Perth and Peel Green Growth Plan for 3.5 million

Strategic Assessment of the Perth and Peel Regions

Draft EPBC Act Strategic Impact Assessment Report

Appendix

December 2015
Acknowledgements

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CONDITION STATEMENT – BECHER POINT RAMSAR SITE

EXECUTIVE SUMMARY

The Becher Point Wetlands Ramsar site is located 9 km south of the City of Rockingham and 50 km south of Perth within the Swan Coastal Bioregion of Western Australia and covers 677 hectares, of which less than 10% is wetland area (Figure D1).

The Becher Point Wetlands Ramsar site is part of the Port Kennedy Scientific Park (Nature Reserve 44077). Excluding a small section in the southwest, the reserve is vested in the Conservation Commission for the purpose of ‘Conservation of Flora and Fauna’ and is administered under the Department of Parks and Wildlife as part of the Rockingham Lakes Regional Park.

The Becher Point wetlands are a series of wetlands formed in the linear depressions (beach ridges) between the parallel sand ridges, termed dunal swales. These wetlands become progressively younger towards the coastline forming a geological progression of the progradation process. Today, the wetlands are different ages and are at different stages of initiation and development. These wetlands stand as a record of a generally uninterrupted and progressive wetland initiation over a period of 5,000 years. The Becher Point Wetlands Ramsar site covers only a proportion of the Becher cuspate foreland, encompassing approximately 60 of the 300 Becher Suite wetland basins and 2 of 3 Cooloongup Suite wetlands that were originally mapped in 1986-88.

The Becher Point Wetlands Ramsar site was designated on 5 January 2001 as meeting two of the nine listing criteria as it represents an example of shrub swamps and seasonal marshes in a near natural condition and a rare example of a geomorphological sequence of Holocene wetlands containing a sedgelands community (Threatened Ecological Community), being particularly important for demonstrating a continuous depositional history of sediment during the last 3,000 years.

Although the Ramsar site is primarily reserved for nature conservation purposes, passive recreation that does not impact on natural values or ecosystems of the reserve is permitted. The greatest threats to the values of the lakes from visitor access are from uncontrolled and unauthorised access by four-wheel drive vehicles. These activities cause trampling of plants, spread weeds and disease, disturbs native fauna, including roosting shorebirds and soil compaction and erosion. The Ramsar site is largely fenced, but the gate is constantly broken by members of the community to allow vehicle access. The site is accessible via entry along the beach.

Re-evaluation of the Becher Point Wetlands Ramsar site for the drafting of the Ecological Character Description (ECD-2007) and in 2011 for the Commonwealth’s Rolling Review of Ramsar sites in Australia, confirmed the criteria for listing the system remain and while significant pressures were recognised and gaps in knowledge and monitoring existed, the site retained the biotic components and ecological processes that were the basis for recognising the site as a wetland of international significance. The evaluation conducted in this condition report is the most extensive conducted since the publication of the 2007 ECD.
Serious threats exist at the Ramsar site, the most significant being fire frequency which combined with declining groundwater levels in the northern and eastern sectors of the site and continued access by off-road vehicles has led to weed invasions along the access tracks and in cases these have spread to significant areas, particularly in the northern and eastern sectors, closest to urban infrastructure. Beach erosion has removed one occurrence of the TEC (BP1) in the last 5 years and sea level rise will likely become the most significant threat in future years.

Groundwater levels are generally stable, although levels in wetlands closest to urban infrastructure have declined in recent years. It is unclear whether this can be attributed to a reduction in rainfall, groundwater abstraction or potentially both. Importantly, the annual monitoring of the Threatened Ecological Community (TEC) vegetation condition has not indicated any alteration by the recent decline in groundwater levels. The site would benefit from having a dedicated monitoring program designed to facilitate reporting on the condition of the site's key values, including the nationally listed TEC and the processes that maintain these values and the expression of water in the interdunal swales. The Department of Water is currently reviewing the adequacy of the existing groundwater monitoring program and licensed groundwater use in this locality as part of implementing the Rockingham – Stakehill groundwater management plan 2008. Particular regard will be given to further examining the local hydrological processes in order to maintain adequate water levels at the Becher wetlands Ramsar site.

Elsewhere in the site, groundwater levels remain static. Nutrient loads are within eutrophic levels as a result of nutrient leakage within the catchment, but is not resulting in algal growth within the wetlands. The pH and conductivity are within acceptable limits and not identified as threats.

Monitoring of vegetation in wetlands is limited to the north-east of the Becher Point Wetlands Ramsar site closest to the Port Kennedy golf course and a strategic vegetation monitoring program is required, particularly to better delineate the TEC and wetland vegetation and changes in extent and condition that may occur through future pressures from climate change and urban pressures.
1 Introduction

1.1 INTRODUCTION TO THIS REPORT

The purpose of this technical report is to provide a Condition Statement for the Becher Point Wetlands Ramsar site. It will be used to inform the development of Draft Commonwealth Impact Assessment Report (CIAR) and the Draft Strategic Conservation Plan for the Strategic Assessment of the Perth and Peel Regions (SAPPR).

This report has been developed collaboratively by a number of Western Australian State Government Agencies, as the technical experts regarding the Ramsar site. Agencies authors include:

- Department of Water.
- Department of Parks and Wildlife.
- Department of Premier and Cabinet.

The content of this report is based on:

- Information Sheet on Ramsar Wetlands (RIS)-updated November 2014.
- Ecological Character Description for the Becher Point Wetlands Ramsar site (Draft V & C Semeniuk Research Group 2007) (ECD).

1.2 BECHER POINT WETLANDS RAMSAR SITE OVERVIEW

The Becher Point Wetlands Ramsar site was listed as a Wetland of International Importance under the Ramsar Convention in January 2001. The Ramsar site comprises a portion of the system of interdunal wetlands on the beachridge plain which forms the geomorphic surface of the Becher cuspate foreland, on the coast of south-west Western Australia. The series of wetlands within the Ramsar site exhibits a continuum of development in geomorphology, sedimentary fill, hydrology, hydrochemistry and vegetation, and is considered by researchers to be a unique wetland system in Western Australia and one of the youngest wetland systems on the Swan Coastal Plain. The sedgelands that occur within the linear wetland depressions of the Ramsar site are a nationally listed Threatened Ecological Community (TEC) under the Australian Government Environment Protection and Biodiversity Conservation Act (1999). The community is recorded as ‘Sedgelands in Holocene dune swales of the southern Swan Coastal Plain’ and is listed as endangered (Figure D1).

