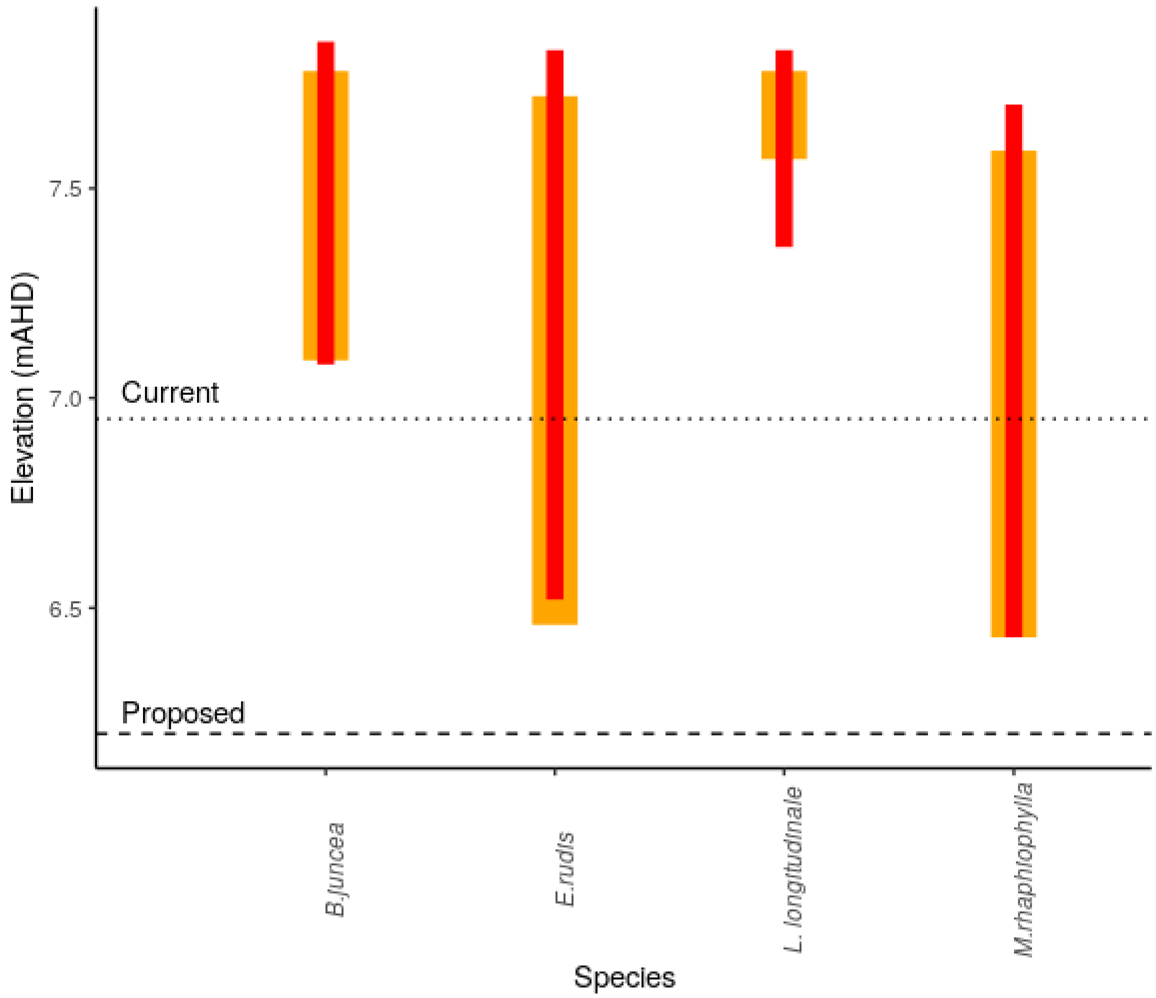

Figure 33 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2014 and 2019 at Loch McNess. Red bars represent the absolute range in elevation and yellow bar represent mean range. The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line.

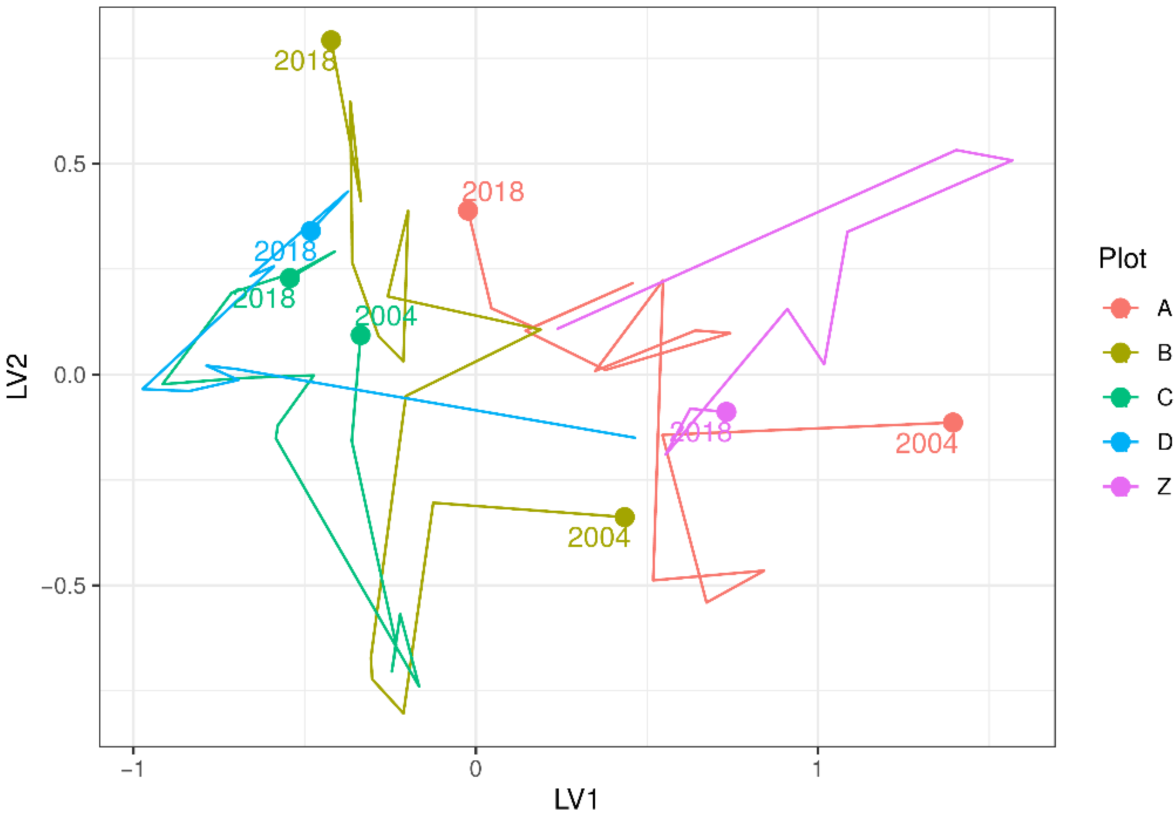

Figure 34 Unconstrained ordination based on the latent variable model for each surveyed year for Loch McNess. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

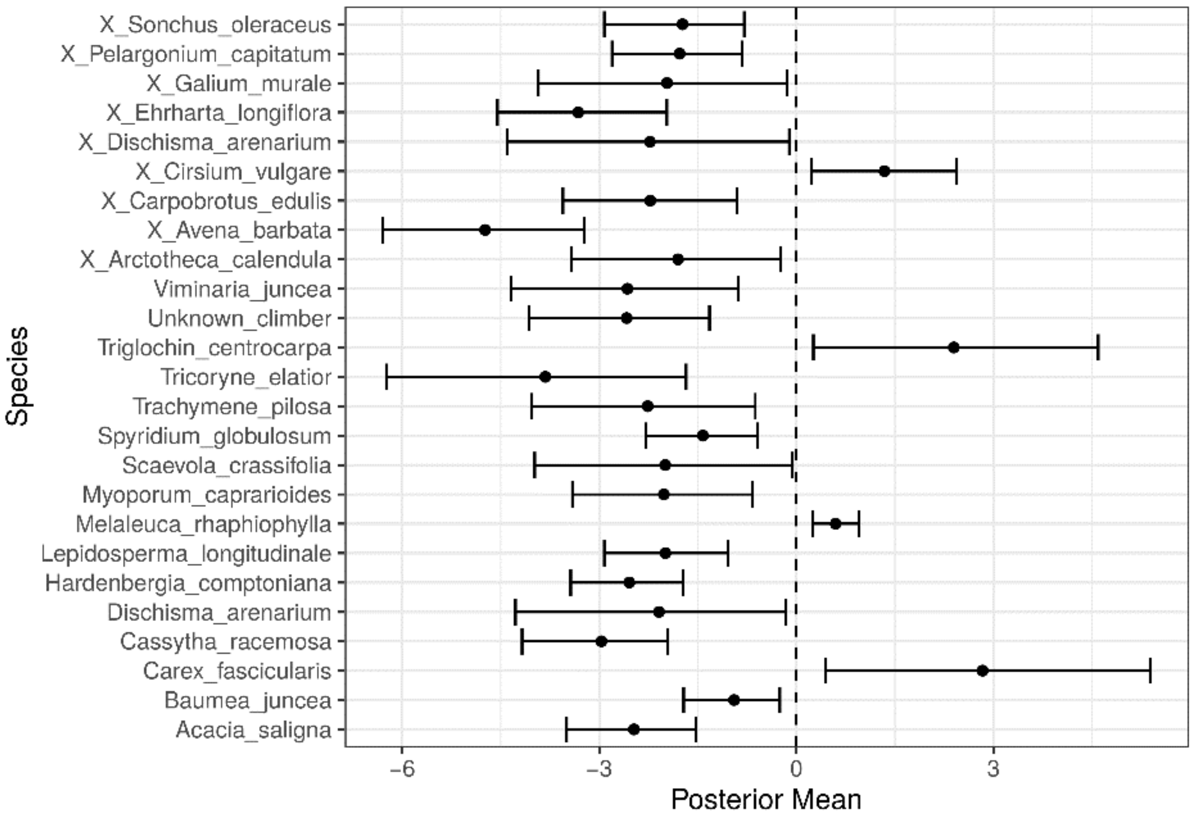

Figure 35 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at Loch McNess on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline while species with positive values are predicted to increase in cover abundance with water increasing water levels. Only those species with coefficients significantly different to zero are shown. Invasive species are identified by the pre-text 'X'.

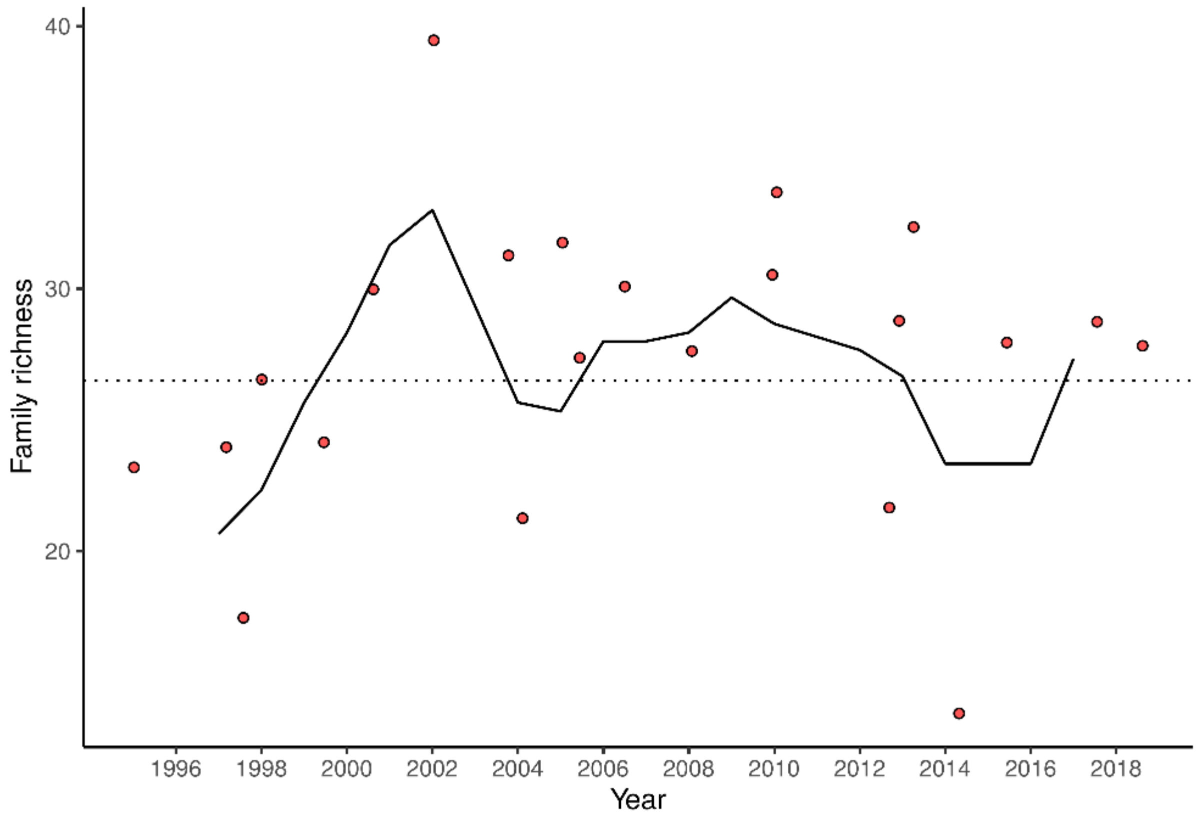

Figure 36 Richness of aquatic invertebrate families for each year. Line is a moving 3-year average at Loch McNess.

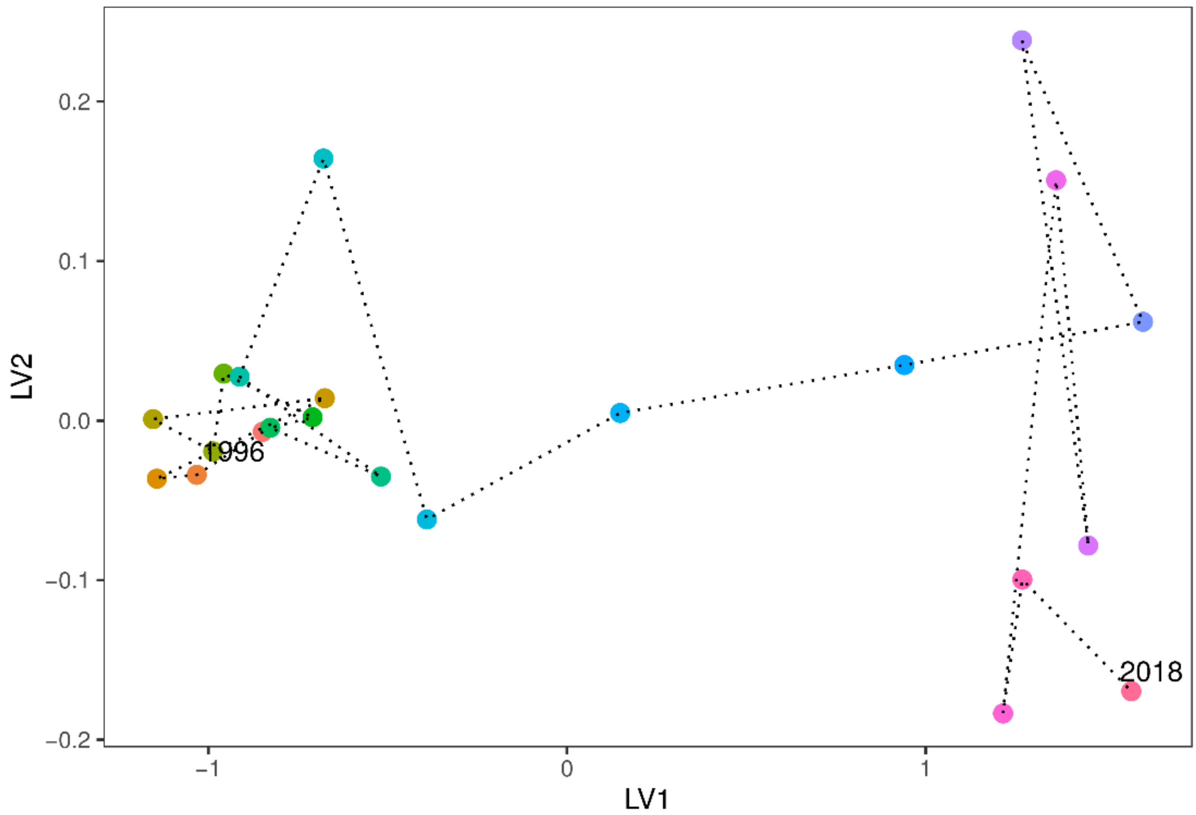

Figure 37 Unconstrained ordination based on invertebrate data for each surveyed year for Loch McNess. Consecutive years are joined by a line with first and last survey years labeled.

Lake Yonderup

Water quality

Lake Yonderup has the lowest nutrient levels of all the monitored wetlands on the Gnangara groundwater system (Judd and Horwitz, 2019). However, the most recent observations for spring 2018 indicate that total nitrogen levels may be increasing. Otherwise, the water chemistry of the lake has remained relatively stable. Stable alkalinity and a pH that consistently remains above 7.0 suggests there is little risk of acidification.

Vegetation dynamics

The vegetation transect, established in 1997, is located 750 m south of the basin and is therefore not representative of vegetation at the wetland itself. The lake provides habitat for *Baumea articulata* although there is recent evidence of *Typha orientalis* invading the wetland (Judd and Horwitz, 2019). At the vegetation monitoring transects, the site was reported to have a rich exotic community before monitoring began in 1997 and this characteristic of the site has persisted. Currently, exotics account for 60% of the cover abundance and native richness has been declining (Buller et al., 2019).

Vegetation at the monitoring transect is located more than 1.5 m higher than current minimum surface water levels of the lake (Figure 38). It is therefore likely that some individuals are experiencing water stress at times during the year. The proposed threshold, although a slight improvement over current conditions, will not ensure the health of key wetland species. This is particularly true for *M. rhaphiophylla* which has a mean maximum depth to ground water of 2.14 m in the Gnangara groundwater system (Froend et al. 2004b). The managing water levels at the proposed minimum threshold of 5.7 mAHD is likely to maintain the stressed state of *M. rhaphiophylla* that occurs in the vegetation monitoring transects as the plants will be experience water levels only 0.3 m above their mean maximum depth.

The shifts in vegetation composition at each plot suggest vegetation has changed dramatically since 1997 but largely stabilised in the late 2000s (Figure 39). There was a dramatic shift in vegetation composition after the 2004/2005 fire which also coincided with an increase in the rate of decline of surface waters. All the native species, including *Banksia attenuata* and *Melaleuca preissiana*, are likely to decline in cover abundance under a scenario of sustained low water levels or further declining groundwater levels (Figure 40). In fact, *B. attenuata* and *M. preissiana* have already disappeared from the monitoring transect, while stands of *Melaleuca rhaphiophylla* are unhealthy.

Aquatic invertebrates

Taxonomic richness of the macroinvertebrate assemblage in Lake Yonderup has been declining since 2012 (Figure 41). Richness is now lower than previous records and the trend may suggests some shifts in ecological processes due to declining water levels. The composition of the Lake Yonderup macroinvertebrate community is variable (Figure 42). Many taxa are not recorded every year, or are absent for periods, such as Ceinidae, Oligochaeta and Orthocladiinae. Other taxa have declined, or perhaps become locally extinct, including the beetle families of Dytiscidae and Hydrophilidae. Three families of damselflies have not been recorded in spring families in about the last decade. Chironominae, Cyclopoida, Cyprididae and Leptoceridae have been recorded in nearly every sampling event at Lake Yonderup.