Historically, as the cuspate foreland prograded seawards, a series of beach ridges were progressively produced and a chain of wetlands formed in the linear depressions between the parallel sand ridges – these wetlands become progressively younger towards the coastline. Today, the wetlands are different ages and are at different stages of initiation and development. These wetlands stand as a record of a generally uninterrupted and progressive wetland initiation over a period of 5,000 years. The Becher Point Wetlands Ramsar site covers only a proportion of the Becher cuspate foreland, encompassing approximately 60 of the 300 Becher Suite wetland basins (Semeniuk 1988) and 2 of 3 Cooloongup Suite wetlands (Semeniuk 1988).

The Becher Point Wetlands Ramsar site is located in the City of Rockingham (local government authority) in the State of Western Australia with a population of approximately 2.24 million in 2011 (Australian Bureau of Statistics 2014). The Ramsar site is 9 km south of the City of Rockingham,
which had a population of 104,105 in 2011 (Australian Bureau of Statistics 2014), in the State of Western Australia and covers 677 hectares, of which less than 10% is wetland area.

The Becher Point Wetlands Ramsar site is part of the Port Kennedy Scientific Park (Nature Reserve 44077). Excluding a small section in the southwest, the reserve is vested in the Conservation Commission for the purpose of ‘Conservation of Flora and Fauna’ and is administered under the Department of Parks and Wildlife as part of the Rockingham Lakes Regional Park.

Individual wetlands within the Ramsar site have not been formally named. However, they have been allocated an alpha-numeric designation (Figure D1) as part of a long term study of the Becher and Cooloongup Suite wetlands (Semeniuk 2007). These alpha-numeric designations are used in the ECD, as follows:

**Becher Suite wetlands:**

- Wetland 35 (sites 1-6), wetland 9 (sites 1-14), wetland swi (sites 1-3), wetland swii (sites 1-4), wetland swiii (sites 1-6) and wetland 1N (sites 1-2).

**Cooloongup Suite wetlands:**

- Wetland BP1 (sites 1-4) and wetland BP2 (sites 1-5).

Occurrences of the TEC at the Becher Point Wetlands Ramsar site have been designated a unique identifier (FID) shown in Figure D1. Discrepancies in delineation of TECs and wetlands are likely due to a combination of boundary drift during digitisation of hard copy mapping of wetlands and incomplete delineation of wetlands.
Figure D1: Wetland mapping, TEC location and water monitoring bores at Becher Point Wetlands Ramsar Site
2 Ramsar listing

2.1 LISTING CRITERIA

The Becher Point Wetlands Ramsar site meets two of the nine Ramsar listing criteria. The listing criteria and justification are presented in Table D1 below and have been taken from the Ramsar Information Sheet (RIS) for the site.

Table D1: Ramsar listing criteria and justification

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near natural wetland type found within the appropriate biogeographic region.</td>
<td>The Becher Point Wetlands Ramsar site comprises an example of shrub swamps and seasonal marshes formed in an extensive sequence of interdunal depressions that have arisen from seaward advancement of the coastline over recent millennia. This geomorphological sequence of Holocene wetlands is rare in the South-West Coast bioregion and is one of the youngest wetland systems on the Swan Coastal Plain. Examples of this type of geomorphological sequence in equally good condition and within a protected area are considered rare globally (Semeniuk 2007). In addition to the presence of a nationally endangered sedgeland community, the conservation values of the wetlands are primarily related to the geomorphic significance of the site and the respective location of the wetlands along the evolutionary time sequence. When conserved as a representative unit, the relative youth of the wetlands, and the range of wetlands of different ages in association with their geomorphic history, provide important opportunities for research on wetland evolution (V &amp; C Semeniuk Research Group 1991).</td>
</tr>
<tr>
<td>2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or Threatened Ecological Communities.</td>
<td>The Becher Point Wetlands Ramsar site supports a nationally listed Threatened Ecological Community ‘Sedgelands in Holocene dune swales of the southern Swan Coastal Plain’. The sedgeland community is nationally listed as Endangered under the Australian Government Environment Protection and Biodiversity Conservation Act (1999). The sedgeland community has a restricted distribution and is almost entirely located within linear wetland depressions (swales) occurring between parallel sand ridges of the Rockingham-Becher Plain in south-west Western Australia. The best record of the sedgeland community occurs along a linear transect from the Ramsar site through to the hinterland, which spans the last 8,000 years of the Holocene Epoch (Department of Environment and Conservation 2011). The sedgeland community within the Ramsar site is particularly important for the outstanding demonstration of a continuous depositional history of sediment during the last 3,000 years.</td>
</tr>
</tbody>
</table>

2.2 RAMSAR SITE VALUES

The values of the Becher Point Wetlands Ramsar site are described in detail in the draft ECD and are summarised below.
The site includes a substantial part of the suite of approximately 200 discrete, small wetlands located between Becher Point (Indian Ocean coast) and the Perth-Mandurah Road. The Ramsar site comprises a portion of the system of interdunal wetlands on the beachridge plain which forms the geomorphic surface of the Becher cuspat e foreland, on the coast of south-west Western Australia. The series of wetlands within the Ramsar site exhibits a continuum of development in geomorphology, sedimentary fill, hydrology, hydrochemistry and vegetation, and is considered by researchers to be a unique wetland system in Western Australia and one of the youngest wetland systems on the Swan Coastal Plain. The sedgelands that occur within the linear wetland depressions of the Ramsar site are a nationally listed Threatened Ecological Community under the Australian Government Environment Protection and Biodiversity Conservation Act (1999). The community is recorded as ‘Sedgelands in Holocene dune swales of the southern Swan Coastal Plain’ and is listed as endangered.