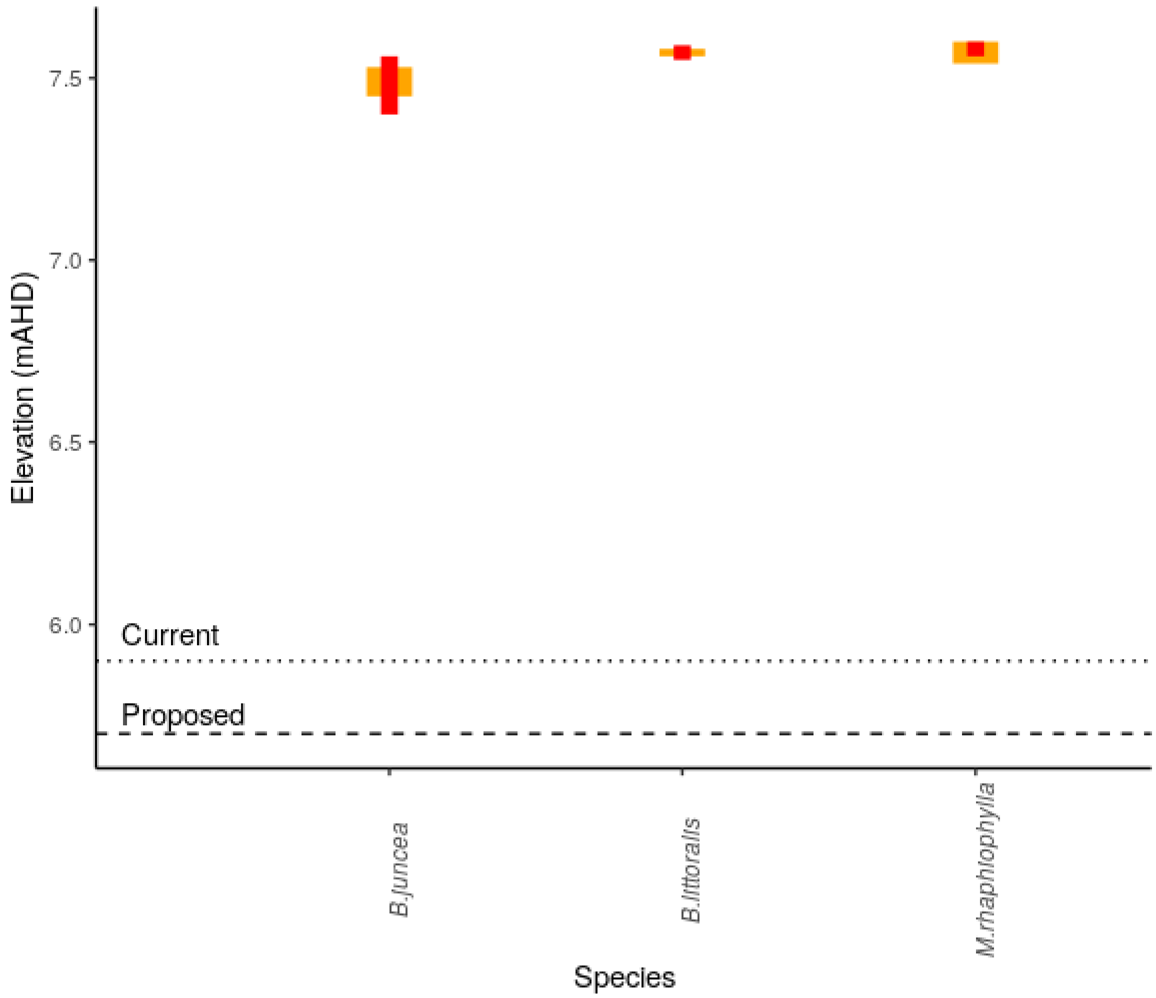

Figure 38 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2014 and 2019 at Lake Yonderup. Red bars represent the absolute range in elevation and yellow bar represent mean range. The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line.

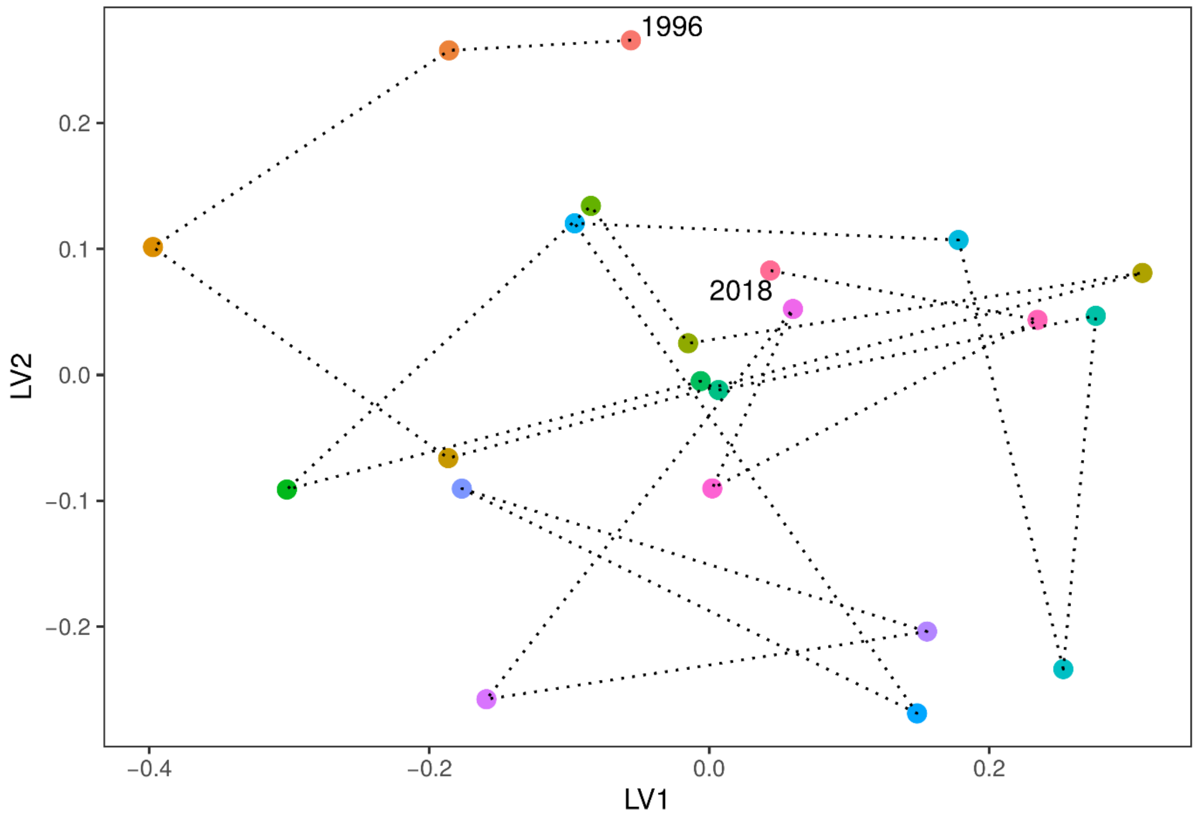

Figure 39 Unconstrained ordination based on the latent variable model for each surveyed year for Lake Yonderup. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

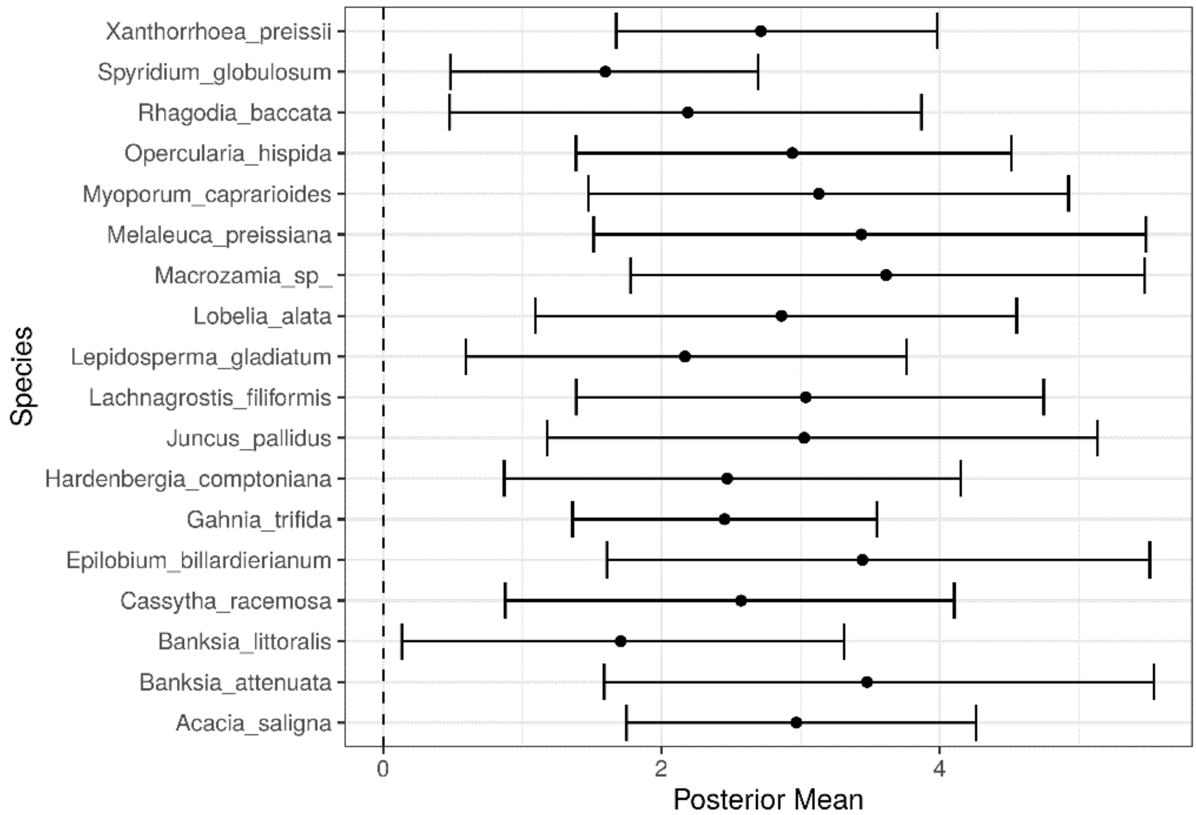

Figure 40 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at Lake Yonderup on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline. Only those species with coefficients significantly different to zero are shown.

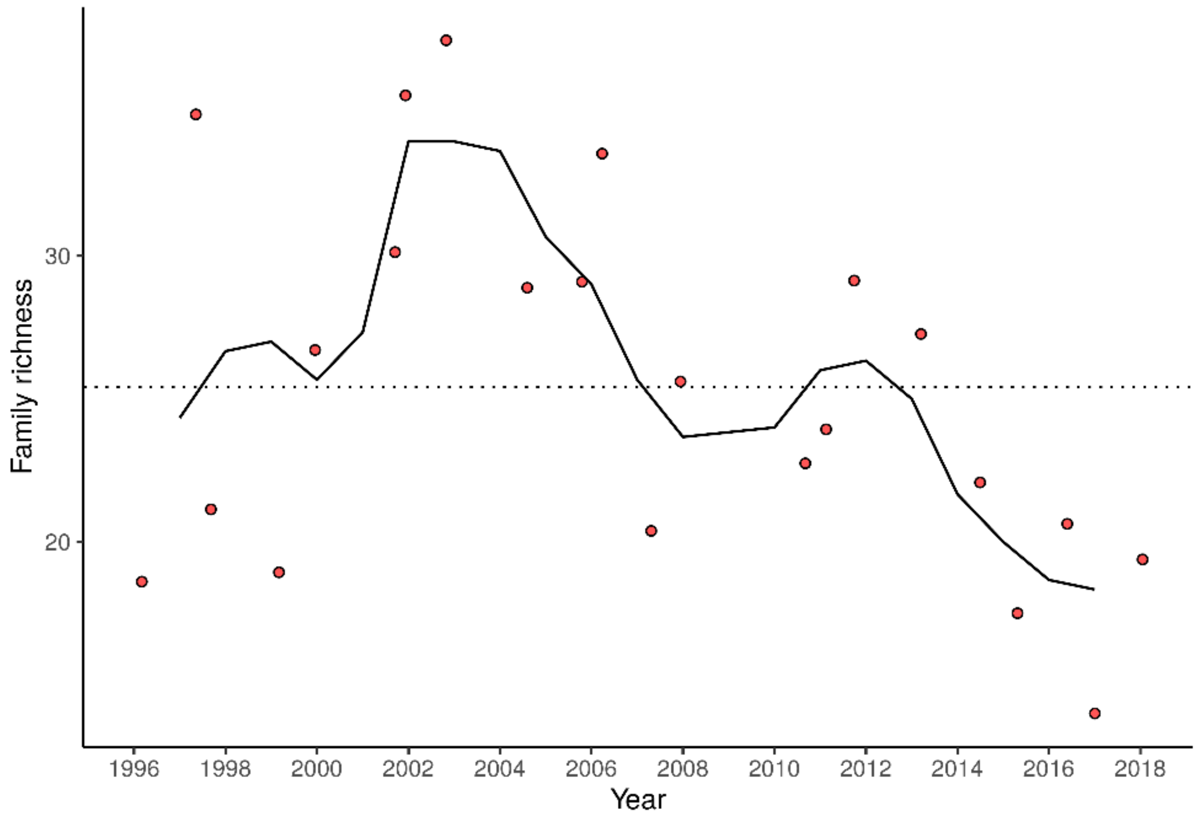

Figure 41 Richness of aquatic invertebrate families for each year at Lake Yonderup. Line is a moving 3-year average.

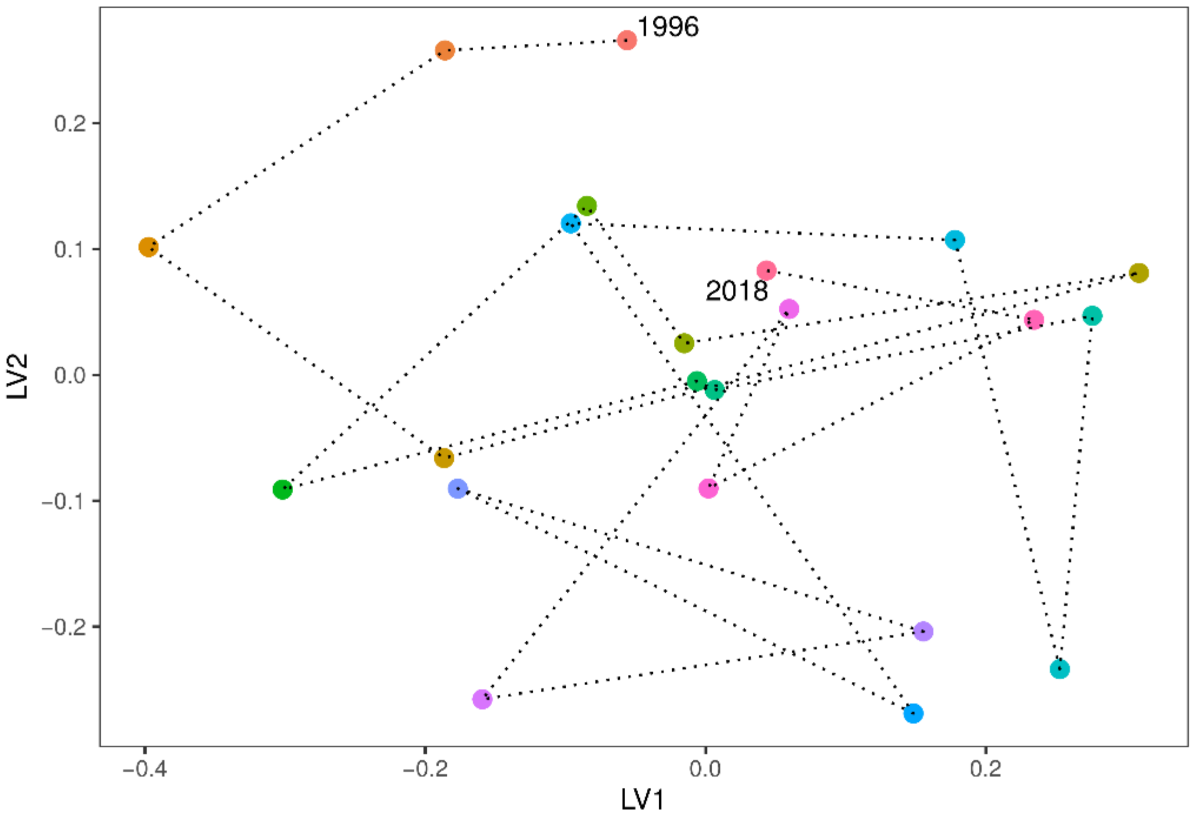

Figure 42 Unconstrained ordination based on invertebrate data for each surveyed year for Lake Yonderup. Consecutive years are joined by a line with first and last survey years labeled.

Lake Joondalup

Water quality

Recent monitoring suggests pH has been increasing from 6.8 in 2016 up to 8.4 in 2018, probably attributable the higher water levels (Judd and Horwitz, 2019). The lake often has the lowest levels of acidity and highest alkalinity of all the monitored wetlands. Total nitrogen and phosphorus levels have been high in Lake Joondalup, which is now typical of Spearwood dune lakes in modified urban landscapes. These high nutrient levels need to be considered carefully, particularly if combined with increases in water temperatures because they may lead to algal blooms.

Vegetation Dynamics

Vegetation surveys have been conducted along a northern and southern transect at Lake Joondalup since 1996 and were last surveyed in 2015. *Melaleuca raphiophylla* dominates the overstory of plots in the northern transect while exotic species are abundant in the understory vegetation. There has been an increasing trend in cover abundance of the exotics *Bromus diandrus*, *Ehrharta longiflora*, *Euphorbia terracina*, *Fumaria muralis* and *Pelargonium capitatum* in recent years. Fires in 2003 reduced the canopy condition and abundance of *M. raphiophylla* in the southern transect, and despite the slightly higher cover abundance of native species, native and exotic species richness is equal along the transect. The site also contains healthy stands of *Baumea articulata* in the submerged regions of the transect. The proposed minimum threshold is likely to be beneficial to a number of key wetland species, including *B. articulata* and *M. rhaphiophylla*, as they are more likely to have their ecological water requirements met (Figure 43).

All plots in both transects have displayed similar trends in community compositional change during the survey periods (Figure 44). In the southern transect, ordination reveals separation of the plots along the first axis, with a general temporal trend along the second axis, except for a period around 2003 - 2006 where there was a hiatus. This hiatus may be associated with the 2003 bushfire and represents a recovery period where species composition changed little. The trajectory for plot A is different, however, as the trend away from the original 1996 survey has reversed and the contemporary community is now becoming more like the 1996 communities. Similar patterns have been observed in the northern transect despite the transect not being impacted by the 2003 fire event. A number of native species are likely to increase in cover abundance at the transects if water levels remain at present levels or increase further, including *Baumea articulata* (Figure 45). Other natives are likely to decline in cover abundance under a similar scenario of high-water levels, including a number of *Acacia saligna*, *Banksia menziesii* and *Banksia prionotes*.

Aquatic Invertebrates

Aquatic invertebrates have been sampled from Lake Joondalup every year since 1996. During this period, 16-30 families of aquatic invertebrates have been recorded per sampling event, except for the latest round in 2018 where family richness was only nine (Figure 46). This exceptionally low family richness was likely due to the lack of insects and associated parasitic mites among the sampled communities. Three families of beetles and one damsel fly family have been missing from spring monitoring samples in recent years. The phreatoicid isopod *Amphisopus palustris* was also absent in 2018 despite being collected every spring in Lake Joondalup (except 2004). Furthermore, this reduced richness occurred during a period of relatively high surface water levels, suggesting other anthropogenic factors may be responsible for the decline of insect fauna within the lake, like an as yet undiagnosed water quality issue. Otherwise, the lake hosts abundant populations of Ceinidae (amphipods), *Palaemonetes australis* (crustacean), *Calanoid copepods* and Cyprididae (ostracods). There is high variation in the composition of annual macroinvertebrate community composition making it difficult to interpret a trajectory of compositional change (Figure 47). There has been a general trend of community composition shifting away from the initial 1996 community.

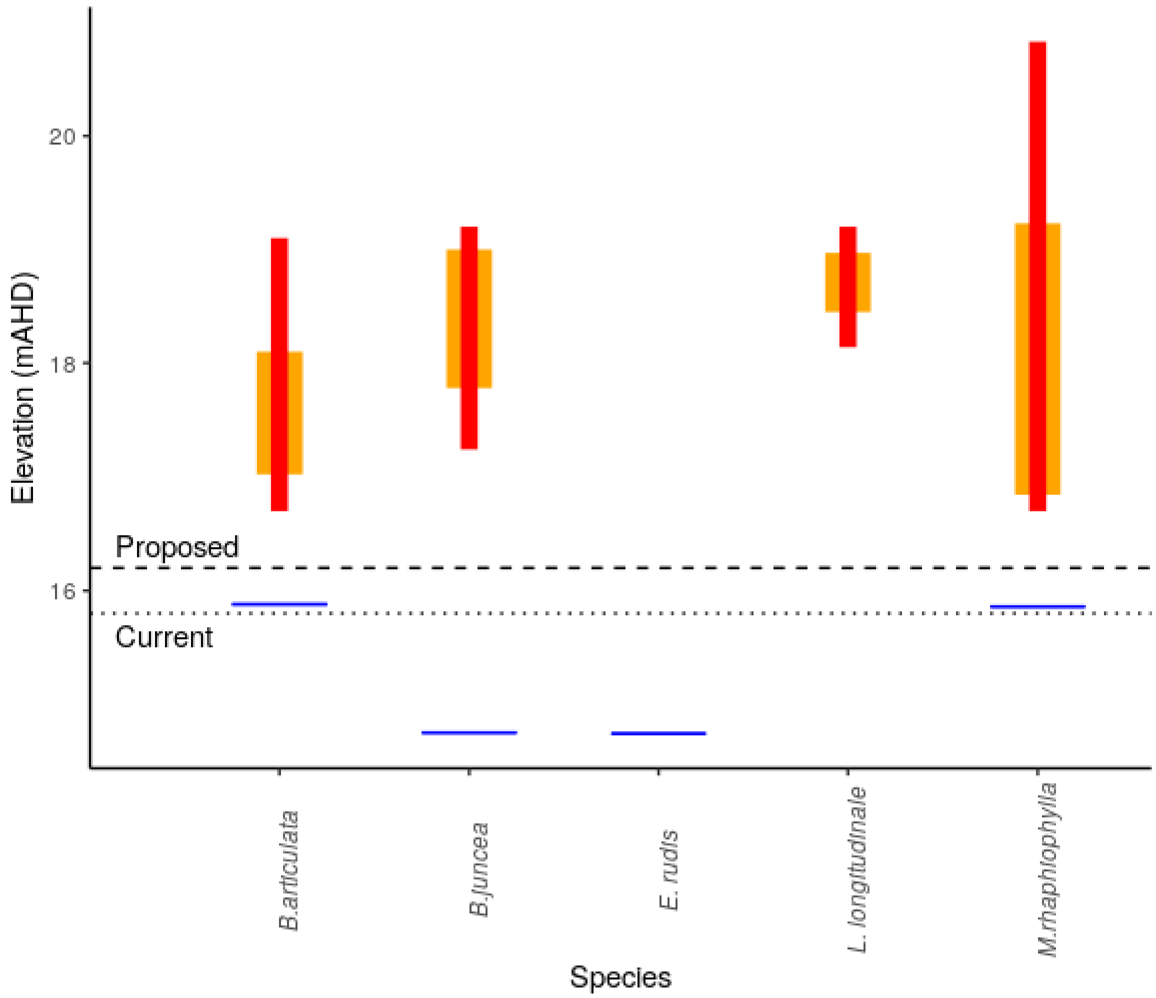

Figure 43 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2014 and 2019 at Lake Joondalup. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line. *Eucalyptus rudis* currently does not occur in the monitoring transects, hence there is no elevation data for this species.