At its seaward edge, if progradation continues, there is the potential for further Becher Suite wetlands to develop. If progradation ceases and erosion becomes dominant in the long term there is also the potential for the Becher Suite wetlands to change fundamentally from what is observed today. As the geomorphic template upon which the wetlands have developed, the Becher cuspat e foreland itself is a contributing factor to their being a rare type of wetland system.

As a result of forming at different times during the last 5,000 years, the wetlands are at different stages of their evolution and exhibit variable degrees of internal complexity. One of the important values of the Ramsar site is the information that can be gained about the geoheritage of wetland formation on the Swan Coastal Plain. From the younger wetlands, it is possible to deduce how the wetlands were initiated and to observe the early plant colonisers and first plant successions. In older wetlands, stratigraphy and geohydrology are more complex; there are different rates and styles of accretion, sediment types and structures, and a greater number of hydrological mechanisms. From the progressively older wetlands, it is possible to see how relative simplicity has developed into internal complexity even in a very small wetland basin, and how the individual older wetland interacts with and perturba tes sub-regional groundwater patterns that in turn influence its internal sedimentology and biology.

2.2.1 Geomorphology and geology

The Becher cuspat e foreland, with its beachridge plain, is the geomorphic template for the formation of the Becher Suite wetlands. The components which determined the formation of the cuspat e foreland and the beachridge plain, and consequently, the chronological sequence and spatial distribution of the Ramsar site are:

- the nearshore bathymetry;
- the supply of calcareous sediment in the nearshore zone;
- the low energy cell, leeward of the Garden Island offshore ridge; and
- the gentle nearshore and beach profile.

The Becher cuspat e foreland accreted on the Pleistocene surface of the inter-ridge depression between the Spearwood Ridge on the mainland and the nearshore Garden Island Ridge, in response to a falling sea level during the middle to late Holocene period. A simple shoaling sequence of submarine banks and beachridge plains developed. The Becher cuspat e foreland is triangular and asymmetrical and is approximately 5 km long north to south and 6 km from the seaward-projecting...
apex to the margin of the Holocene accreted plain where it abuts the Pleistocene limestone hinterland.

**Size, shape, number and distribution of wetland basins**

The Becher Point wetlands are a sequence of discrete interdunal basins mirroring the orientation of the beachridges (relic foredunes) and the changing asymmetry of the Becher cusparse foreland. The wetlands are located between microscale beachridges, 1-3 m high and 30-60 m apart. The swales grade from continuous linear troughs with slightly undulating floors, to linear troughs bisected by low, transverse ridges, to linear chains of discrete basins. Of the 24 chains comprising approximately 275 basins in the beachridge swales, five chains and approximately 60 wetland basins occur within the Ramsar site. Most of these belong to the Becher Suite - leptoscale to microscale, sumplands and leptoscale to mesoscale damplands. The sumplands are generally narrow, and vary from irregular to linear with steep sides. The damplands are shallow and vary from narrow ribbon shapes to rounded with undulating floors. The wetlands range in age between 4,500 and 500 years approximately, generally becoming younger towards the coast. Within the present boundaries of the Ramsar site, the oldest wetland is approximately 3,000 years.

Two other wetlands, which occur at Point Becher itself, just landward of a shoreline barrier, belong to the Cooloongup Suite. They have been formed most recently (<100 years) and are both small ovoid sumplands. The wetland nearest the point is sometimes breached during storms, thus altering its geomorphological characteristics.

**Sediment components**

Generally the wetland fills in the Becher Point wetlands are less than 1 metre. There are six wetland sediment types each one indicative of a different rainfall regime:

- peat;
- peaty sand;
- carbonate mud (calciutite);
- calcilutaceous muddy sand;
- organic matter enriched calcilutaceous muddy sand and sandy mud; and
- humic sand (Semeniuk and Semeniuk 2004).

Peat forms under relatively wetter conditions with frequent inundation, a longer hydroperiod, increased plant density, and slower plant decay. During drier conditions within a given wetland, freshwater aquatic carbonate mud forms in shallow water through biogenic carbonate production associated with the green algae *Chara*, followed by in-situ disintegration of these carbonate materials during the evaporation phase (Scholle et al. 1983, Anadon et al. 1991). The carbonate mud in the Becher Point wetlands is linked to a strongly seasonal climate (Platt and Wright 1992), with features that indicate alternating emergence and water inundation/saturation.

Throughout the wetlands, sedimentary fills vary in thickness, sedimentary sequence, microstructures, diagenetic overprints and stratigraphic relationships. Thickness varies from 30 to 120 cm. Three distinct sedimentary stratigraphic sequences occur; muddy sand dominated, carbonate mud dominated, and peat influenced. The muddy sand is the most common wetland fill and generally varies from being 25-60 cm. Carbonate mud sediment ranges in thickness from 30-5 cm from oldest
to youngest deposit. Peat dominated sediments are currently accumulating and occur as peat impregnated carbonate mud less than 10 cm thick.

In addition to composition, the sediments are heterogeneous in structure, fabric, and texture. The sediment structures include roots, shells, burrows, mottles, layers, colour differentiation and lack of structure. The fabric of the wetland fill sequence changes from mudstone through packstone to grainstone down profile (i.e. a fabric that varies from mud dominated, to muddy sand, to sand). Similarly, the texture (i.e. grain size of the sedimentary particles) of the wetland fill down profile ranges from mud dominated to medium/coarse sand dominated. Heterogeneity is increased through diagenetic overprints such as carbonate cementation and carbonate dissolution, and pedogenic structural features such as brecciation and dessication.

2.2.2 Hydrology

The seasonal and shallow nature of the wetlands is a key component of the Becher Point wetlands, influencing the nature and development of the wetland sediments or fills, playing a role in dissolution and precipitation, altering concentrations of chemical elements in both the groundwater and the soils, and fundamentally determining the wetland water storage capacity and therefore the dynamic biological responses from both flora and fauna. In an average rainfall year, sumplands are inundated to a depth of 10-50 cm for approximately 1-4 months, while in damplands, waterlogging ranges from surface and near-surface levels to depths of 20 cm below ground.

Recharge by seasonal precipitation

Rainfall recharges the groundwater, which annually rises to inundate or waterlog the wetland basins. The annual pattern of rainfall is seasonal, concentrated between the months of May and November, and coincides with the period of lowest evaporation. Rainfall events outside this period are sporadic, and usually insignificant, but recently, there has been a trend towards decreasing annual rainfall, and an increased number of significant out of season events.

Groundwater under the Becher cuspate foreland, resides unconfined in the Safety Bay Sand and Becher Sand aquifers. The water body is approximately 25 m deep at maximum thickness and its upper surface (the water table) slopes west, northwest and southwest forming a convex surface. The height of the water table varies between 2.8 and 4.2 m AHD. Generally, there is a steepening of the gradient closer to the shorelines. Where the water table has intersected the beachridge plain topography, it has created a specific pattern of wetland distribution which has taken place over 5,000 years.

The Superficial Aquifer is underlain by the Rockingham Sand aquifer, which is also an unconfined aquifer that is in hydraulic connectivity with the superficial formation. However, hydraulic connection between the two is in some places restricted by a bed of clay, or clayey-sand which occurs at the base of the Superficial Aquifer.

Along the coast is a saltwater wedge which underlies the outflowing groundwater. The position of the wedge is dependent on the outflowing water and local hydraulic gradients. A positive gradient needs to be maintained to ensure that the saltwater does not encroach inland.
**Water table gradients and hydraulic conductivities**

Groundwater flows have different properties at different geographic locations on the cuspate foreland. They exhibit different water table gradients, hydraulic conductivities, volumes of water, and frequencies, in response to rainfall patterns and position of the water table. Over the cuspate foreland, the water table gradients are low, typically 1:1,000 and in some places 1:3,000 (Semeniuk 2007). Between beachridges on either side of a given wetland, the east to west groundwater flow is low enough to consider most wetlands to be closed hydrological systems during the period of inundation or waterlogging. However, there are flows between wetland basins and adjacent ridges, generated by 10 cm differences in piezometric height in the corresponding water tables, which can be quite rapid and frequent. Examples of these flows include: up gradient ridge to wetland, wetland to down gradient ridge, and down gradient ridge back to wetland. Water table gradients between ridge and wetland, when present (early and late winter and spring), are the driving mechanism for flow to, from, or through each wetland. North to south flow between the wetlands in the same swale is negligible.

In the parent sands, the average hydraulic conductivity has been estimated as 16-48 m/day (Binnie and Partners 1988), however, vertical or horizontal flow in the wetland sediments themselves is much lower 1.3-2.7 cm/day (Semeniuk 2007).

Groundwater flow is in a westerly direction across the site towards the Indian Ocean (Coterra 2013).

**Water table morphology under wetlands**

Water table morphology under the wetlands is one of the unusual features of the Becher Point site. It is dynamic in nature, responding to different recharge rates through lenses of relatively impermeable wetland sediment and a highly porous regional sand body. Morphological changes to the water table under individual wetlands include mounds, troughs, and reversal or sublimation of east/west gradient. These morphological changes are short lived and small scale phenomena but indicative of important hydrological and stratigraphical interactions and of wetland hydrological mechanisms within each basin.


Baseline measures have been established, based on 18 years of monthly monitoring for the wetlands in the Becher Suite and 5 years for the wetlands in the Cooloongup Suite for absolute values above or below the ground surface, measures of seasonal fluctuation, timing of peaks and troughs, and periodicity. During that time, Western Australia experienced a decrease in rainfall and these figures reflect the combined average and below average rainfall. Overall, most hydrographs (Figure D2) continued to exhibit the sinusoidal shaped seasonal curve, but the trend after 1991 was a decrease in water levels to a new, fairly constant position for minimum levels. Eccentricity in the hydrographs is caused by a rate of recharge which is more rapid than the rate of discharge and this has not altered. Seasonal fluctuations have been averaged over 18 years but do vary up to 5 or 10 cm in a very wet or very dry year. Frequency of inundation can be variable and both plants and sediments are able to adapt to longer or shorter periods, however, the limit of acceptable change was set so that sumplands and damplands continue to experience inundation or waterlogging as the prevailing condition (Table D2).
Table D2: Baseline measures for water regime attributes for the Becher Point Wetlands Ramsar site (V & C Semeniuk 2007)

<table>
<thead>
<tr>
<th>Wetland</th>
<th>Water levels above or below ground (cm) 1991-2008</th>
<th>Seasonal fluctuations (cm)</th>
<th>Timing of peak and trough</th>
<th>Frequency of inundation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean maximum</td>
<td>Mean minimum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35-4</td>
<td>-4</td>
<td>-91</td>
<td>73</td>
<td>Aug; Apr</td>
</tr>
<tr>
<td>9-6</td>
<td>18</td>
<td>-52</td>
<td>71</td>
<td>Aug; May</td>
</tr>
<tr>
<td>9-14</td>
<td>17</td>
<td>-69</td>
<td>71</td>
<td>Aug; Apr</td>
</tr>
<tr>
<td>swi</td>
<td>-22</td>
<td>-76</td>
<td>47</td>
<td>Sept; Apr</td>
</tr>
<tr>
<td>swii</td>
<td>-24</td>
<td>-87</td>
<td>46</td>
<td>Sept; Apr</td>
</tr>
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<td>swiii</td>
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<td>-48</td>
<td>48</td>
<td>Sept; Apr</td>
</tr>
<tr>
<td>1N-2</td>
<td>-73</td>
<td>-126</td>
<td>57</td>
<td>Sept; Apr</td>
</tr>
<tr>
<td>BP1</td>
<td>11</td>
<td>-42</td>
<td>59</td>
<td>Jun; Jan</td>
</tr>
<tr>
<td>BP2</td>
<td>44</td>
<td>-28</td>
<td>63</td>
<td>Jun; Jan</td>
</tr>
</tbody>
</table>
2.2.3 Hydrochemistry

The aspects of hydrochemistry that characterise the Becher Point wetlands include: salt concentrations measured as Total Dissolved Solids (TDS), Total Phosphate, and pH of groundwaters and interstitial waters. The baseline data on the hydrochemistry of groundwaters include salinity levels, cation and orthophosphate content, and pH is summarised in Table D2.