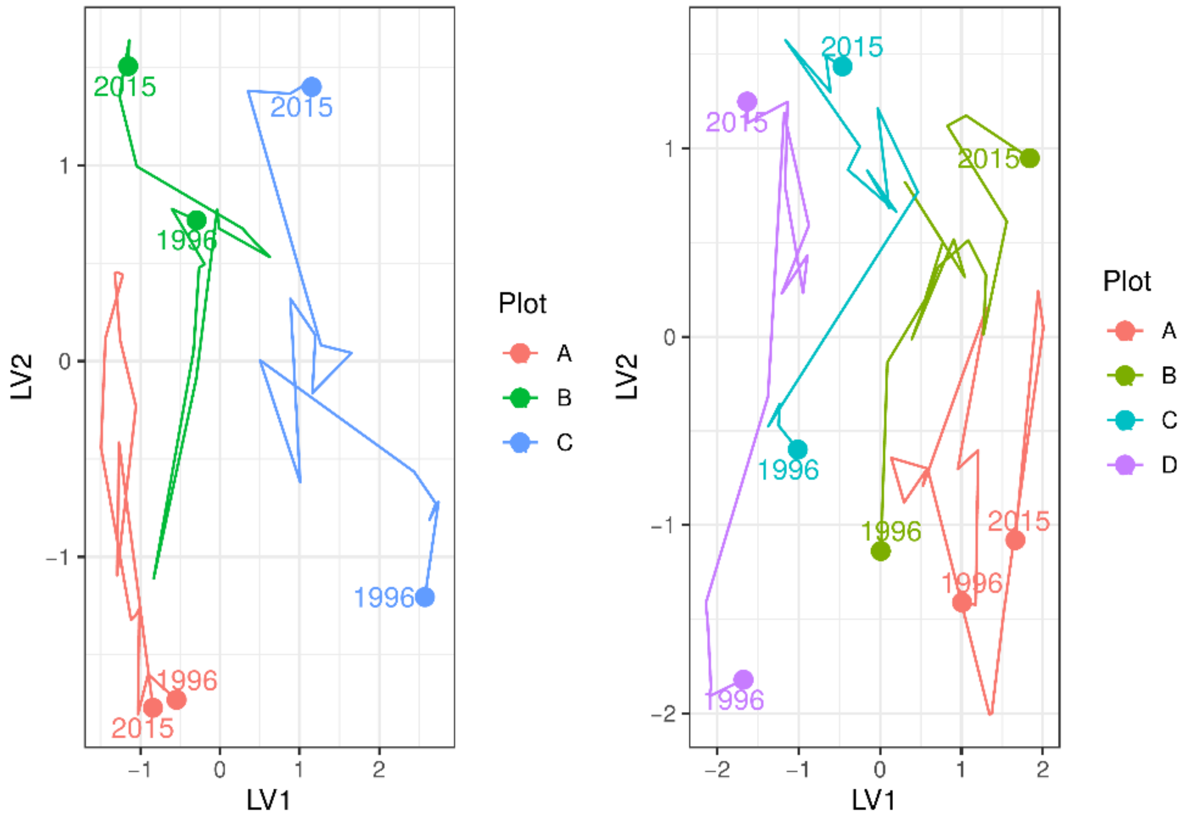

Figure 44 Unconstrained ordination based on the latent variable model for each surveyed year for the northern (left) and southern (right) Lake Joondalup transects. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

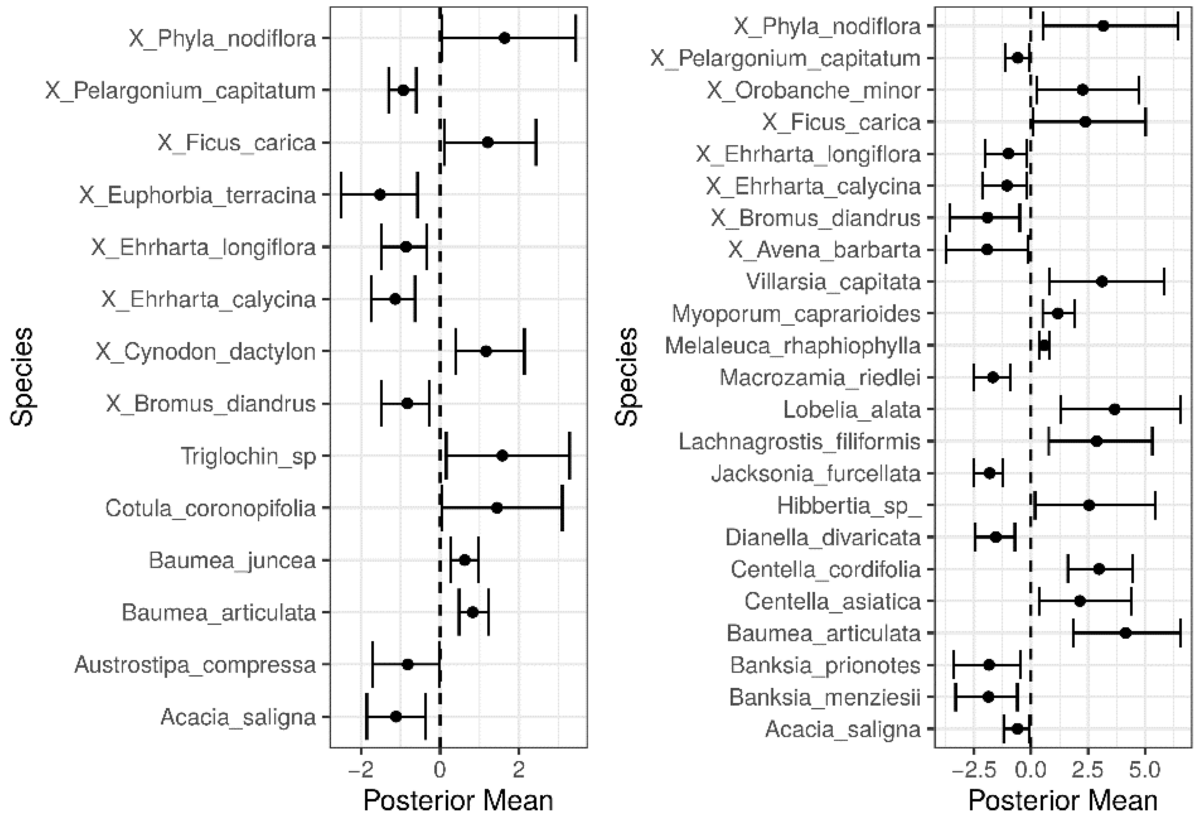

Figure 45 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at the northern (left) and southern (right) Lake Joondalup transects on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline and species with positive values are likely to increase in cover abundance when water levels increase. Only those species with coefficients significantly different to zero are shown. Invasive species are identified by the pre-text ‘X’.

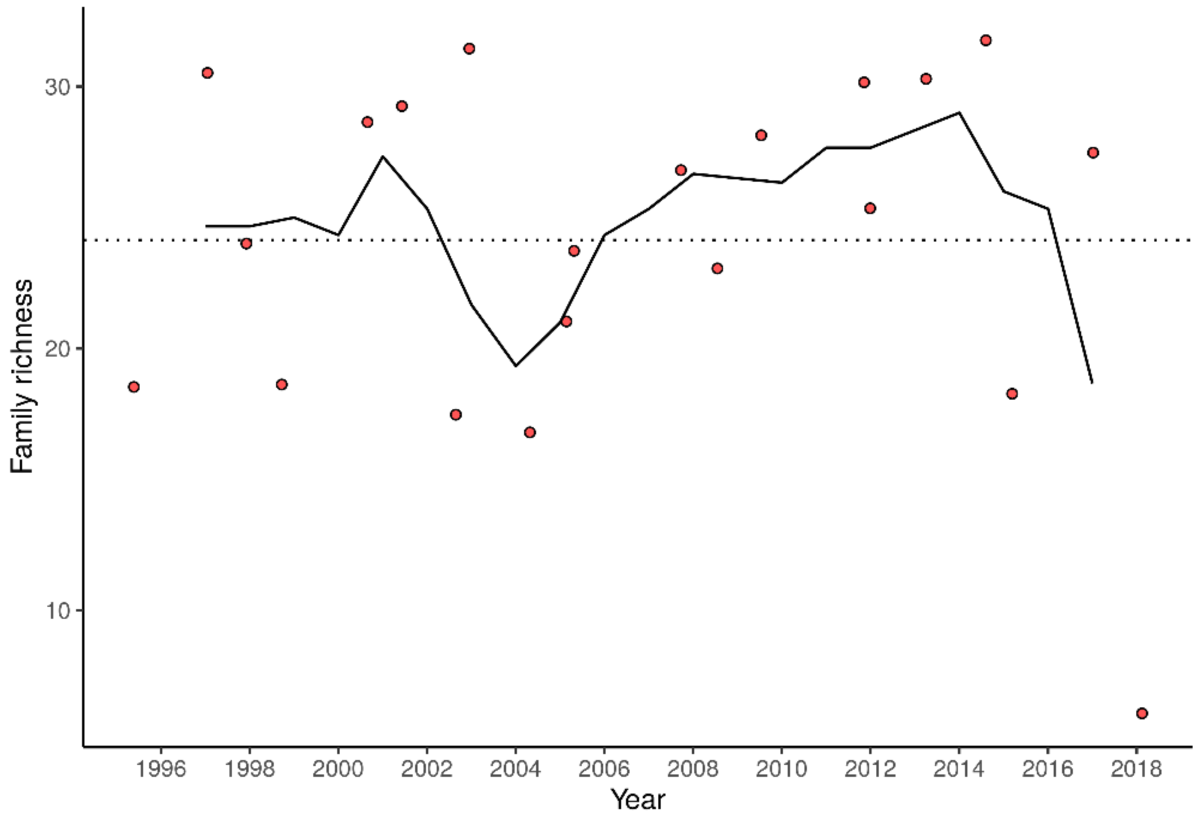

Figure 46 Richness of aquatic invertebrate families for each year at Lake Joondalup. Line is a moving 3-year average.

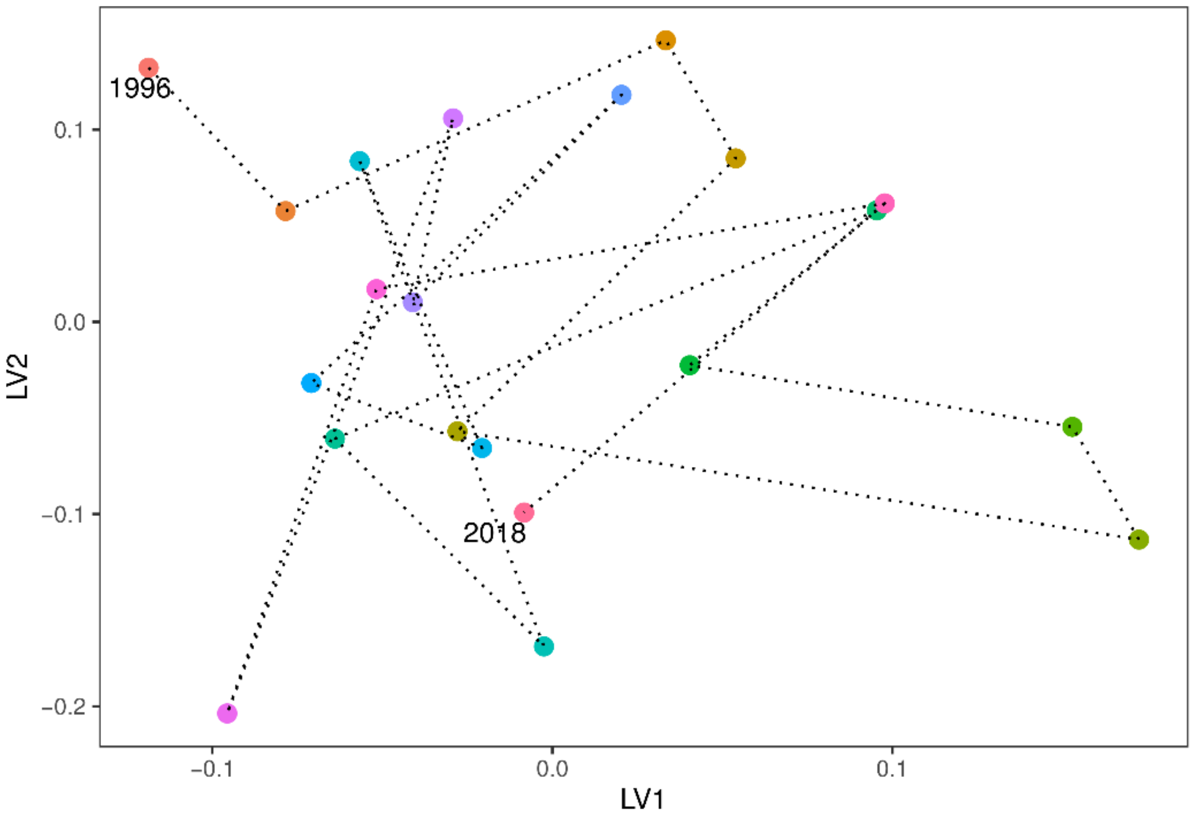

Figure 47 Unconstrained ordination based on invertebrate data for each surveyed year for Lake Joondalup. Consecutive years are joined by a line with first and last survey years labeled.

Lake Mariginiup

Water quality

Acidification has affected the water quality at Lake Mariginiup. Since 2005, the pH of the surface water has consistently been below 4.0 with only 2018 levels slightly higher (4.3; Judd and Horwitz (2019)). Alkalinity is below 1 mg/L suggesting that the lake has lost its capacity to buffer changes in pH. Recent changes in acidification are likely due to the rises in surface waters since 2015 that has helped reduce the sulphate concentrations. Ammonia and total nitrogen levels of Lake Mariginiup are the highest of any lake monitored on the Swan Coastal Plain. Recent total phosphorus levels have doubled due to unknown causes.

Vegetation dynamics

Vegetation composition and shifts in composition are similar along the length of the transect at Lake Mariginiup which was established in 1996. *Baumea articulata* was present at high cover abundance throughout the transect until the early 2000's but has since disappeared from the transect as surface water levels declined (*B. articulata* still occurs in other regions of the wetland). *Eucalyptus rudis* has declined in the lower parts of the plots and *Melaleuca rhaphiophylla* is no longer present in the transect. There has been a general increase in the cover abundances of exotics throughout the monitoring period. There was a shift in community composition at all three plots around 2005 which was driven by increases in *Exocarpus sparteus* and *Jacksonia furcellata* and some exotics, such as *Ehrharta calycina*, *Ehrhatah longiflora*, *Lotus suaveolens* and *Ursinnia anthemoides* (Figure 49).

The projected increases in surface water levels are going to have a dramatic effect on the vegetation at Lake Mariginiup. For instance, the current range of *B. articulata* and *E. rudis* along the monitoring transects are likely to become frequently inundated (Figure 48). Both of these species are able to tolerate 12 months of inundation (Froend et al. 2004b. However, it will be important to ensure maximum water depth ranges are not exceeded. For instance, the absolute maximum water depth that *B. articulata* occurs in is 0.81 m and 1.03 m for *E. rudis.* Surface waters exceeding these depths are very likely to cause the death of these species. Regression analysis reveals a number of native species that will increase in cover abundance with increasing surface water levels (Figure 50). Species likely to increase in cover abundance include *Angianthus* sp., *Epilobium billardierianum*, *Isolepis cernua*, *Juncus* sp., *Lepyrodia muirii*, *Lobelia alata* and *Villarsia capitata*. Other natives, including *Acacia cyclops*, *Acacia saligna* and *E. sparteus*, are likely to decrease in cover abundance as water levels increase.

Aquatic invertebrates

Lake Mariginiup has been sampled yearly 1996 - 2002, 2004 - 2009, 2012, and – 2018. Missing years make it difficult to interpret trends in community change. Despite the acidification that has occurred in the lake, there is a remarkably high richness of invertebrates (Figure 51) and there seems to be a recovery since the 2012 sampling event where family richness was 13. Nonetheless, richness has been below average for the site since 2005 when acidification processes began affecting the assemblage. Recent increases in water levels may be promoting higher richness by increasing habitat availability and diversity. There has been a dramatic shift in macroinvertebrate community compositions between 2002 and 2004 (Figure 52). Recent data suggests the community may be returning to pre-2004 composition, which again may be attributable to increased surface waters and habitat availability. Some families have disappeared from the lake, including Amphisopidae, Ceinidae, Chydoridae and Cyprididae.

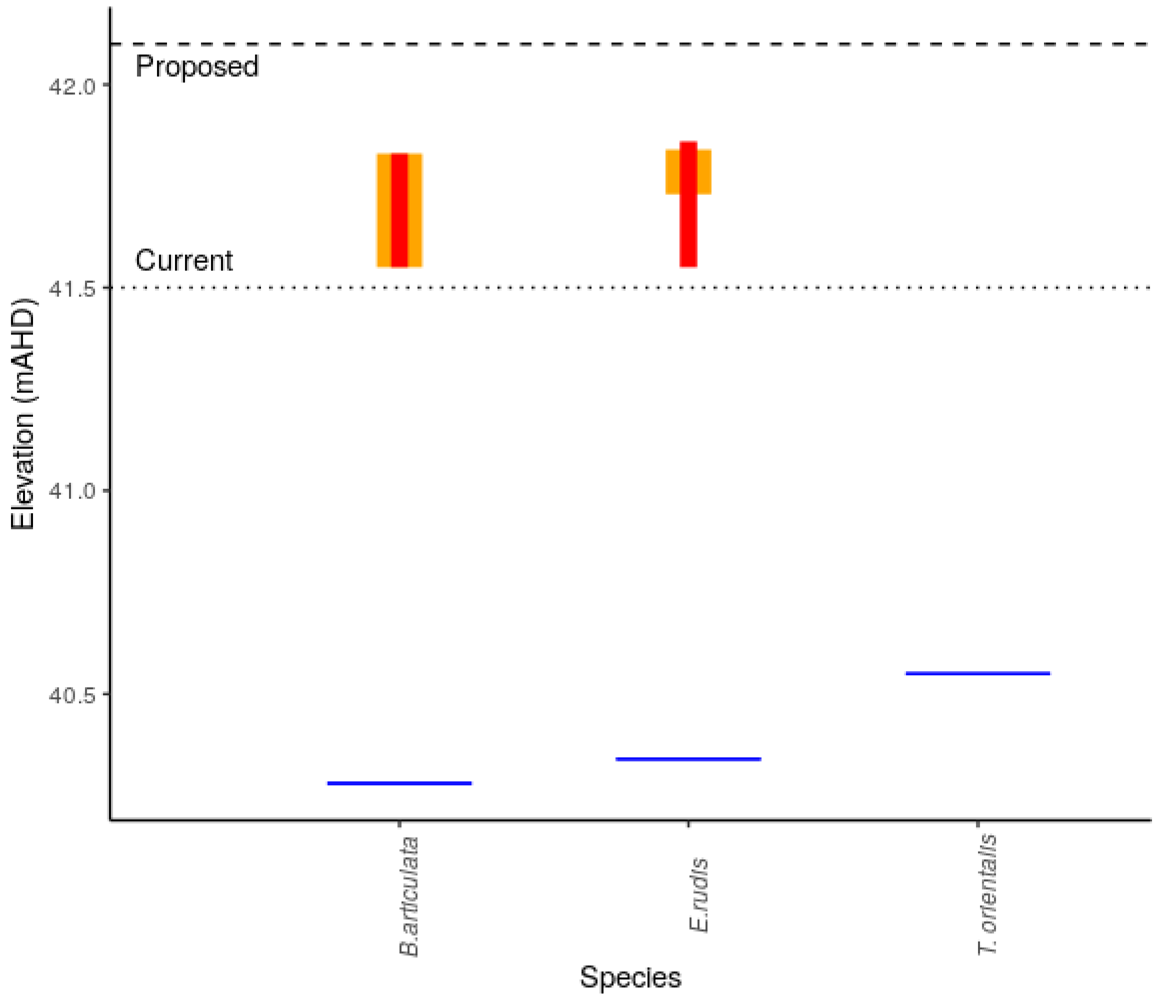

Figure 48 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2014 and 2019 at Lake Mariginiup. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line. There is no data for *T. orientalis* as it is not currently observed in the vegetation monitoring transects.