**Wetland groundwater and soil water salinities**

The Becher Suite wetlands can be classed as freshwater, the salt content in the groundwater predominantly below 1,000 ppm, although it varies seasonally between 250 ppm and 1,000 ppm. For one or two months of the year, December to March (summer and early autumn) and June to July
(early winter), groundwater is slightly subhaline (1,000-3,000 ppm). As this is true for all the wetland sites monitored in the Becher Suite, it seems to be an important and consistent factor. Each winter, rainfall leaches the wetland sediments of any build-up of salt from the previous year. It is this pattern rather than specific concentrations which is important.

The groundwater in the Cooloongup Suite wetlands tends to be more saline than the Becher Suite wetlands although still classed as predominantly fresh to subhaline, the mean salt content is around 700-3,000 ppm ($n = 36$, 1991-1994), although it varies seasonally. For one or two months of the year, December to March (summer and early autumn) and June to July (early winter), groundwater is hyposaline and in dry years can become mesosaline (20,000-35,000 ppm).

**Nutrient concentrations in the groundwater**

Nutrient concentrations can only be quantified for Total Phosphate in the groundwater. Levels of Total Phosphate in groundwater are generally low, less than 0.1 mg/L **(Table D3)**. Overall, variability in the groundwater content is low, and is related to seasonal events, such as the first flush of rain and spring plant growth. Most of the phosphorus is locked in the organic material and the carbonate sediments.

**Groundwater pH**

The pH of the groundwater under the wetlands ranged between 7.1 and 8.3, but was nearly always around neutral. This range is the result of a balance between the organic matter generated within the wetlands (driving the waters towards acidity) and the calcareous nature of the underlying Safety Bay Sand aquifer, which contributes calcium, magnesium and bicarbonate ions to the groundwater (driving the waters towards alkalinity).

**Table D3 : Baseline data for chemical constituents of groundwater (V & C Semeniuk 2007).**

<table>
<thead>
<tr>
<th>Wetland name</th>
<th>Mean groundwater salinity (ppm) ($n = 36$)</th>
<th>Mean groundwater cation content (mM/L) ($n = 30$)</th>
<th>Mean groundwater pH ($n = 36$)</th>
<th>Mean groundwater Total-P concentrations (ppm) ($n = 12$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35-4</td>
<td>694 ± 281</td>
<td>Ca 4 ± 2</td>
<td>7.5</td>
<td>0.55 ± 0.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg 1.9 ± 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Na 6 ± 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>K 0.3 ± 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-6</td>
<td>885 ± 352</td>
<td>Ca 3.1 ± 0.8</td>
<td>7.5</td>
<td>0.08 ± 0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg 3 ± 0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Na 10 ± 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>K 0.2 ± 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-11</td>
<td>571 ± 142</td>
<td>Ca 3.1 ± 0.8</td>
<td>7.4</td>
<td>0.17 ± 0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg 3 ± 0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Na 10 ± 3</td>
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<td></td>
<td></td>
<td>K 0.2 ± 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-14</td>
<td>973 ± 568</td>
<td>Ca 2.4 ± 0.5</td>
<td>7.4</td>
<td>0.05 ± 0.02</td>
</tr>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Wetland name</td>
<td>Mean groundwater salinity (ppm) (n = 36)</td>
<td>Mean groundwater cation content (mM/L) (n = 30)</td>
<td>Mean groundwater pH (n = 36)</td>
<td>Mean groundwater Total-P concentrations (ppm) (n = 12)</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------</td>
<td>-------------------------------------------------</td>
<td>----------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>swi</td>
<td>786 ± 471</td>
<td>Ca 2.9 ± 1</td>
<td>7.5</td>
<td>0.24 ± 0.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg 1.6 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Na 7 ± 4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>K 0.2 ± 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>swii</td>
<td>753 ± 222</td>
<td>Ca 3.1 ± 0.7</td>
<td>7.6</td>
<td>0.13 ± 0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg 2.1 ± 0.3</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td>Na 8 ± 1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>K 0.3 ± 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>swiii</td>
<td>919 ± 306</td>
<td>Ca 3.5 ± 1.2</td>
<td>7.4</td>
<td>0.11 ± 0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg 2.9 ± 0.9</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td>Na 14 ± 6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>K 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1N</td>
<td>857 ± 304</td>
<td>Ca 2.7 ± 0.4</td>
<td>7.5</td>
<td>0.43 ± 0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg 2.5 ± 0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Na 8 ± 1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>K 0.3 ± 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BP1</td>
<td>2563 ± 920</td>
<td></td>
<td>7.4</td>
<td>0.18 ± 0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BP2</td>
<td>3708 ± 2811</td>
<td></td>
<td>7.5</td>
<td>0.07 ± 0.03</td>
</tr>
</tbody>
</table>

### 2.2.4 Ecology

**Plant species and physiognomies**

The distributions of plant communities within and among the wetlands are diverse and extremely dynamic, resulting in heterogeneous mosaics within these tiny wetland basins and very different assemblages between wetlands even as little as less than 20 metres apart. Numbers of individuals and the distributions of the herb, rush and sedge communities within each wetland basin change annually, determined by below or above average rainfall in the previous year, and maps need to be carefully compared to extant plant distribution in the field in order to detect whether the change which has occurred is within or outside acceptable limits. Some species numbers are constant, e.g. *Melaleuca rhaphiophylla* and *M. cuticularis*, however, while stem numbers may have remained constant over a decade, the percent cover of these species also has changed annually.

Eleven plant associations have been identified (V & C Semeniuk 2007) and these are listed below under the dominants of each assemblage:
- Low forest - *Melaleuca rhaphiophylla*, understorey *Ficinia nodosa* or no understorey.
- Sedgeland - *Baumea juncea*, overstorey *Melaleuca teretifolia*, understorey *Centella asiatica*, *Sporobolus virginicus*.
- Heath - *M. teretifolia*, understorey *C. asiatica*.
- Heath - *Melaleuca viminalis*, understorey *C. asiatica*, *Lepidosperma gracile*.
- Heath - *Xanthorrhoea preissii*, understorey *B. juncea*, *S. virginicus*.
- Sedgeland – *B. juncea*, understorey *C. asiatica*, *S. virginicus*.
- Sedgeland - *Schoenoplectus validus*.
- Sedgeland - *Lepidosperma gladiatum*.
- Rushland - *Juncus kraussii*, understorey *C. asiatica*.
- Herbland – *C. asiatica*.
- Sedgeland/herbland - *B. juncea/C. asiatica*.