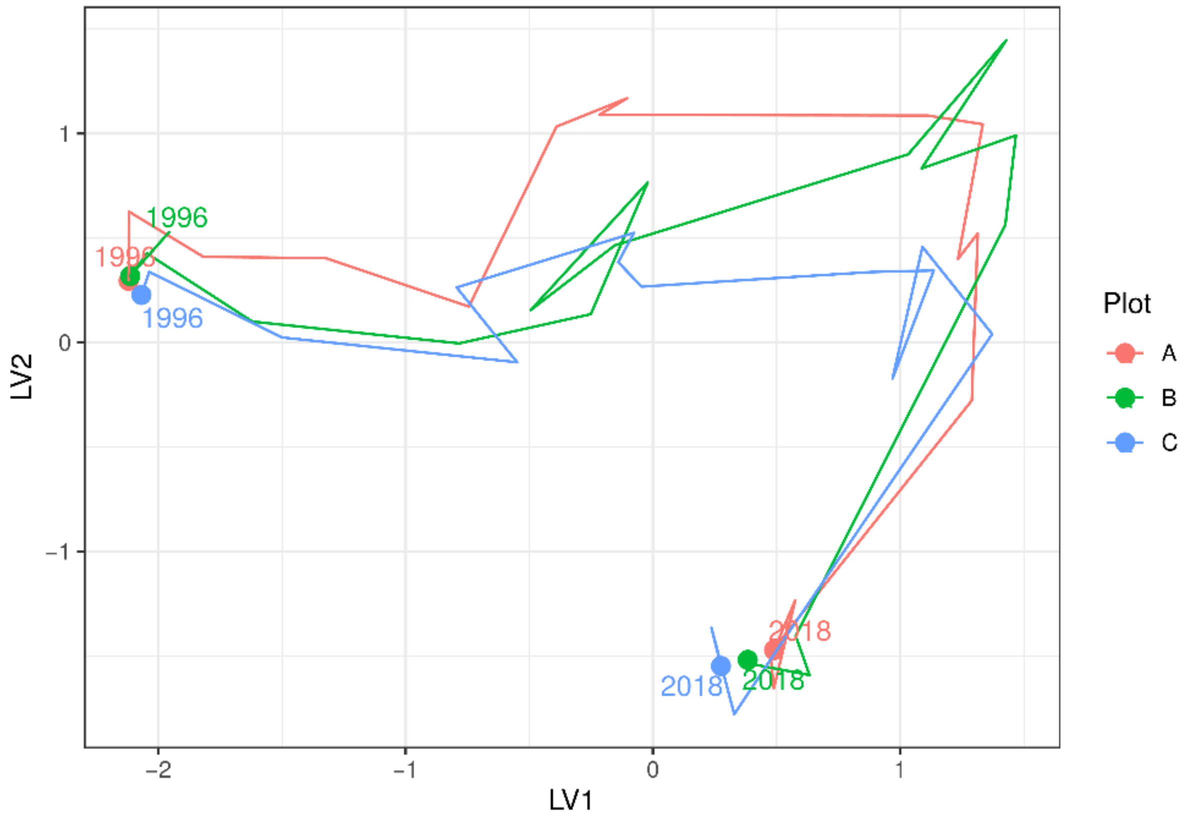

Figure 49 Unconstrained ordination based on the latent variable model for each surveyed year for Lake Mariginiup. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

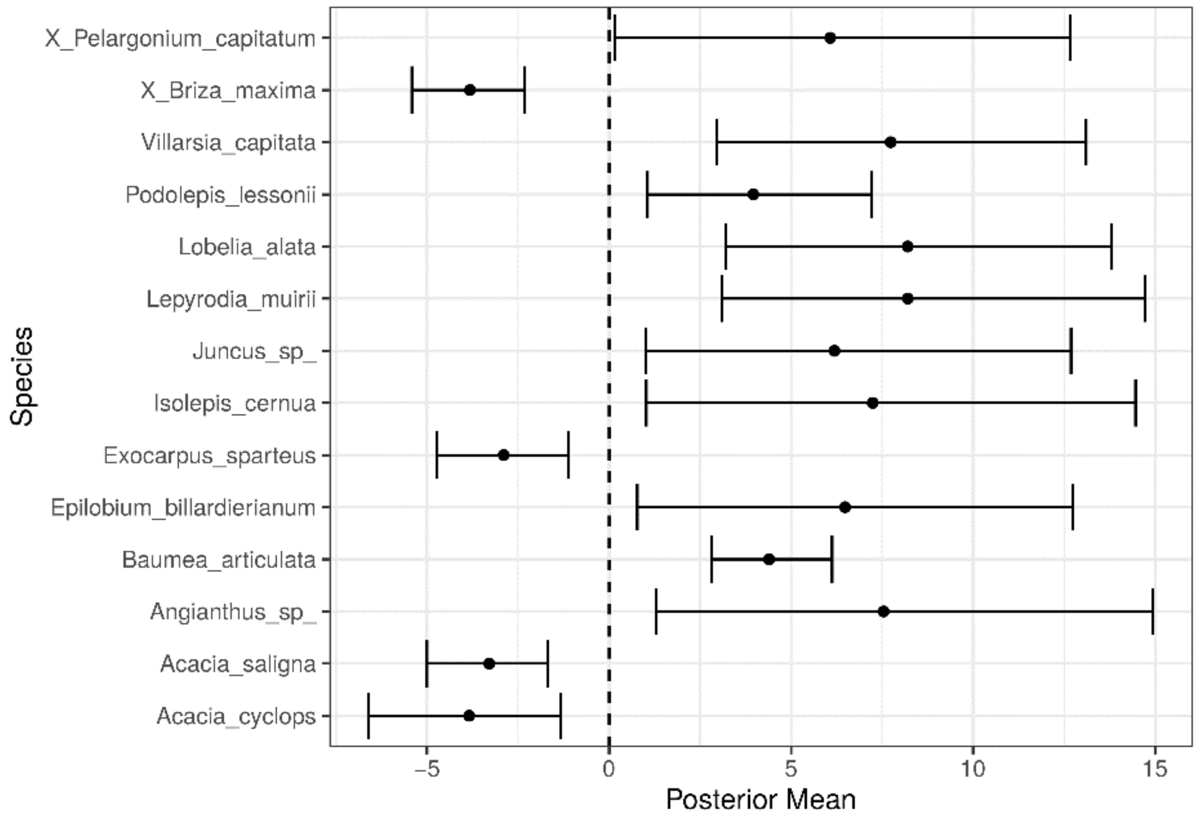

Figure 50 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at Lake Mariginiup on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline and species with positive values are predicted to increase in cover abundance with increasing water levels. Only those species with coefficients significantly different to zero are shown. Invasive species are identified by the pre-text ‘X’.

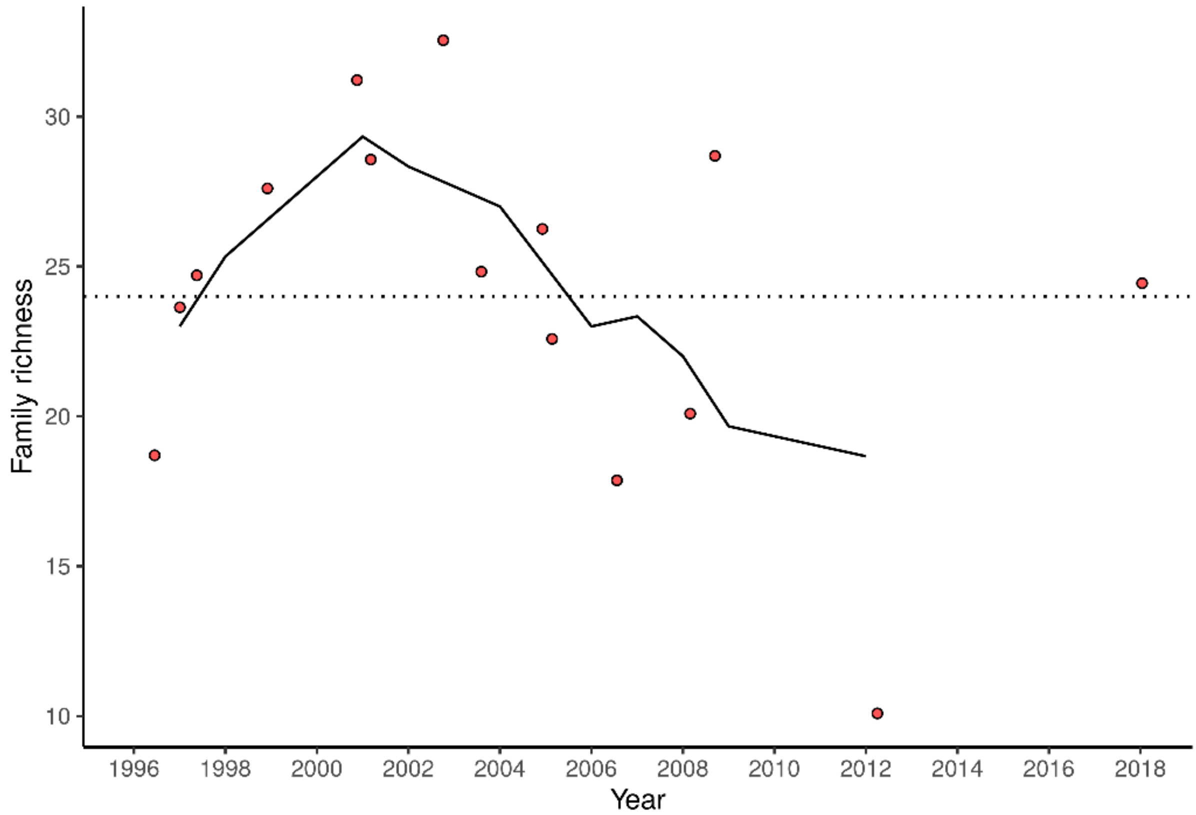

Figure 51 Richness of aquatic invertebrate families for each year at Lake Mariginiup. Line is a moving 3-year average.

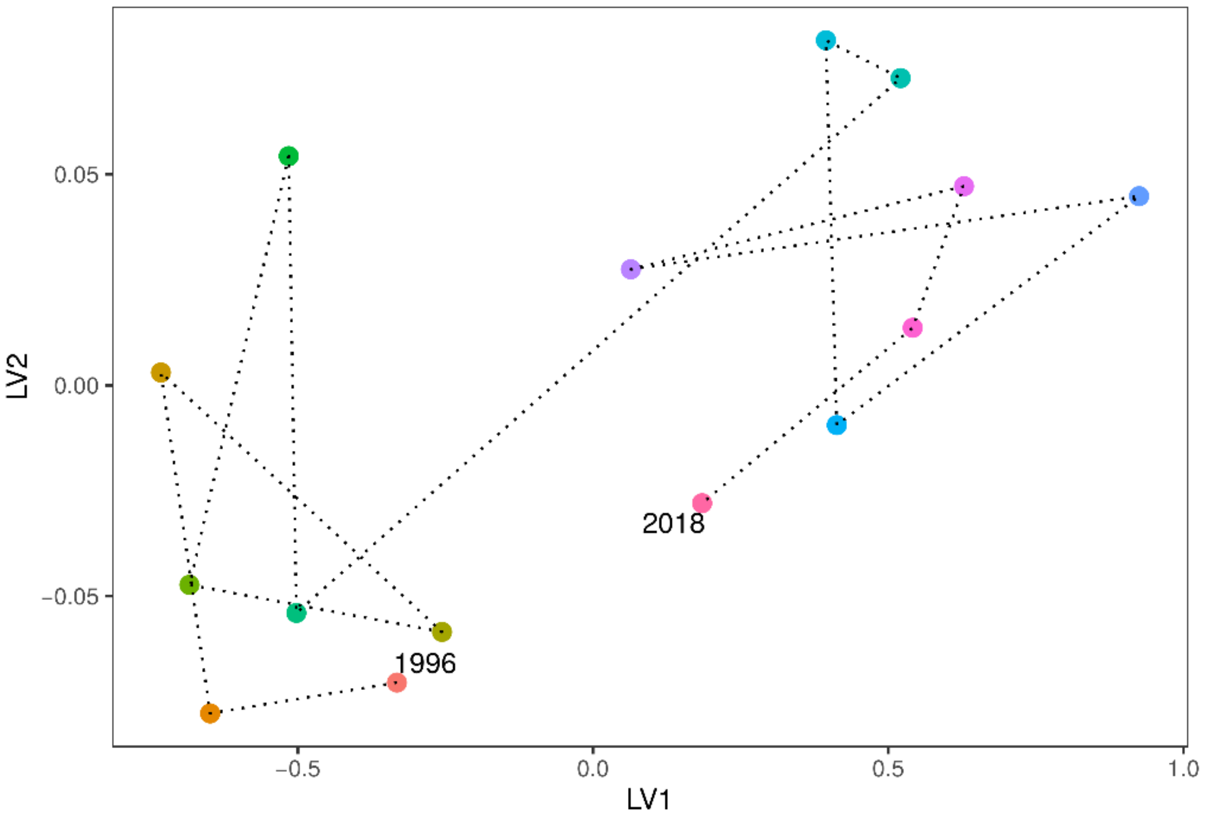

Figure 52 Unconstrained ordination based on invertebrate data for each surveyed year for Lake Mariginiup. Consecutive years are joined by a line with first and last survey years labeled.

Lake Jandabup

Water quality

The pH of Lake Jandabup has not exceeded 7.0 since 2011 and is currently between 6.1 and 6.6. Low water levels expose sediments at Lake Jandabup, making it susceptible to acidification and past episodes drove the pH to <4. Alkalinity is currently very low, suggesting that the lake may be losing its capacity to buffer further pH changes. Deterioration of the chloride:sulphate ratio is also concerning. Maintaining high water levels will be essential to preventing the drying of sediments around the lake margin and subsequent acidification of this wetland. Typically, Lake Jandabup is a low nutrient wetland, however total nitrogen and phosphorus levels are currently the highest recorded for the annual spring monitoring programme.

Vegetation dynamics

The Lake Jandabup wetland consists of a diverse community of native vegetation. In the 2017-2018 season, 43 native species were recorded with only 14% of the total cover abundance belonging to exotic species (Buller et al., 2019). There are four overstorey species present at the wetland, including *Banksia attenuata*, *Banksia ilicifolia*, *Banksia menziesii*, *Eucalyptus rudis* and *Melaleuca preissiana*, all of which have been increasing in health. This is likely a result of the ecological water requirements for these species being met (Figure 53). A dense understory of *A. scoparia*, *B. elegans* and *H. angustifolium* exists at the lower elevated plots A and B. There has been a continual shift in community composition of Lake Jandabup throughout the monitoring period that reflects changes in invasive species' cover abundances (Figure 54). A number of species are predicted to increase in cover abundance with increasing water levels, particularly *Euchilopsis linearis* which is currently present in the lower parts of the basin (Figure 55).

Aquatic invertebrates

Family richness of aquatic macroinvertebrates in Lake Jandabup is distinct and higher than other monitored sites because of the relatively high degree of habitat diversity. However, the family richness of the lake has been below average for the lake since 2016 (Figure 56). There has been a recent shift in community composition away from the 1996 community, suggesting that the community may continue to shift away from what has typically been recorded in the lake in future years as water quality and hydrological changes alter ecosystem processes (Figure 57). The decline of water beetles in the lake is concerning and warrants further investigation. The highly variable communities between 1996-2006 may be in response to acidification events. Ceinidae, Calanoida, Daphniidae and Notonectidae are usually present in the lake at high abundance.

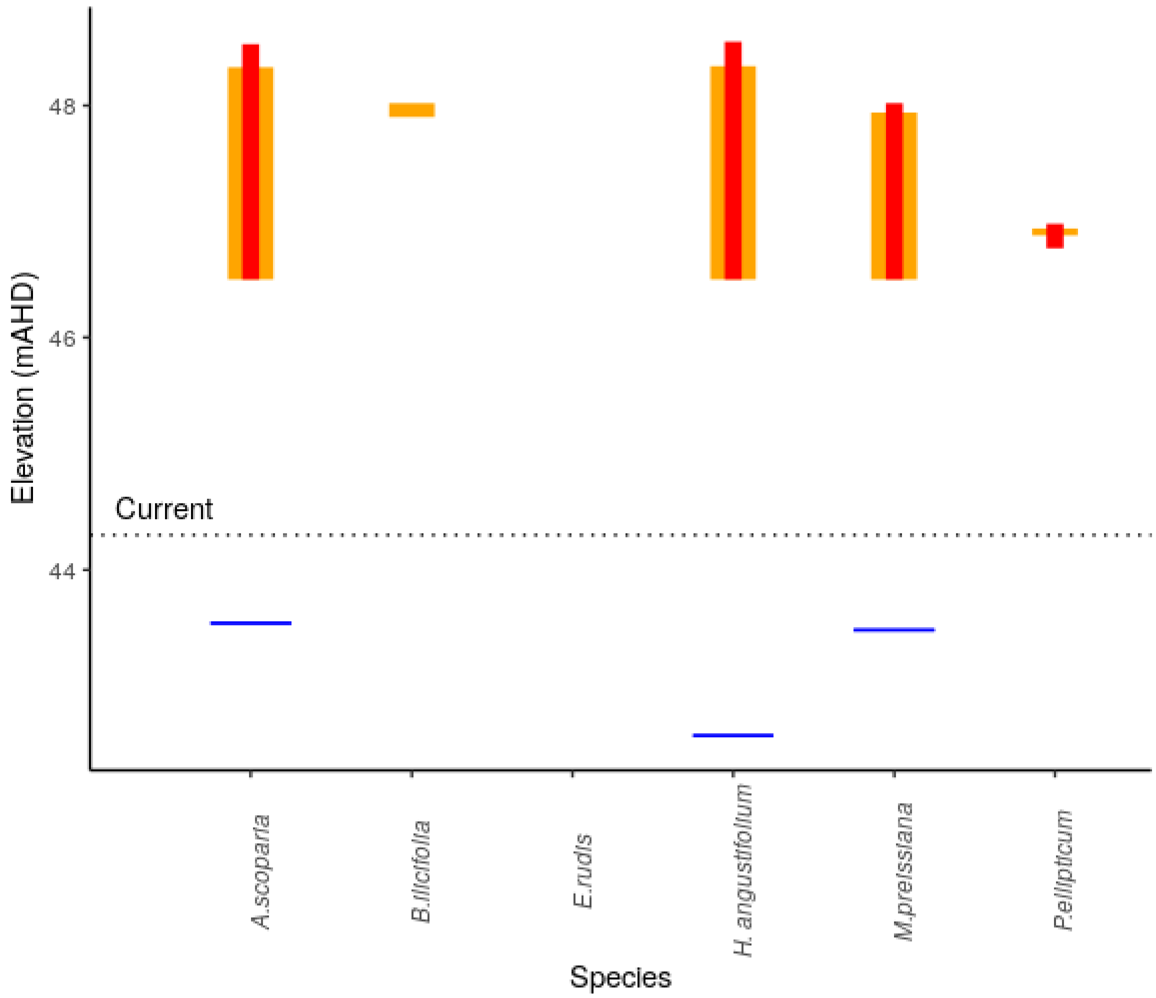

Figure 53 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2014 and 2019 at Lake Jandabup. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line. There is no data for *E. rudis* as it is not currently observed in the vegetation monitoring transects.

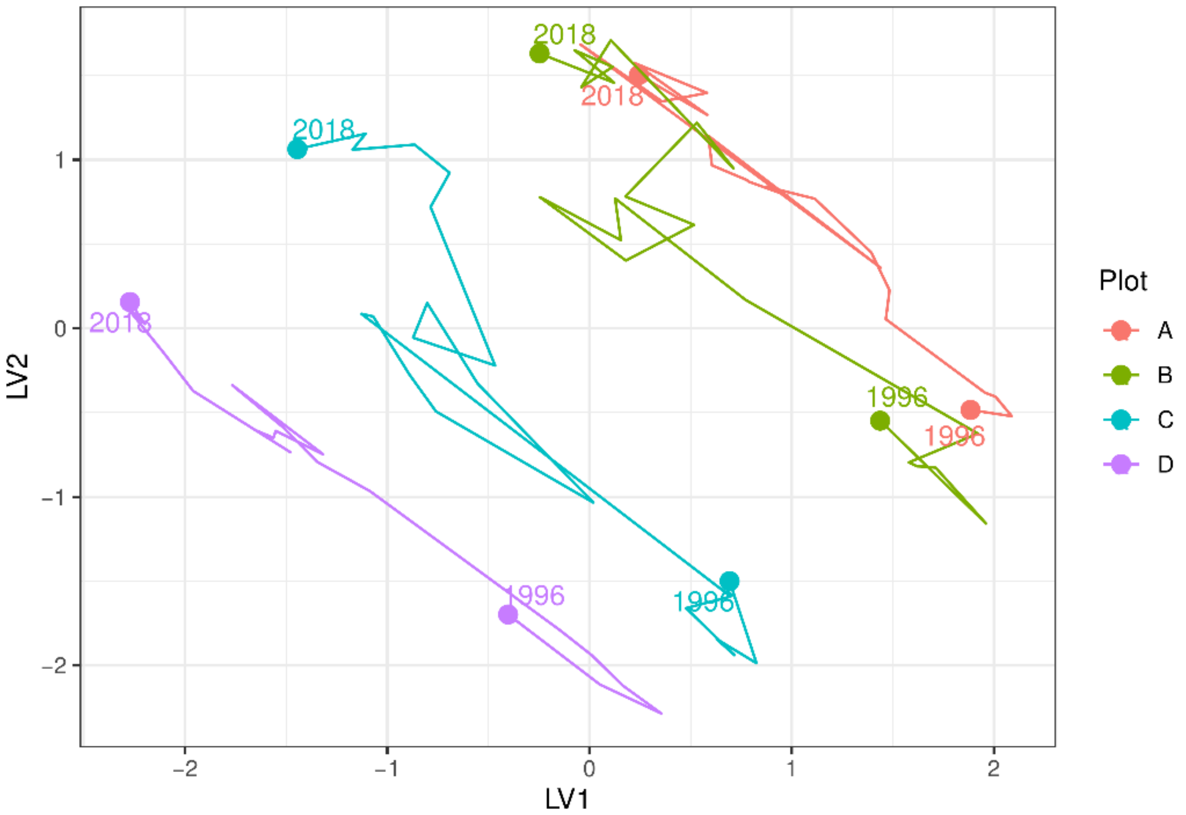

Figure 54 Unconstrained ordination based on the latent variable model for each surveyed year for Lake Jandabup. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

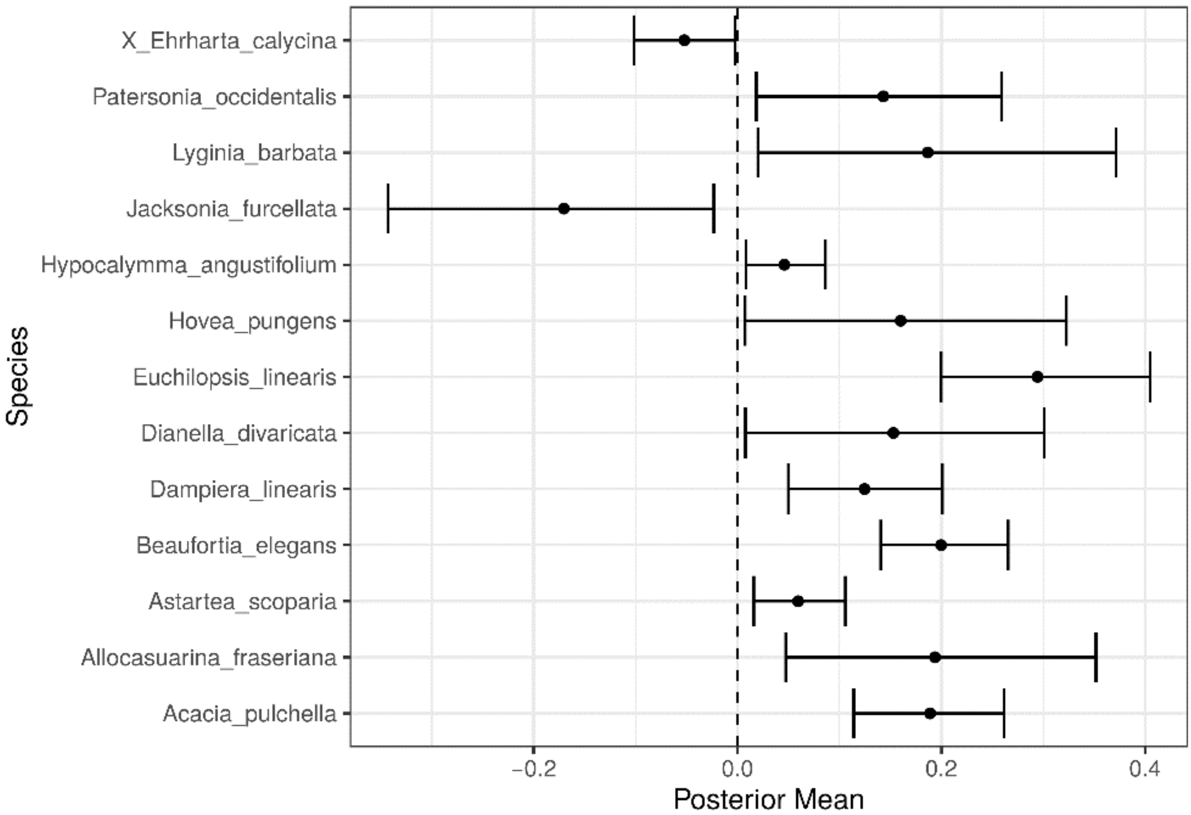

Figure 55 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at Lake Jandabup on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline while species with positive values are likely to increase in cover abundance as water levels increase. Only those species with coefficients significantly different to zero are shown. Invasive species are identified by the pre-text 'X'.

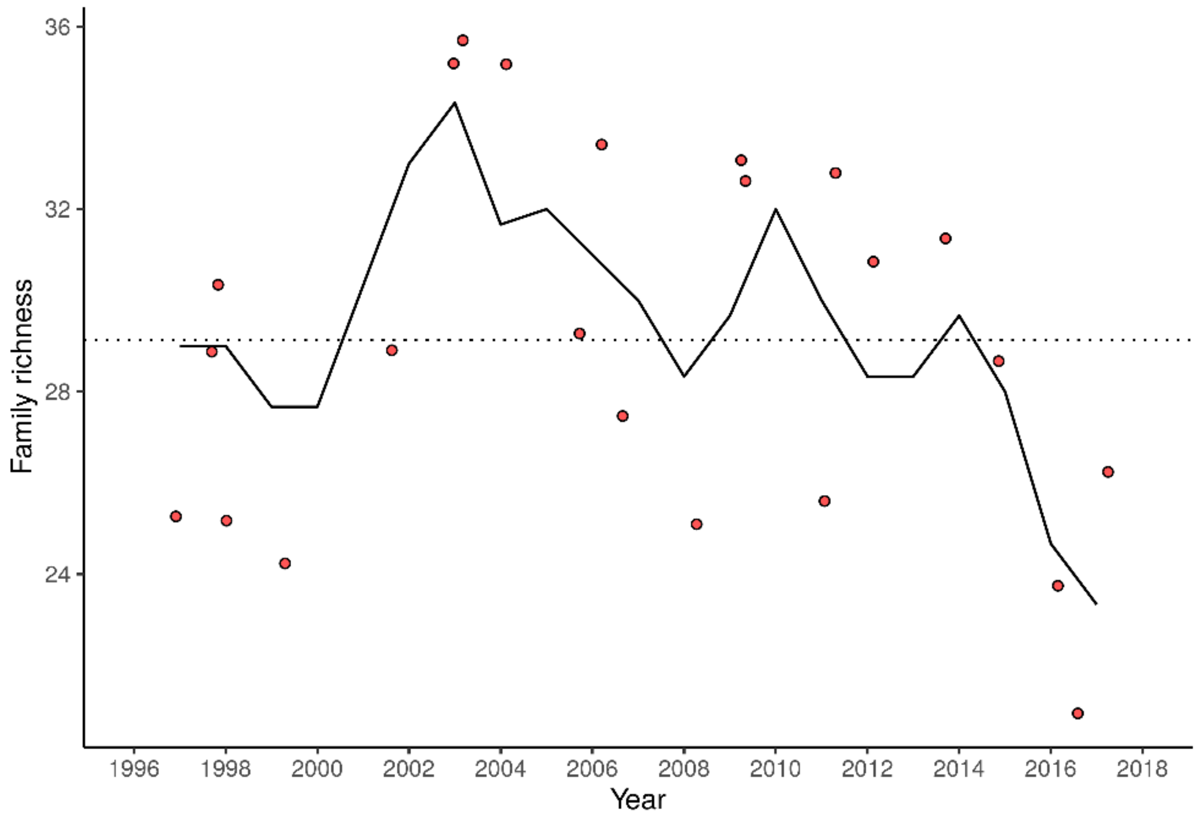

Figure 56 Richness of aquatic invertebrate families for each year at Lake Jandabup. Line is a moving 3-year average.

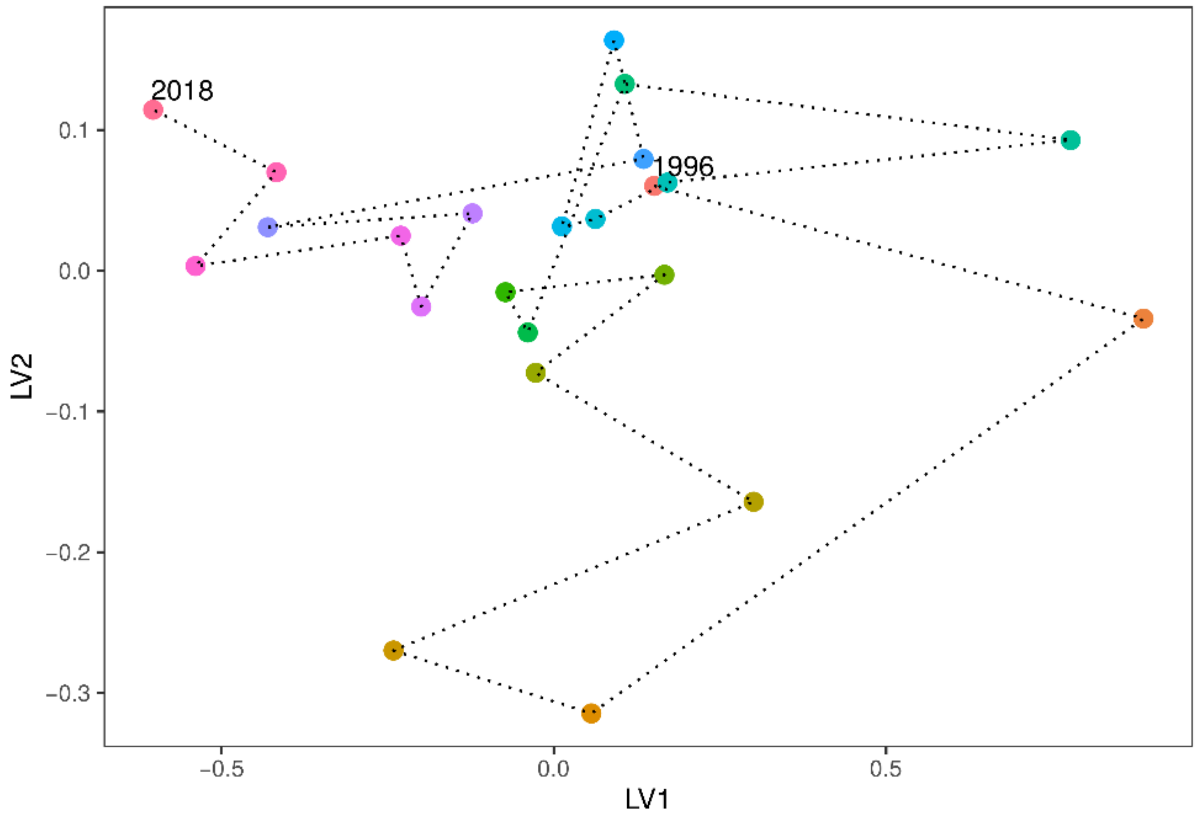

Figure 57 Unconstrained ordination based on invertebrate data for each surveyed year for Lake Jandabup. Consecutive years are joined by a line with first and last survey years labeled.

Lake Nowergup

Water quality

Water quality in Lake Nowergup is remarkably stable given the declines in surface waters and associated groundwaters (Judd and Horwitz, 2019). Acidity is usually low and alkalinity high, indicating that the lake has sufficient capacity to buffer against acidification. A pH above 9 is not unusual for this system. Recent monitoring suggests the lake currently has high nutrient levels, with current total nitrogen and total phosphorus at record high concentrations for the lake, and among the highest for all Spearwood Dune wetlands. Current nitrogen levels are twice the long-term mean levels. Livestock have recently been able to access the lakebed and may in part be the cause of elevated nutrients.

Vegetation Dynamics

There are two vegetation monitoring transects at Lake Nowergup, one in the northern part of the lake and one in the southern part. Both transects were established in 1996 and the northern one was last surveyed in 2016 while the southern one was last surveyed in 2018. In 2001, the original plots were realigned to better encompass wetland vegetation near the lake. Therefore, only post 2001 data is analysed here.

The ecological water requirements have been satisfied for a number of key wetland species found at Lake Nowergup, and the proposed minimum threshold will ensure that these requirement continue to be met (Figure 58). In both transects, there has been a recent shift in vegetation composition of the down-slope plots (A and B) transitioning towards the higher, more terrestrial plots (C and D; Figure 59). This shift has been driven by declines of *B. articulata* and *M. rhaphiophyla* and the increase of *E. rudis*. Increases in water level are likely to increase the abundance of fringing vegetation *B. articulata* and *Typha orientalis*. Other native species, including *E. rudis*, *Lepidosperma longitudinale* and *Rhagodia baccata* are likely to decrease in abundance (Figure 60)at lower elevations of the basin.

Aquatic invertebrates

Aquatic invertebrate richness has been below average for Lake Nowergup since 2010, with 19 families detected for the last three sampling occasions (Figure 61). There is currently a trend of declining richness since 2008. This decline in richness is likely due to the loss of fringing macrophytes due to declining water levels and submerged macrophytes in the center of the lake which have also disappeared (GMEMP 2018). Loss of macrophytic habitat has coincided with elevated nutrient levels which would have also altered ecological processes and invertebrate assemblages. Ordination reveals a marked change in assemblage composition from 1996 to 2018 (Figure 62). Communities appeared to be shifted most dramatically from 2002 to 2006 which coincides with both drying and supplementation of surface waters by artificial watering. The current shift away from the 1996 community may be driven by the high nutrients being experienced at the lake. The lake was best known in terms of invertebrates for its population of the bivalve family Sphaeridae. It can no longer be found at the wetland. Two families of aquatic mites, the beetle family Scirtidae and damsel fly family Cordulidae, have disappeared from spring monitoring samples. Further changes can be associated with a loss of the crustacean families Ceinidae, Amphisopidae, Notodromadidae and Chydoridae. As stated by Judd (2019) "*The macroinvertebrate monitoring undertaken in 2018 confirms the trends of reduced richness and changing assemblages. The artificial maintenance regime at this wetland was clearly inadequate to maintain ecological integrity and has failed to prevent a loss of habitats, the consequence of lowered water levels. The resulting change in invertebrate assemblages may well be irreversible and steps to restore more representative assemblages must involve more than maintenance of minimum water levels.*"

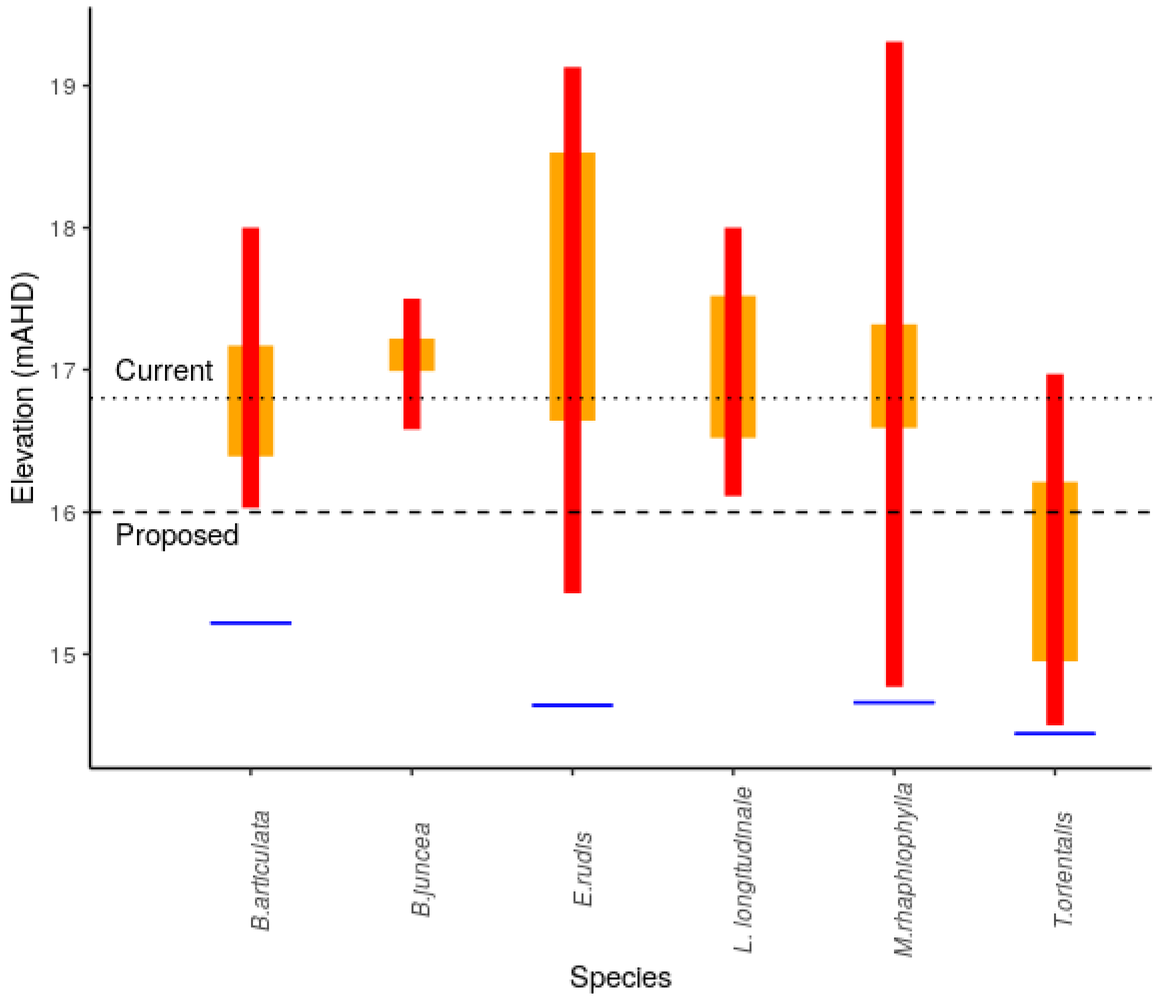

Figure 58 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2014 and 2019 at Lake Nowergup. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line.