Within the wetland basins, these assemblages form mosaics which are constantly expanding and contracting in size, however, the composition of each assemblage remains fairly consistent. Identification of pollen throughout the sedimentary pile confirms that these species have been present in the wetlands since their inception several thousand years ago (V & C Semeniuk 2007). From west to east on the cuspatte foreland, coinciding with youngest to oldest wetlands, sedgeland gives way to heath and then low forest.

**TEC**

The Becher Point wetlands contain 20.3 ha of a Threatened Ecological Community listed as endangered under the *EPBC Act 1999*, namely, Sedgelands in Holocene Dune Swales of the Southern Swan Coastal Plain. This represents 12.4% of the global distribution (164 ha) of this TEC. This TEC is divided into two subtypes 19a and 19b (further investigation may reveal these to warrant separation into two separate communities). The Becher Point wetlands comprise 18.4 ha of type 19a (17.5 ha within the Ramsar boundary) and 1.9 ha of type 19b (all within the Ramsar boundary).

Typical species include *Baumea juncea, Ficinia nodosa, Lepidosperma gladiatum, Juncus kraussii* and *Gahnia trifida* (English et al. 2002). The current distribution is limited, the total area is very small and often isolated, and the community is known to be extremely vulnerable to threatening processes. Wetlands account for less than 10% of the Ramsar site and not all of these wetlands support this community. The Holocene sedgeland community is often confined to younger wetlands and damplands. *Baumea juncea* inhabits damplands while *Lepidosperma gladiatum, Juncus kraussii* and *Ficinia nodosa* colonise the younger wetlands. In older wetlands they form marginal associations. Wetlands 1N, swi, swii, 9-3, and 9-14 support this community but in most of wetland 9 and wetland 35, there are only one or two elements present and these occupy the margins.

**Fauna**

A number of notable fauna have been recorded at the site, including: quenda (*Isoodon obesulus fusciventer*), carpet python (*Morelia spilota imbricata*), Perth lined lerista (*Lerista lineata*) and black-striped snake (*Neelaps calanotus*) and at least four species of amphibians and 21 species of reptiles.
The following shore/waterbirds have been recorded on the beach section of the Becher Point Wetlands Ramsar site: Red-necked Stint (M) *Calidris ruficollis*, Ruddy Turnstone (M) *Arenaria interpres*, Sanderling (M) *Calidris alba*, Whimbrel (M) *Numenius phaeopus*, Red-capped Plovers *Charadrius ruficapillus*, Pied Oystercatchers *Haematopus Longirostris*, Pied cormorant *Phalacrocorax varius*, Little Black cormorant *Phalacrocorax sulcirostris* and Australian Pelicans *Pelecanus conspicillatus*, however, it is unlikely that this habitat area has more significance than casual roosting for the above species due to the lack of tidal flats and the high energy ocean conditions. *(M – migratory species, listed under EPBC Act)*.

These fauna were not identified as ‘critical ecosystem components’ within the draft ECD (V & C Semeniuk Research Group 2007) as; there was insufficient information to confirm whether their presence is pivotal in determining the ecological character for the Ramsar site, and they are not considered important for supporting the Ramsar criteria.

### 2.2.5 Social and cultural values

A history of traditional owner use of the Becher Point Wetlands Ramsar site has not been determined and the key social and cultural values of the site have been described within the ECD in terms of the site’s non-indigenous use. In the earlier part of the twentieth century the Ramsar site was used for grazing and was inhabited by a small group of fishermen who built makeshift huts along the northern shore of the cuspatc foreland. In the 1980’s, urban development began to replace the wetlands in the northern half of the Becher cuspatc foreland and this process has continued to the eastern and southern boundaries of the Ramsar site. The area is still used for recreational beach fishing and for driving of four-wheel drive vehicles.

### Scientific and Educational values

The key scientific and educational values of the Becher Point Wetlands Ramsar site have been described in terms of the wetland evolution and climate history. As such, the site comprises part of a vanguard in terms of importance to humans in that the wetlands straddle several categories of wetland values, namely ecological, socio-cultural and economic (de Groot et al. 2006).

The sequence of wetlands spans the last 5,000 years of the Holocene period, but the wetlands did not all originate or commence wetland functions at the same time and it is this staggered initiation which results in different natural history records throughout the suite. The Ramsar site is a paramount site for investigating the evolution of wetlands and wetland vegetation associations. The Ramsar site as a whole contains evidence of Holocene climate and coastal history, and has been a monitoring and major scientific site for coastal and marine research, landscape evolution, soil development, climate studies, vegetation and palynology, and wetland research (Steedman and Craig 1979, Steedman and Craig 1983, Collins 1983, Woods and Searle 1983, Woods 1984, Searle 1984, Searle and Semeniuk 1985, Searle et al. 1988, Semeniuk et al. 1988, Tauss 2002, Semeniuk et al. 2006a, Semeniuk et al. 2006b, Semeniuk 2007).

### 2.3 PAST, EXISTING AND FUTURE THREATS

#### Urban development

The major threatening activity, which may have already, or could impact on the ecological character of the Ramsar site, is urban development. Potentially, urban development can initiate impacts which
range from long to short term, from intense to superficial, from widespread to local, and from irreversible to ameliorated. These threats derive from outside the site boundaries but their effects can occur within the site. Urban pressures include the drawdown of groundwater from increased groundwater abstraction, leaching of nutrients and other pollutants into the groundwater from garden fertilisers and septic systems, loss of wetland buffers from clearing and encroachment of weeds, increased predation of fauna from pets and accumulation of litter, organic waste and dumped vehicles and appliances.

The rapid southern movement of the Metropolitan development front reached Rockingham in the early 1990s and resulted in considerable pressure being exerted on the remaining areas of conservation value (Coastwise Consultants 2003). In 2001, the population of the City of Rockingham was approximately 74,000, and growth was just under 3% per annum (Australian Bureau of Statistics 2006). At around that time, the then Ministry for Planning prepared a population projection for the City of Rockingham for 15 years into the future, to the year 2016. The projection of an increase was based on a 2.4% increase annually; however, in 2004, 2005, 2006, 2007, Rockingham grew respectively by 3.3%, 3.6%, 5.1% and 4.8%, igniting the demands for housing, utilities, transport and recreation.

At the time of listing in 2001, urbanisation was well established on the Becher cuspate foreland that included the residential areas north of Warnbro Rd and the light industrial area east of Port Kennedy Drive. The Kennedy Bay golf course, just east of the Ramsar site, holiday houses and car parks had been constructed in the northern central part of the beachridge plain, and the horse racing track was operating at Lark Hill. In the south, the settlements of Secret Harbour and Golden Bay abutted the boundary of the Ramsar site. The pattern of the linear chain wetlands had been disrupted, and many wetlands remained as isolated fragments. Many beachridges were truncated, flattened and cleared for residential development, roads and recreational or industrial estates.

**Changes to hydrological regimes**

Wetland water regimes have been under considerable pressure over recent years due to a combination of an increasingly dry climate, groundwater abstraction, and the influence of drainage (Water and Rivers Commission 2001). Other factors contributing to pressures on the groundwater include changes in vegetation cover and the increasing presence of impervious surfaces associated with urbanisation. As urban development increases in the catchment of the reserves, so do the threats to the wetlands. Such changes may see the wetlands change from being groundwater dominated to surface water dominated, as surface runoff from urban areas increases.

Mean annual rainfall from 1991-2001 was 798 mm; mean annual rainfall from 2001-2008 fell to 694 mm. The lowest annual total occurred in 2006 (514 mm). In addition, 13-29% of rainfall occurred outside the winter period, facilitating short term storage in the vadose zone and rapid evapotranspiration. There is likely to have been very little lateral flow of water due to the low east west gradient of the surface of the water table. The changes in wetland water levels and the local changes to wetland flows from decreased rainfall, and consequent changes to the regional water table, flow paths and gradients, are within the bounds of normal climatic variation.

Wetland minima have decreased slightly, the wetlands nearest the coast by 5-7 cm and those further inland by 10-12 cm. Wetland maxima have decreased 20 cm across the board. The length of time wetlands experience low water levels (3-4 months) has increased and the period of inundation and waterlogging (≤ 1 month) decreased (Table D4). Periods of recharge and discharge have stayed the same, indicating that the same wetland processes are still operating under these lower rainfall conditions.
In **Table D4** below, the number of years a wetland has experienced inundation or waterlogging in the 10 year period 1991-2001 is listed as a fraction of 10 under ‘frequency’; for 2001-2008, it is listed as a fraction of 7. In all wetlands the frequency of inundation and waterlogging has declined. This decline is due to a decrease in annual rainfall. The greatest impact is observed in the through-flow basins at the coast, 1N, swi, swii, swiii, which show a downturn in waterlogging also. Currently, based on water regime alone, wetland 1N is not functioning as a wetland.

**Table D4 : Changes in wetland hydroperiods pre and post 2001 (Draft ECD V & C Semeniuk Research Group 2014 and Semeniuk 2007).**

<table>
<thead>
<tr>
<th>Wetland site</th>
<th>Frequency of waterlogging</th>
<th>Frequency of inundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1North</td>
<td>2:10 (20%)</td>
<td>0:7 (0%)</td>
</tr>
<tr>
<td>swi</td>
<td>10:10 (100%)</td>
<td>2:7 (29%)</td>
</tr>
<tr>
<td>swii</td>
<td>9:10 (90%)</td>
<td>1:7 (14%)</td>
</tr>
<tr>
<td>swiii</td>
<td>10:10 (100%)</td>
<td>7:7 (100%)</td>
</tr>
<tr>
<td>9-6</td>
<td>10:10 (100%)</td>
<td>7:7 (100%)</td>
</tr>
<tr>
<td>9-14</td>
<td>10:10 (100%)</td>
<td>7:7 (100%)</td>
</tr>
<tr>
<td>35-4</td>
<td>9:10 (90%)</td>
<td>6:7 (86%)</td>
</tr>
</tbody>
</table>

Plant communities have contracted in some wetlands as a result of less frequent waterlogging and inundation, forming isolated clumps within a formerly broad area within the central basin, e.g. *Centella asiatica* in wetlands 35, swii, swiii and 9. Marginal zones of *Baumea juncea* and *Lepidosperma gladiatum* have also contracted and in some wetlands (35, swiii) disappeared altogether. The sedge *Schoenoplectus validus* has disappeared from wetland swiii probably also due to the lowering of water levels in response to less frequent precipitation.

**Fire**

Unplanned fire is a significant threat to the natural values of the Ramsar site. Several changes have been noted in the plant communities in the Ramsar site since 2001: death of some species due to fires, invasion of plant communities by weeds and loss of some plant species (V & C Semeniuk Research Group 2007).

Fires at the Ramsar site since 2001 have not been part of Parks and Wildlife fire management strategy and were not controlled burns. They occurred in 2001, 2004 and 2008 (Department of Parks and Wildlife Swan Region pers. comm.). They were deliberately lit and were described as very hot fires. The aftermath is a loss of trees and shrubs of *Melaleuca* species, in particular *M. rhaphiophylla*, which does not regenerate after fire if completely burned. If partially burned, the tree will often survive but remain stunted with minimum regrowth. Also, in the aftermath of fires, there is extensive and intensive colonisation by weeds. In the wetlands themselves, the species of weeds which are most virulent are *Lippia* in inundated habitats and grasses in waterlogged habitats. In some of these habitats replacement has been 100%. These weeds have eliminated *Centella asiatica* from the centres of many wetlands. Where *C. asiatica* is still present, it has been restricted to isolated patches of one or two plants or displaced to a narrow zone at the base of the beachridges.
Problem introduced species

Changes to plant communities due to fires and weeds have become an increasingly important problem. As no current plot data are available for the wetlands, the exact magnitude of the change is not quantifiable. It is difficult to separate natural changes due to plant adaptations to rainfall variability, i.e. expansion and contraction of communities and redistribution within wetland basins from loss due to rabbit burrowing, fire and competition by weeds. Of the wetland species pool for the Ramsar site, the only known disappearance is that of the sedge *Schoenoplectus validus*, which is due to the present natural cycle of reduced inundation frequency (Semeniuk 2007).