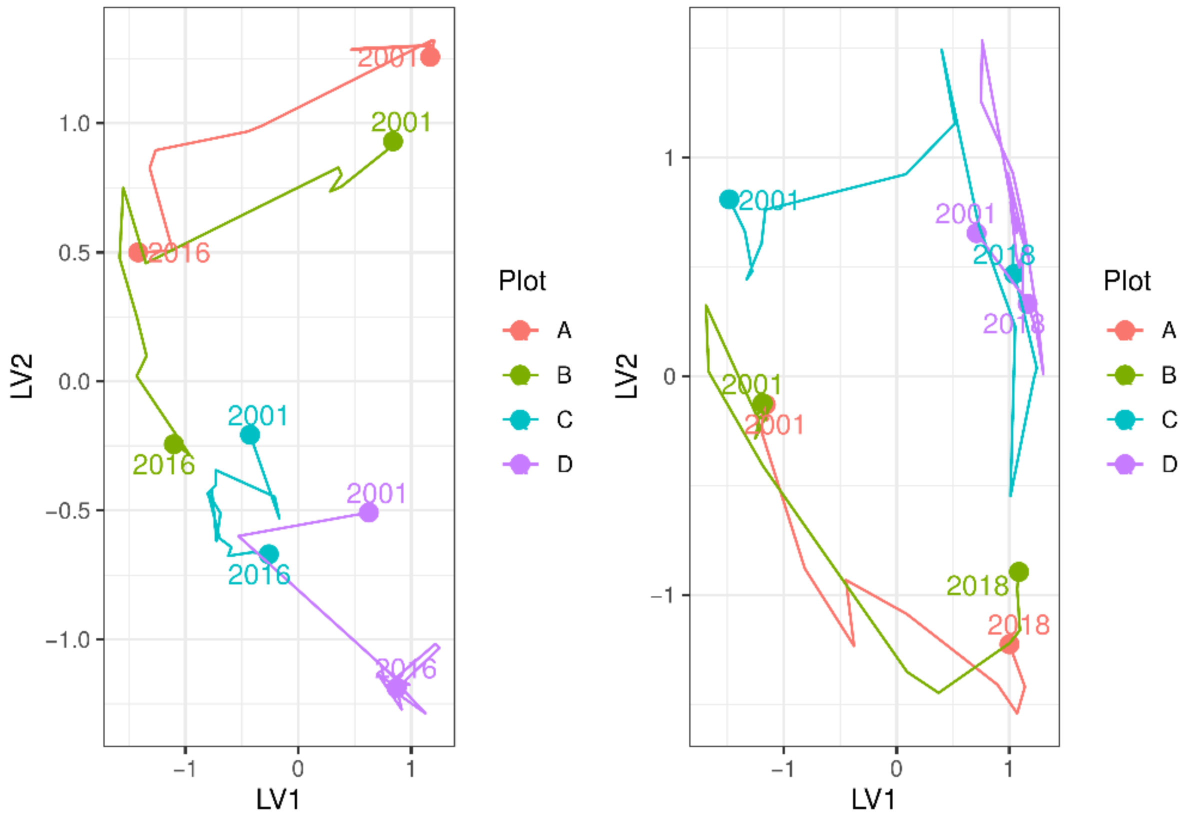

Figure 59 Unconstrained ordination based on the latent variable model for each surveyed year for the northern (left) and southern (right) Lake Nowergup transects. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

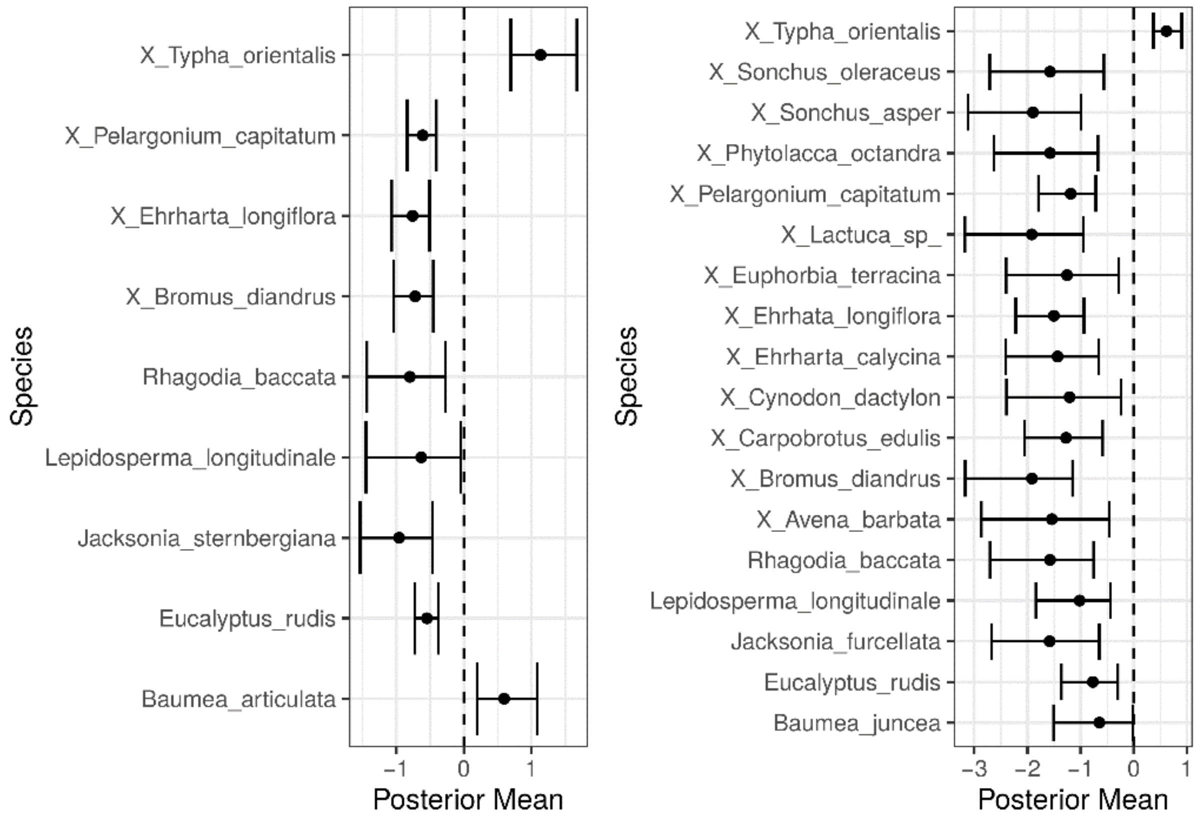

Figure 60 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at the northern (left) and southern (right) Lake Nowergup transects on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline and species with positive values are likely to increase in cover abundance when water levels increase. Only those species with coefficients significantly different to zero are shown.

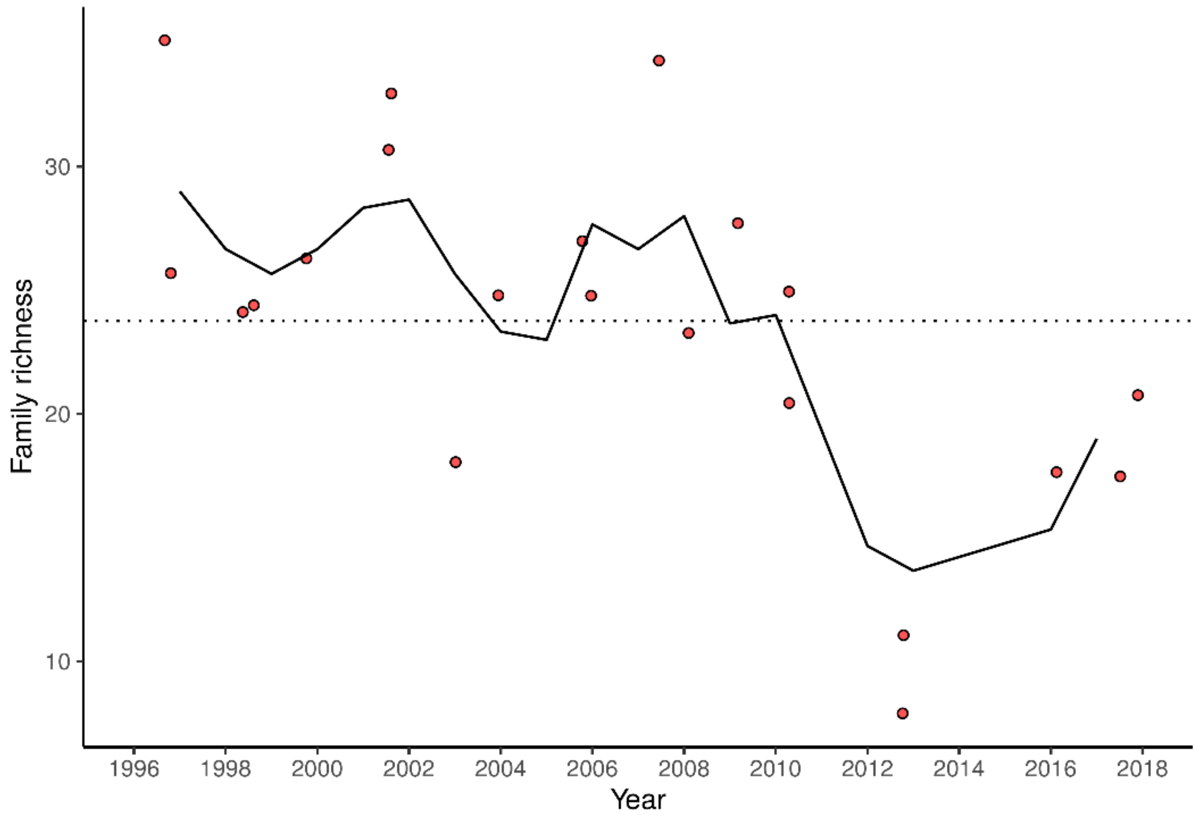

Figure 61 Richness of aquatic invertebrate families for each year at Lake Nowergup. Line is a moving 3-year average.

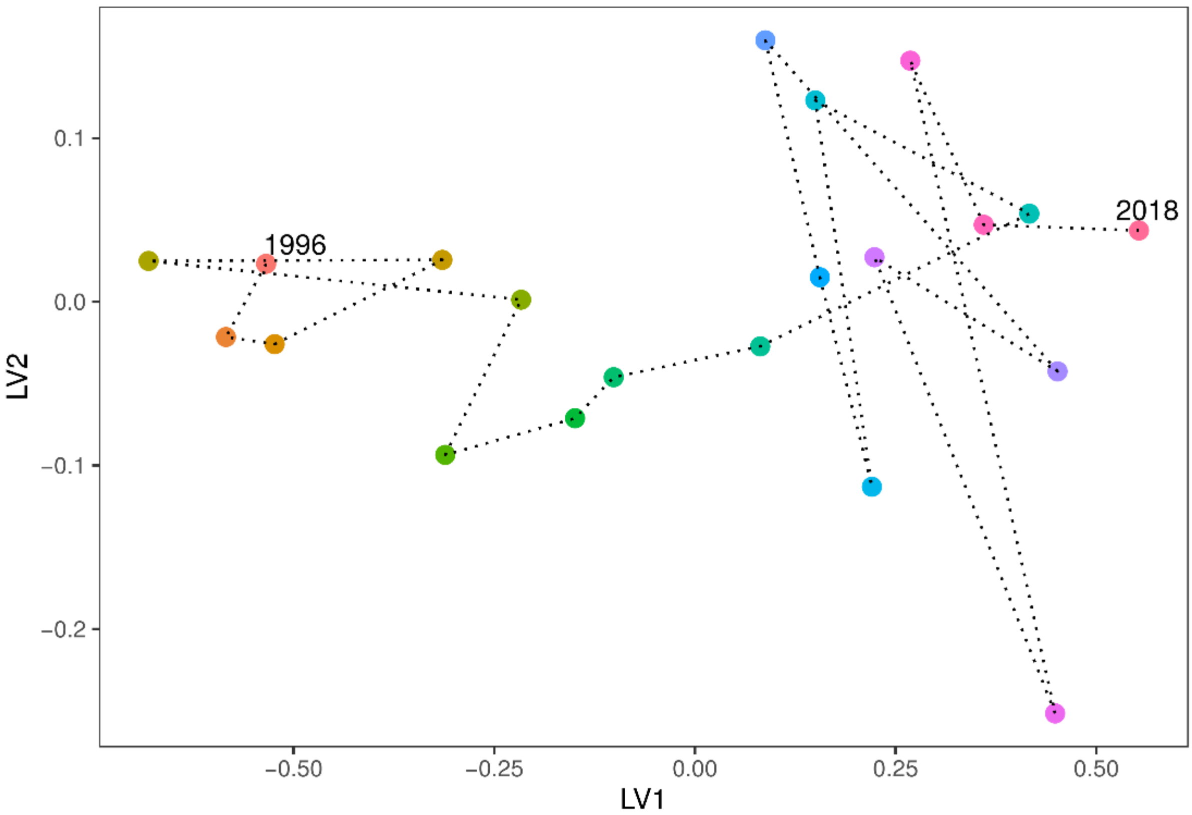

Figure 62 Unconstrained ordination based on invertebrate data for each surveyed year for Lake Nowergup. Consecutive years are joined by a line with first and last survey years labeled.

Lake Wilgarup

Vegetation dynamics

A vegetation monitoring transect was established at Lake Wilgarup in 1997 and was last surveyed in 2012. Two additional sites were added to the transect in 2009 down-slope of Plot A. The sedges, *Baumea articulata*, *Baumea juncea* and *Baumea vaginalis* have all disappeared from the wetland during the monitoring period. Tuart trees (*Eucalyptus gomphocephala*) have migrated down slope during the monitoring period and were recorded in Plot A in 2005. The proposed minimum threshold is going to place extra stress on *M. rhaphiophylla* individuals as their ecological water requirements may not be met (Figure 63). *Plots* A, B and C display similar shifts in community composition during the monitoring period, while Plot D displayed a significant change in composition in 2004-2005 in response to fire (Figure 64). Under a scenario of continuing groundwater decline, regression analysis reveals that a number of exotic species, including *Ehrharta longiflora* and *Bromus diandrus*, are likely to increase in cover abundances (Figure 65).

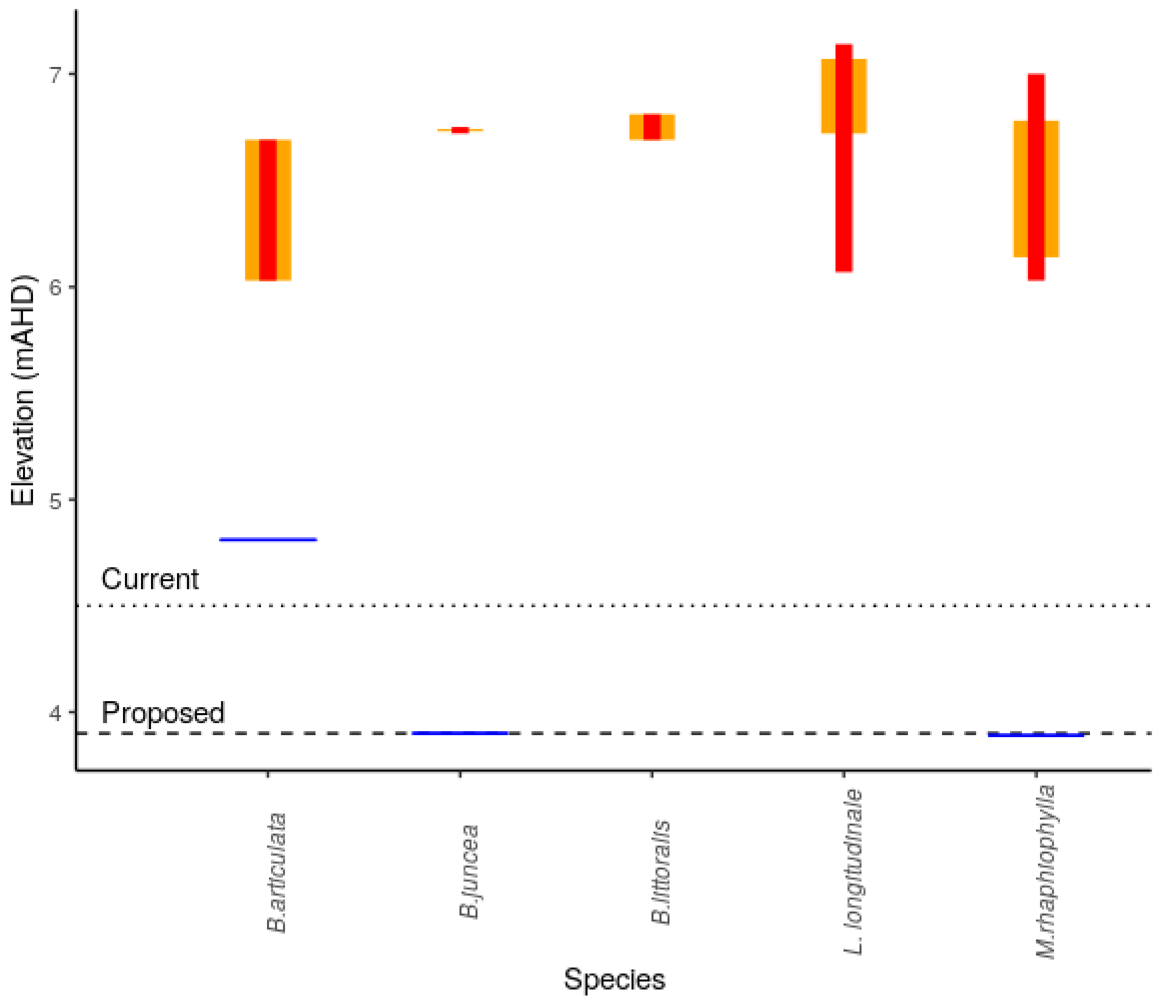

Figure 63 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2011 and 2019 at Lake Wilgarup. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line. *Baumea articulata*, *B. juncea* and *B. littoralis* data is based only on 2001 data.

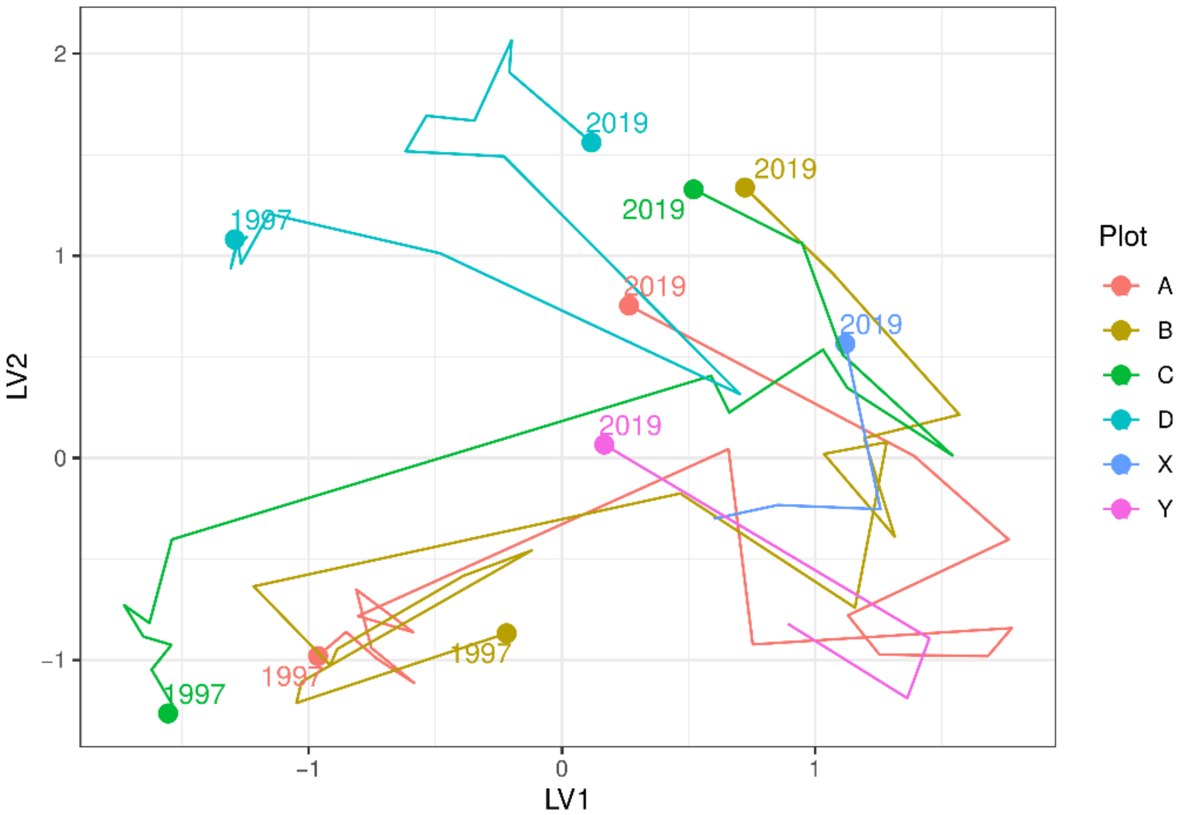

Figure 64 Unconstrained ordination based on the latent variable model for each surveyed year for Lake Wilgarup. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

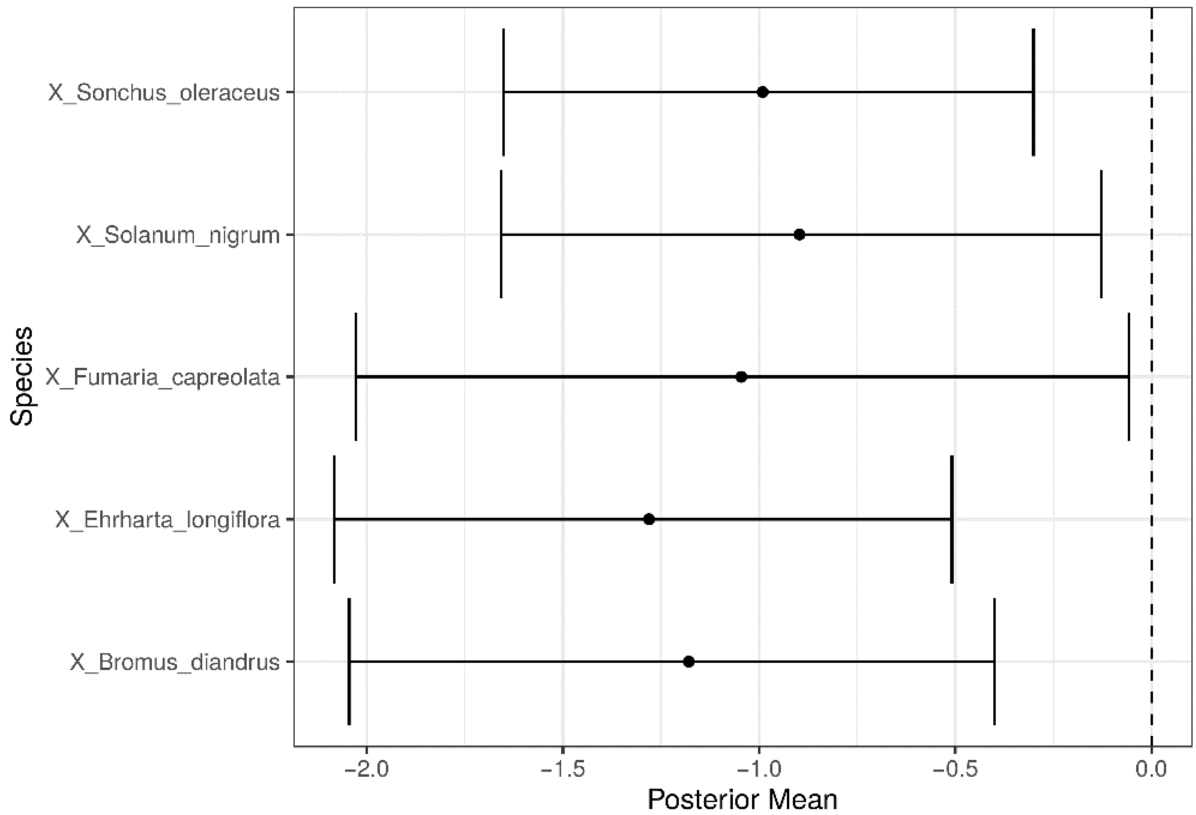

Figure 65 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at Lake Wilgarup on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline. Only those species with coefficients significantly different to zero are shown. Invasive species are identified by the pre-text ‘X’.

Pipidinny Swamp

Vegetation dynamics

The transect at Pipidinny Swamp consists of a series of depressions/swamps interspersed with tracks and grassy banks. The transect was established close to the bore but was only 20 m in length due to the terrain. Subsequently, only four *Melaleuca* trees could be included. Species richness and diversity on and around the transect was low, with *Acacia saligna* the dominant overstorey species, although *Melaleuca rhaphiophylla* appeared in good health (both on and around the transect). *Baumea articulata* was present, albeit in low abundance, several meters up slope from the surface water, and was in moderate health with a couple of dead stems present. No recruitment was recorded. The location's potential value as important habitat was indicated by the presence of a south west carpet python (*Morelia apilota*) in amongst the *Typha orientalis* during the 2019 survey. Several exotic species are abundant at the site, including *Bromus diandrus*, *Ehrharta longiflora* and the potentially invasive native bullrush *T. orientalis*.

Table 43 Vegetation cover abundance at the two plots established at Pipidinny Swamp in September 2019.

Species	Plot A	Plot B	Status
Bromus diandrus	4	9	Exotic
Cirsium vulgare	2	0	Exotic
Ehrharta longiflora	7	9	Exotic
Euphorbia sp.	0	1	Exotic
Fumaria muralis	2	3	Exotic
Pelargonium capitatum	2	2	Exotic
Sonchus oleraceus	2	1	Exotic
Symphiotrichum squamatum	1	0	Exotic
Acacia saligna	6	10	Native
Baumea articulata	2	0	Native
Melaleuca rhaphiophylla	4	0	Native
Myoporum caprarioides	3	2	Native
Rhagodia baccata	3	4	Native
Spyridium globulosum	3	3	Native
Typha orientalis	6	0	Native

Lexia 186

Vegetation dynamics

Vegetation monitoring has been occurring at Lexia 186 since 1997 with the last survey conducted in 2018. Overall canopy health has remained stable with most *Melaleuca preissiana* in good or excellent condition and most *Banksia ilicifolia* with average condition (Buller et al., 2018). Exotic richness is very low at Lexia 186 and natives account for approximately 90 % of total cover abundance at the transect. A number of key wetland species are currently experiencing periods water levels fall below their ecological water requirements, a situation the proposed minimum threshold will not alleviate (Figure 66). Ordination reveals similar trajectories in compositional change for each plot that reflect the continual changes in cover abundances of species (Figure 67). Regression analyses did not reveal significant effects of groundwater levels on any of the species present at Lexia 186. This result suggests that community composition is changing due to other factors that are independent of groundwater level. This is surprising given the significant declines in groundwater at the site. Vegetation may be altered by other processes such as altered sediment processes and acidification.

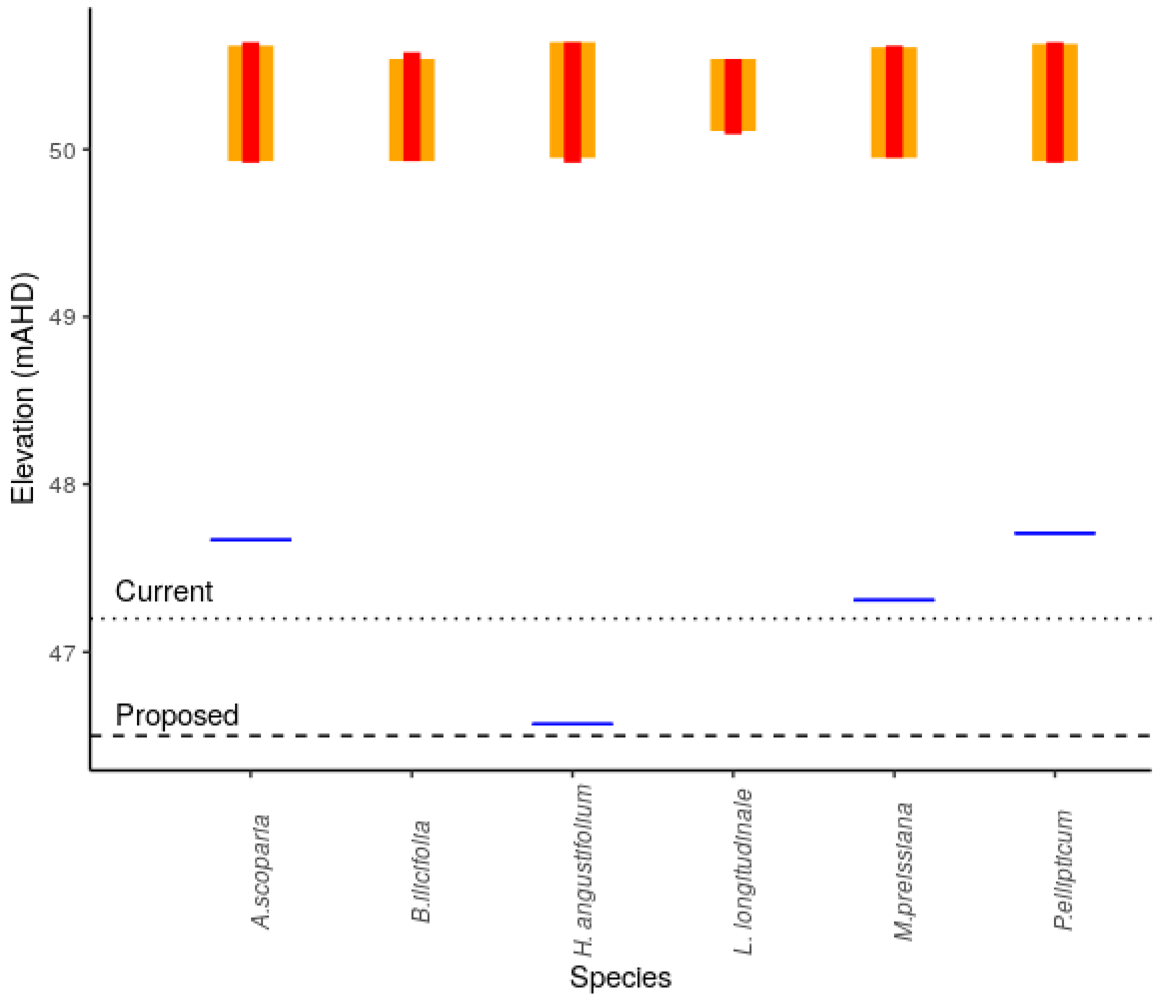

Figure 66 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2011 and 2019 at Lexia 186. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line.

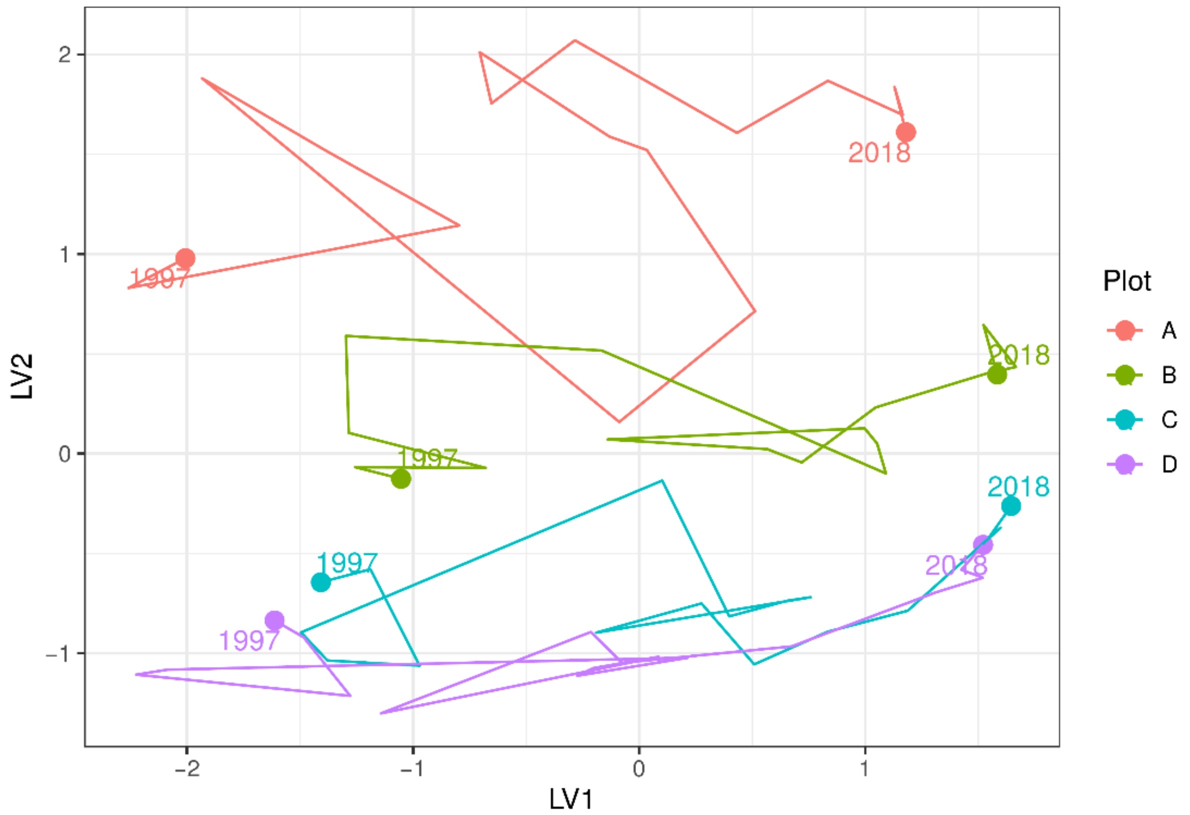

Figure 67 Unconstrained ordination based on the latent variable model for each surveyed year for Lexia 186. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

Melaleuca Park 173

Water quality

Melaleuca Park 173 is the only monitored wetland to show organic acidity (Judd and Horwitz, 2019). The waters are dark and have high gilvin levels (94.7 FTU). The acidic waters have a pH between 3.4 and 5.1 and recent monitoring suggests the current pH is 3.7. The lake usually has total nitrogen levels between 2000 and 2800 μg/L.

Vegetation dynamics

Vegetation monitoring has been occurring at Melaleuca Park from 1997 to 2018 (Buller et al., 2019). There has been marked changes in vegetation composition along the transect during this monitoring period. In 2014, *Baumea articulata* was absent from the transect, however, due to a wet season which saw Plot A and B submerged in 2018, *B. articulata* was recorded in low abundance. Similar changes have been observed for *Astartea scoparia*, which prior to 2018 was recorded wither dead or in poor condition. Since 2018, many of the *A. scoparia* plants were observed with new shoots. Other important vegetation components in Plot A include *Lepidosperma longitudinale* and *Leptocarpus scariosus*, both of which are also present in Plot B, whilst the former is present throughout the transect.

The long-term decline in water levels has had an adverse effect on the health of key wetland species as their ecological water requirements have not been met. The proposed minimum thresholds are going to continue this trend as water levels are projected to reach minimum levels below their ecological water requirements (Figure 68). The important canopy forming function of *M. preissiana* has been compromised due to declining health.

Ordination reveals distinct shifts in community composition since 1997 (Figure 69). Although Plot A is distinct, in terms of vegetation cover abundances, to Plots B, C and D, all plots display an upwards trajectory along the second axis (LV2). For Plot A, this shift in composition is likely due to the loss of *B. articulata* from the plot. Modelling compositional changes in vegetation with changes in groundwater levels suggests a number of species which are likely to increase in cover abundance with declining groundwater levels (Figure 70). These species, such as *Xanthorrhoea preissii* and *Dielsia stenostachya*, are likely to increase in cover abundance in lower areas of the basin under a scenario of continuing declining groundwater levels.

Aquatic invertebrates

Aquatic macroinvertebrate family richness has been declining since the late 2000s when water levels began declining (Figure 71). As water chemistry has changed little during this period, the decline in richness is likely due to the degradation of habitats caused by the lower surface waters and extended dry periods during summer (Judd and Horwitz, 2019). Macroinvertebrate assemblage composition has shifted since the initial 2000 survey (Figure 72). Since 2011, assemblage composition has been shifting away from the 2000 community, suggesting further shifts in composition are likely due to sustained low water levels. Taxa that are no longer found in monitoring samples from the wetland include the crustacean families of Perthiidae and Chydoridae, insect family Leptoceridae, Orthocladiinae midges and Unioncolidae mites.

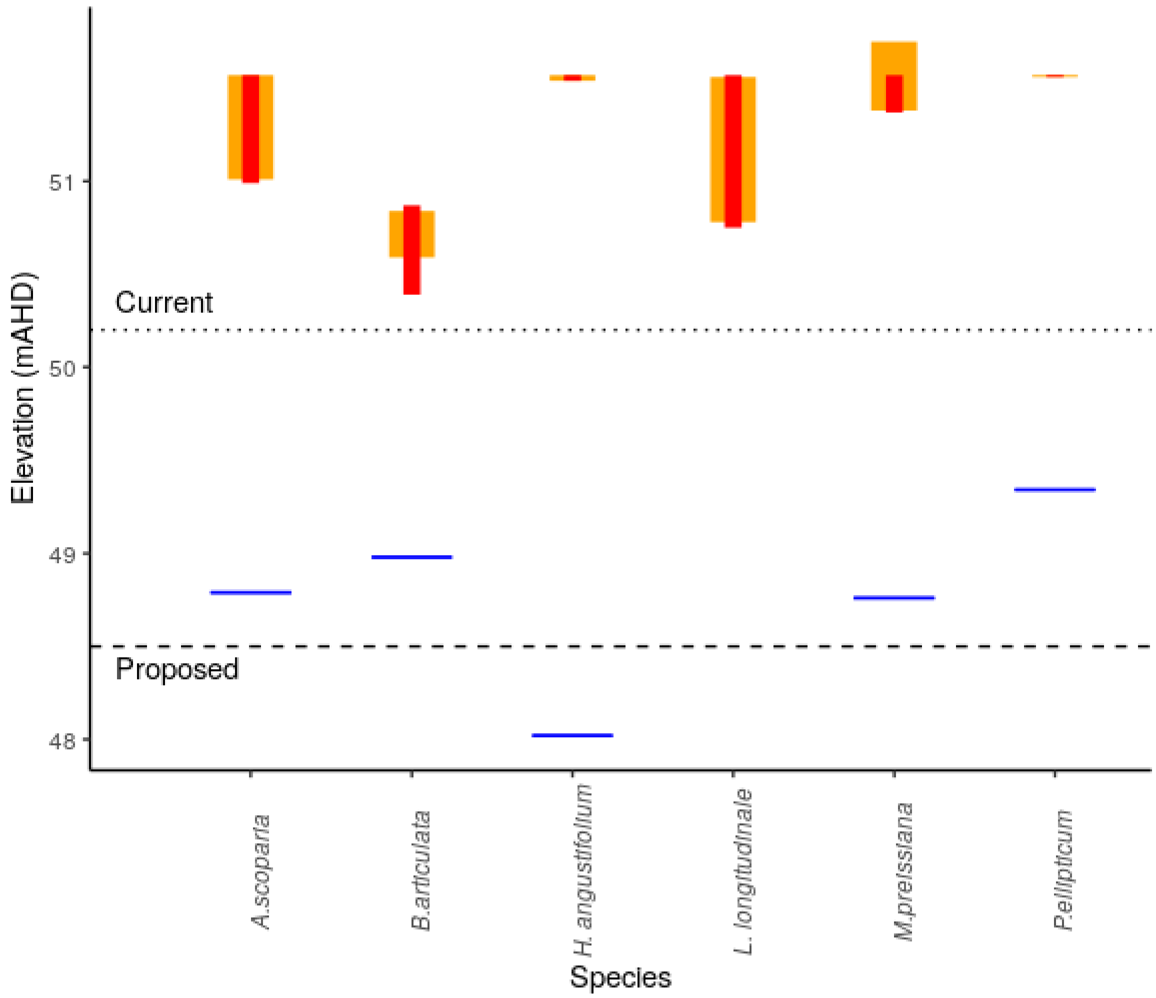

Figure 68 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2011 and 2019 at Melaleuca Park 173. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line.

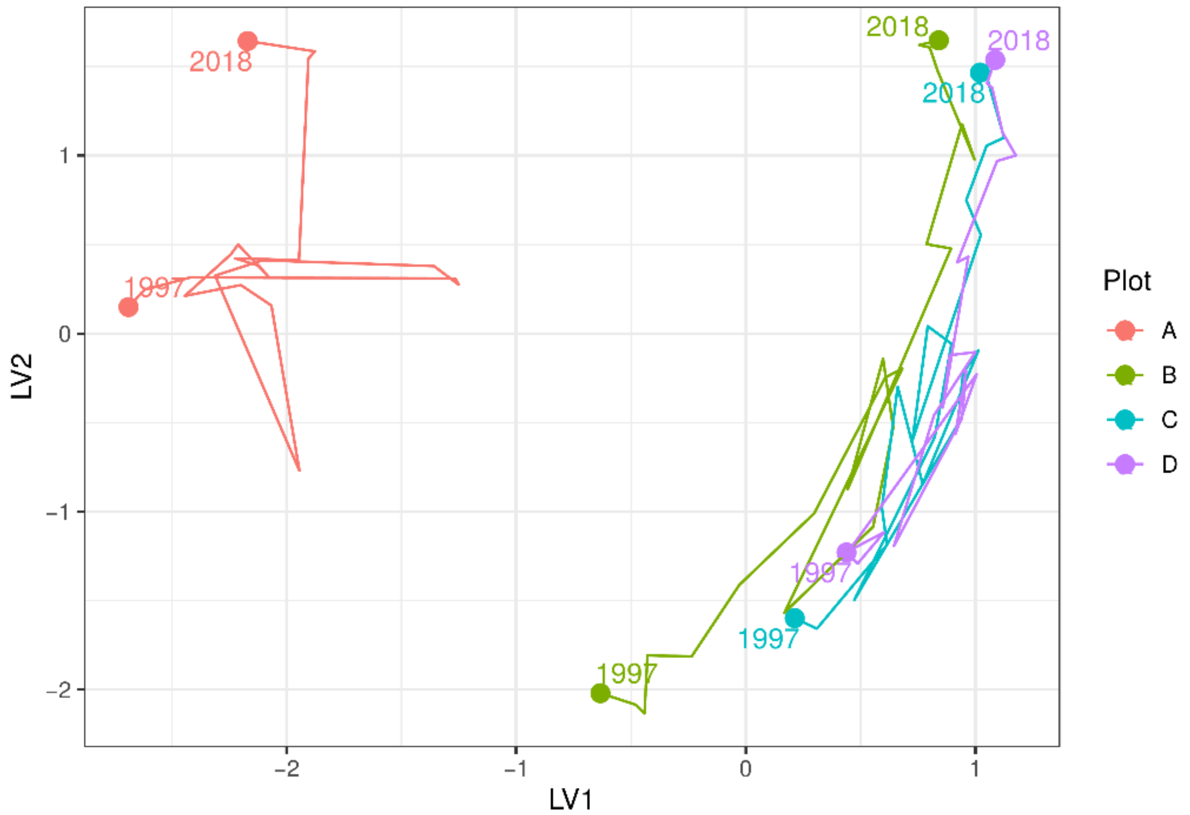

Figure 69 Unconstrained ordination based on the latent variable model for each surveyed year for Melaleuca Park 173. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

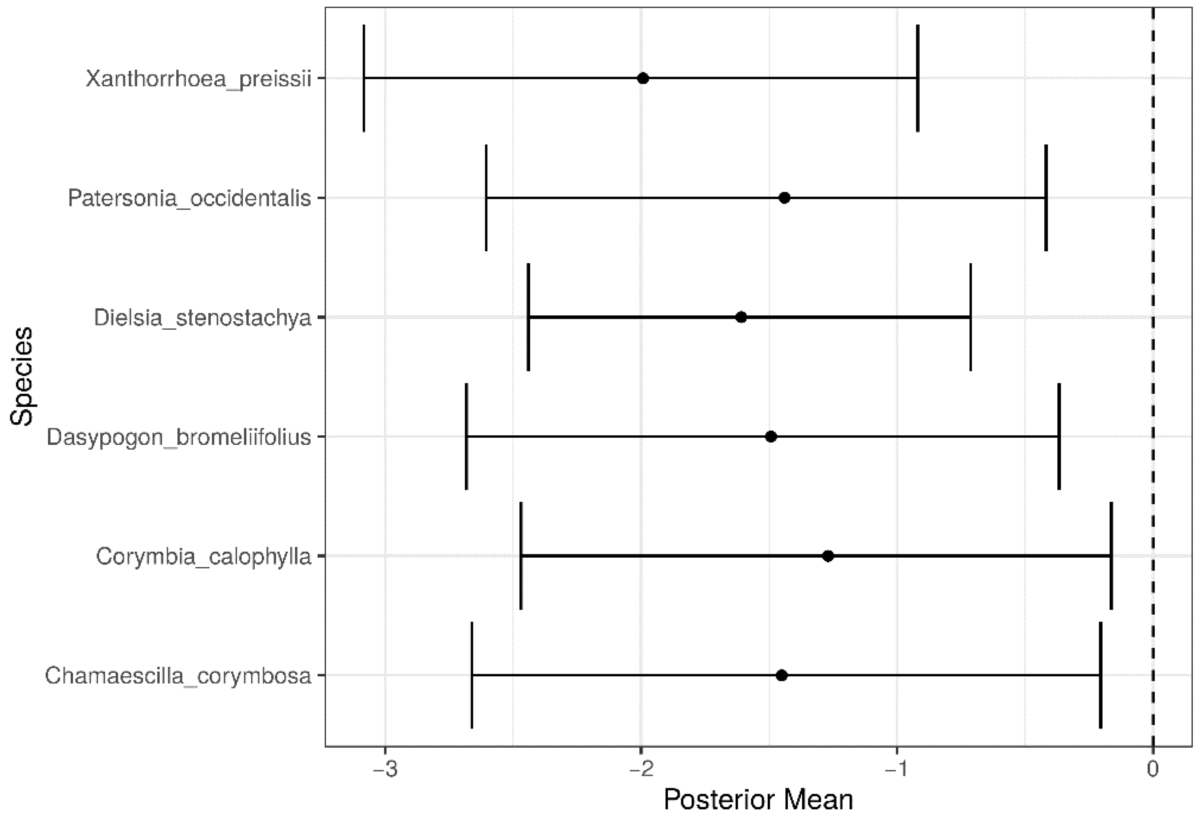

Figure 70 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at Melaleuca Park 173 on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline. Only those species with coefficients significantly different to zero are shown.

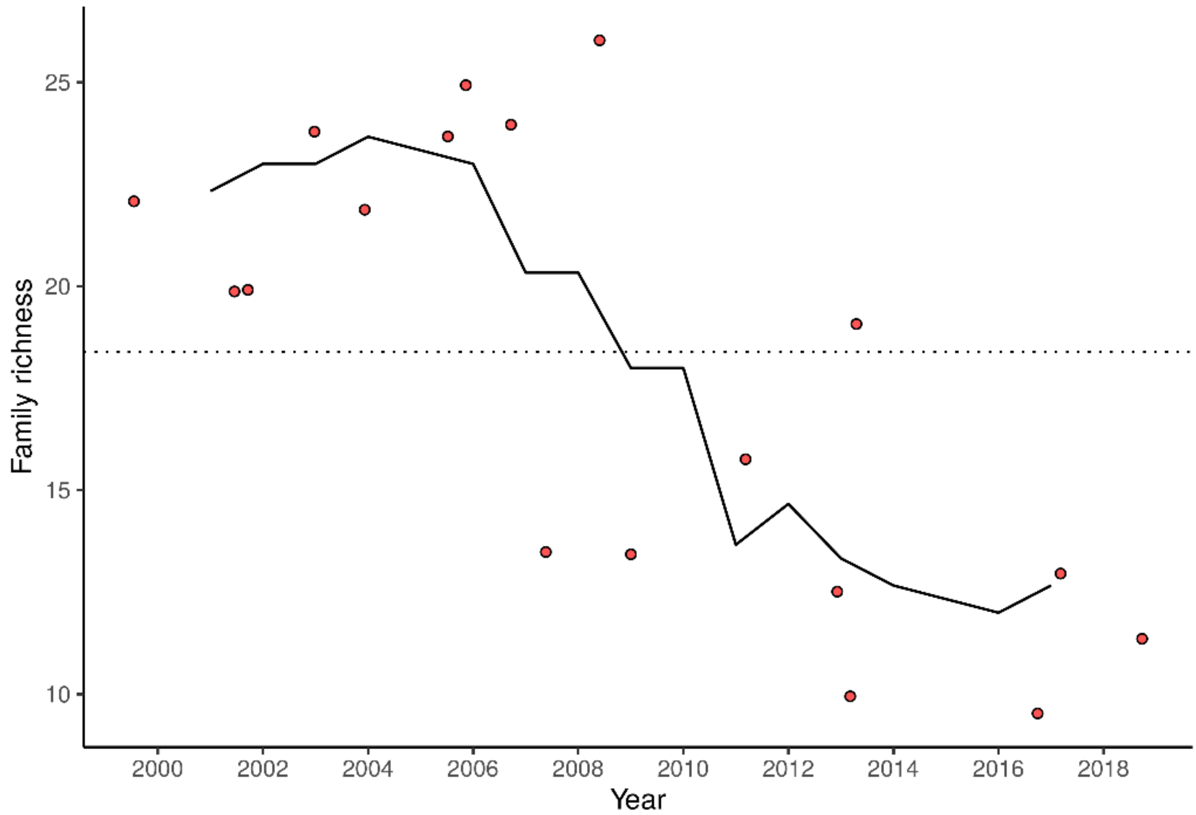

Figure 71 Richness of aquatic invertebrate families for each year at Melaleuca Park 173. Line is a moving 3-year average.

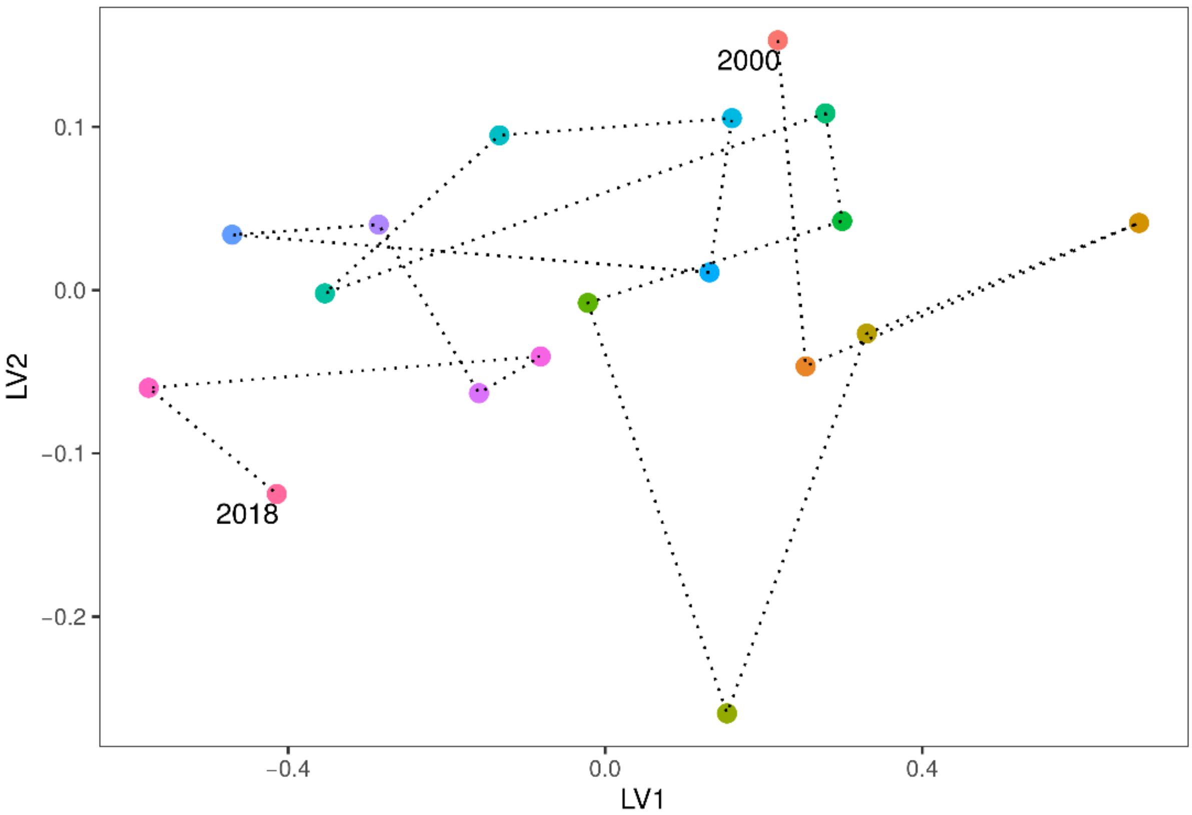

Figure 72 Unconstrained ordination based on invertebrate data for each surveyed year for Melaleuca Park 173. Consecutive years are joined by a line with first and last survey years labeled.

Melaleuca Park 78

Vegetation dynamics

The vegetation transect has been monitored at Melaleuca Park 78 since 1997 and was last surveyed in 2018 (Buller et al., 2019). The site is largely dominated by native species that include a dense understory of *Beaufortia elegans*, *Pultenea reticulata* and *Kunzea glabrescens*. The overstorey is largely composed of *Melaleuca preissiana* throughout the transect and *Banksia attenuata*, *Banksia ilicifolia* and *Banksia menziesii* in the higher parts of the basin. The ecological water requirements of *M. preissiana* have been met and will continue to be met by the projected increases in groundwater (Figure 73). In 2006, the transect was heavily affected by a fire but the vegetation has since made some recovery. *Baumea articulata* disappeared from the transect during this period. Several tree deaths were reported following the fire but there is evidence of recovery, particularly for low-lying stands of *M. preissiana*. Trajectories of compositional change provide further evidence for post-fire recovery as recent plot assemblages are becoming more similar to those recorded before the fire (Figure 74).

Bayesian regression modelling suggests a number of species associated with low groundwater levels (Figure 75), including *B. attenuata*, *Hibbertia subvaginata* and *M. preissiana*, are likely to increase in cover abundance under a scenario of further decreasing groundwater levels. The cover abundance of exotics, including *Aira caryophyllea*, *Briza maxima*, *Ehrharta calycina*, *Hypochaeris glabra*, *Poa annua*, *Sonchus oleraceus* and *Ursinia anthemoides*, is also likely to increase with declining groundwater levels. It is also likely that the richness of exotic species will increase with groundwater decline as the site becomes invaded by exotics not currently recorded at the site.

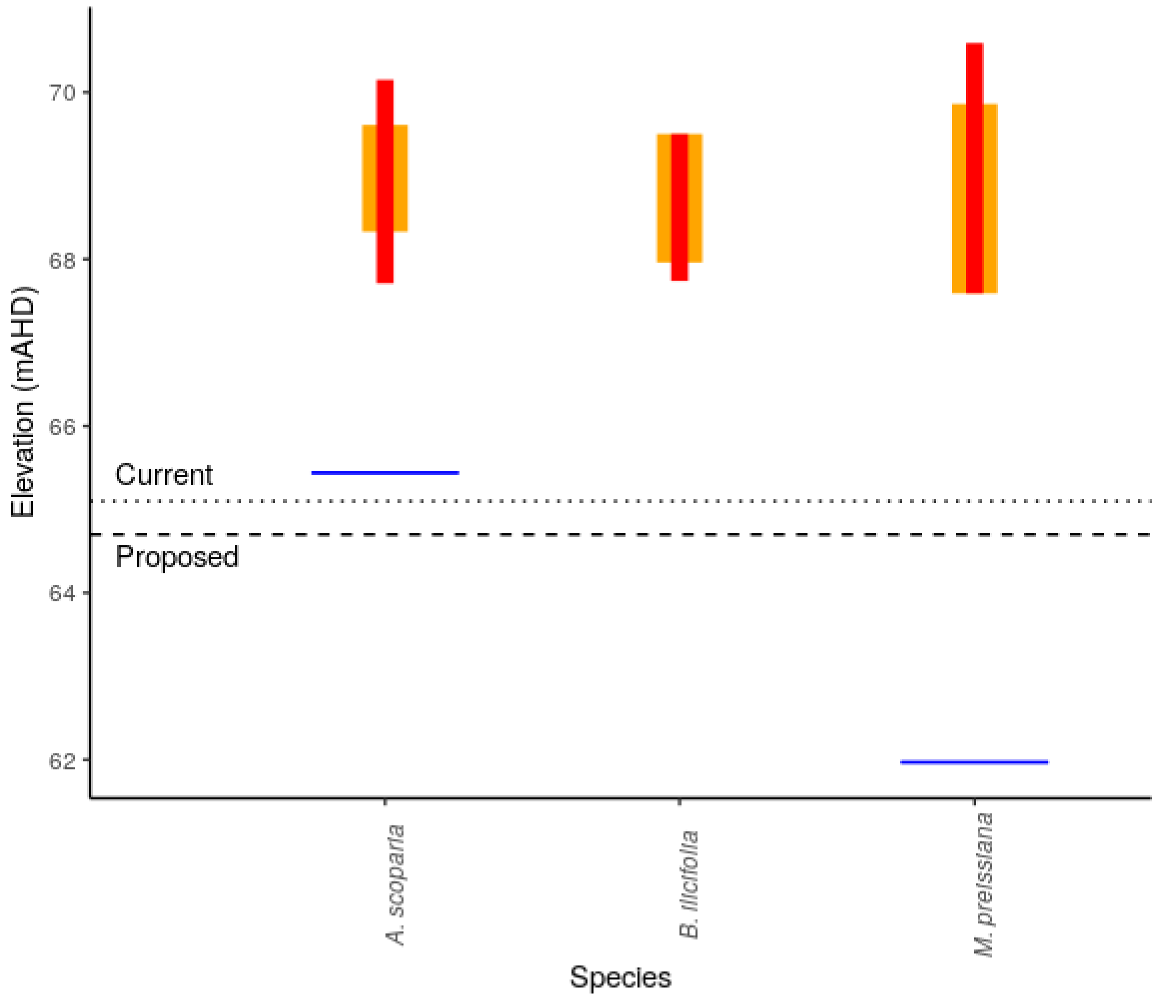

Figure 73 Range in elevation (mAHD) of key wetland species along the vegetation monitoring transects for 2001, 2011 and 2019 at Melaleuca Park 78. Red bars represent the absolute range in elevation and yellow bar represent mean range. Blue bars represent the ecological water requirements for key species at this site as determined by Froend et al. (2004b). The current minimum threshold is provided as a dotted line while the proposed 2030 threshold is provided by the dashed line.

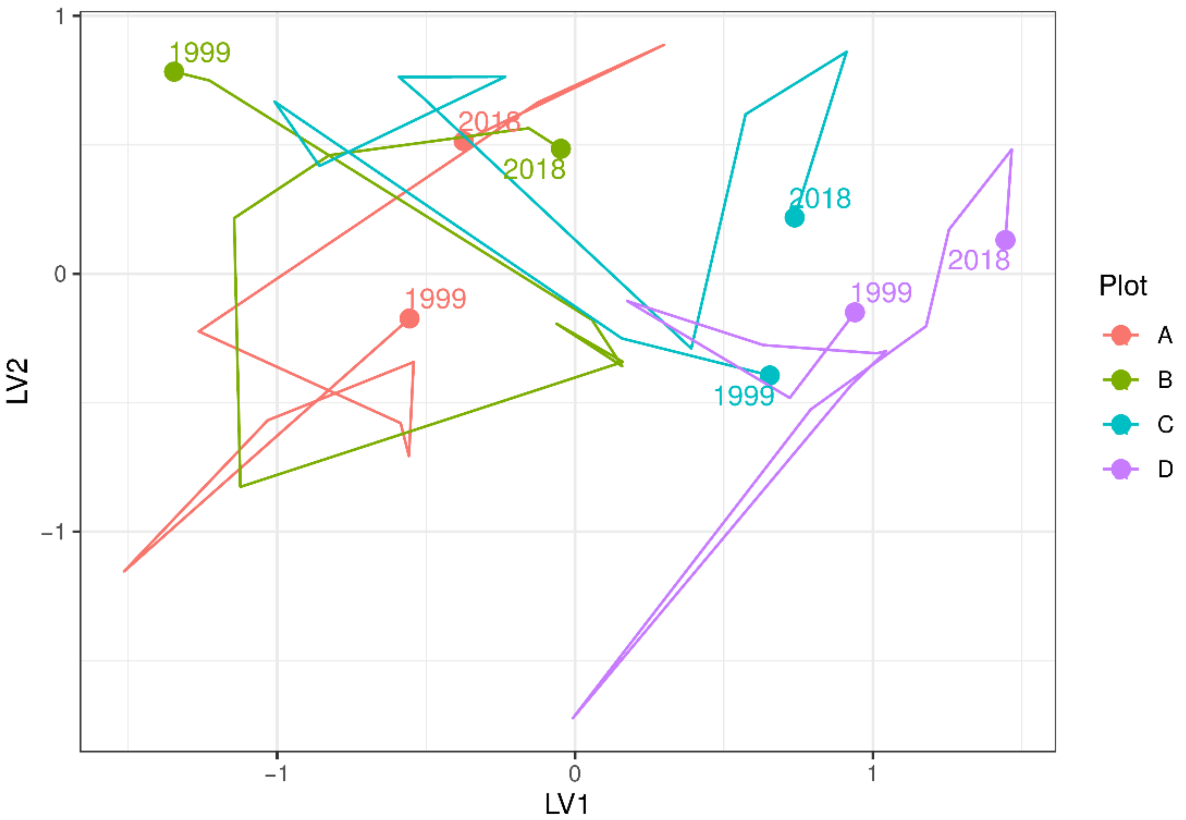

Figure 74 Unconstrained ordination based on the latent variable model for each surveyed year for Melaleuca Park 78. Plots are represented as different colours and consecutive years are joined by a line with first and last survey years labeled.

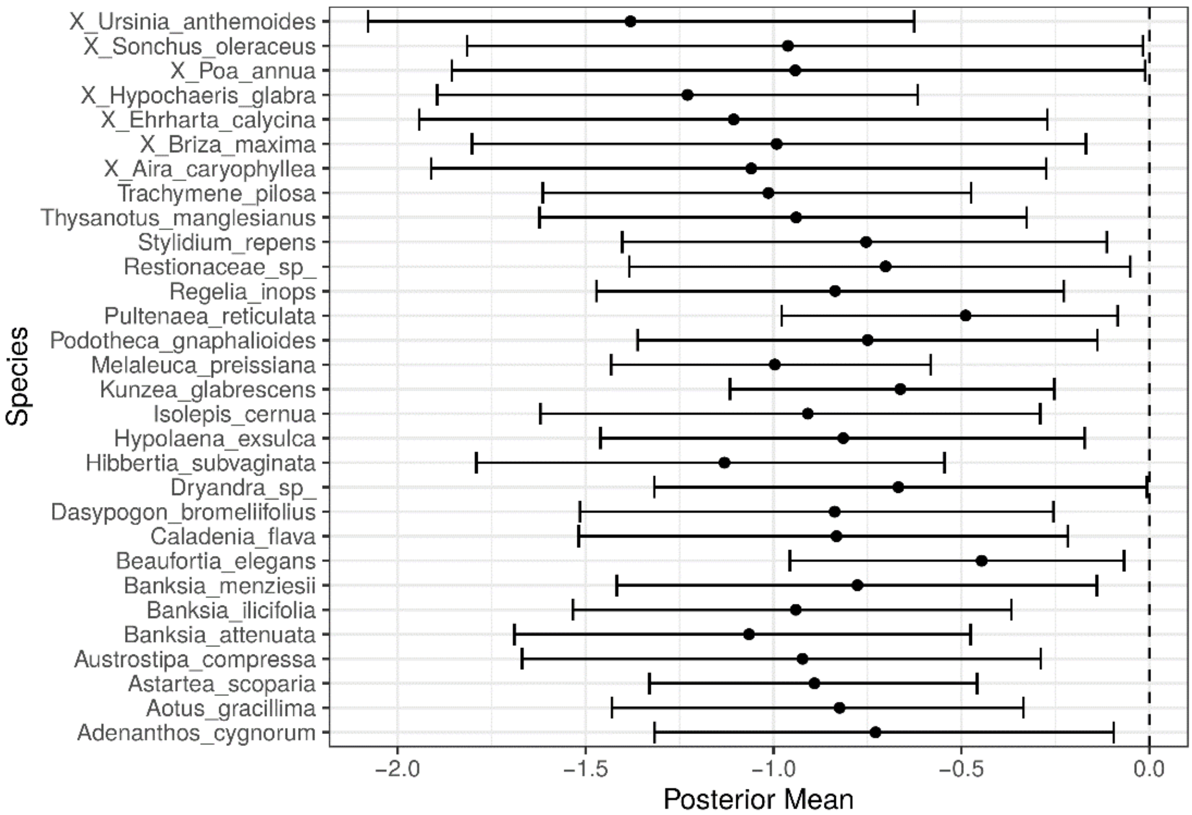

Figure 75 Estimated mean regression coefficients (dots) and 95% credible intervals (bars) for effect of groundwater levels at Melaleuca Park 78 on vegetation species cover abundances based on Bayesian Regression Analysis (Hui, 2016). Species with a negative mean posterior value are likely to increase in cover abundance as water levels decline. Only those species with coefficients significantly different to zero are shown. Invasive species are identified by the pre-text ‘X’.