Since 2001, the incidence of rabbit burrowing has decreased, due in part to a programme of rabbit eradication by Parks and Wildlife, and are now confined mostly to wetland 35.

Recreation

Although the Ramsar site is primarily reserved for nature conservation purposes, passive recreation that does not impact on natural values or ecosystems of the reserve is permitted. The greatest threats to the values of the lakes from visitor access are from uncontrolled and unauthorised access by four-wheel drive vehicles. These activities may cause trampling and grazing of plants, spreading weeds and disease, disturbance of native fauna, and soil compaction and erosion. The Ramsar site is largely fenced, but the gate is constantly broken by members of the community to allow vehicle access. The site is accessible via entry along the beach. Vehicle damage and associated vandalism in wetland swi3ii are causing significant impacts on the site’s values.

Future threats

Future threats to the ecological values of Becher Point Wetlands Ramsar site include:

- Declines in Superficial Aquifer levels, particularly if the climate continues to dry but also if local abstraction of groundwater from the Superficial Aquifer increased above allocation limits. This could result in declines in wetland vegetation health and also impact on inundation periods and sediment formation processes and lead to loss of wetland morphology and function.

Other future risks include:

- water quality issues associated with new urban development and altered drainage;
- fire;
- weed invasion;
- predation of wildlife by pets; and
- rubbish dumping.
2.4 EXISTING MANAGEMENT ARRANGEMENTS

2.4.1 Legislative protection and/or management requirements

Australia is a participant of, and signatory to, a number of important international conservation agreements that influence the management of the Becher Point Wetlands Ramsar site, by promoting consistent standards of management for wetlands. These are:

- Convention on Wetlands of International Importance (Ramsar Convention).
- CAMBA, JAMBA and ROKAMBA bilateral agreements relating to conservation of migratory birds.
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention).

At a national level the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) is the primary piece of legislation relating to Ramsar sites. This Act establishes a legislative framework for environmental protection and biodiversity conservation, including assessment and approvals of proposed actions, species and Ramsar site listing, recovery plans and management plans. The ecological character of Ramsar wetlands is one of the nine matters of national environmental significance under this Act. Any action that has had, will have, or is likely to have a significant impact on a matter of national environmental significance is required to undergo an environmental assessment and approvals process. The EPBC Act also establishes standards for managing Ramsar wetlands through the Australian Ramsar Management Principles, which are stated as Regulations under the Act and which describe the principles and guidelines for the management of Ramsar wetlands (Environment Australia 2001). The Native Title Act 1993 and Wetlands Policy of the Commonwealth Government of Australia 1997 are also relevant.

The Becher Point wetlands contain 20.3 ha of a Threatened Ecological Community listed as endangered on the EPBC Act 1999, namely, Sedgelands in Holocene Dune Swales of the Southern Swan Coastal Plain. This represents 12.4% of the global distribution (164 ha) of this TEC. This TEC is divided into two subtypes 19a and 19b. The site has 18.4 ha of type 19a (17.5 ha within the Ramsar boundary) and 1.9 ha of type 19b (all within the Ramsar boundary).

There is a suite of Western Australian legislation that is relevant to Ramsar sites, both in terms of protecting and managing the sites, but also for regulating potential impacts. The relevant legislation is listed below.

- Environmental Protection Act 1986.
- Aboriginal Heritage Act 1972.
- Rights in Water and Irrigation Act 1914.
- Metropolitan Water Supply Sewerage and Drainage Act 1909.
- Planning and Development Act 2005.
- Bushfires Act 1954.
There are also a number of state, regional and local policies and planning schemes that are relevant to Ramsar sites. These include:

- **Wetlands Conservation Policy for Western Australia 1997.** This policy outlines the WA Government’s commitment to identifying, maintaining and managing the State’s wetland resources, including the full range of wetland values, for the long term. It provides broad objectives for wetlands, waterways, estuaries and shallow marine areas, and provides an implementation strategy specifically for the management of wetlands in Western Australia. It also identifies the agencies involved and their responsibilities.

- **State Planning Policy 2.8 Bushland Policy for the Perth Metropolitan Region.** This policy provides a framework to ensure bushland protection and management issues in the Perth Metropolitan Region are appropriately addressed in the planning process, while also seeking to integrate and balance wider environmental, social and economic considerations. This will secure long term protection of biodiversity and associated environmental values of significant bushland areas. This policy provides the policy and implementation framework for Bush Forever areas shown in the Metropolitan Region Scheme. The Becher Point Wetlands Ramsar site forms part of Bush Forever site 377 ‘Port Kennedy’.

- Metropolitan Region Scheme. The Becher Point Wetlands Ramsar site is within this scheme and is reserved as Parks and Recreation.

- **Local Government Planning Schemes.** Local government authorities are responsible for planning for local communities by ensuring appropriate planning controls exist for land use and development. Becher Point Wetlands Ramsar site is located in the City of Rockingham.

### 2.4.2 Current management of the Ramsar site

**Land management**

The Department of Parks and Wildlife manages the Becher Point Wetlands Ramsar site, which is an A Class Nature Reserve vested with the Conservation Commission of Western Australia under the CALM Act. The Ramsar site is located within the Port Kennedy Scientific Park and forms part of the Rockingham Lakes Regional Park.

The Ramsar site also includes a strip of unallocated Crown land along the beach, which the Department of Lands has direct management responsibility for, with the City of Rockingham and the Department of Parks and Wildlife undertaking regular patrols and enforcement activities within this area.

Management of the Ramsar site, which is located within the Port Kennedy Scientific Park, is guided by the Rockingham Lakes Regional Park Management Plan 2010 (Department of Environment and Conservation on behalf of the Conservation Commission of Western Australia 2010) and the 2011-2016 Interim Recovery Plan (Department of Environment and Conservation 2011) for the EPBC Act listed Threatened Ecological Community Sedgelands in Holocene Dune Swales. The Rockingham Lakes Regional Park Management Plan provides an overview to guide management of the natural environment, cultural heritage, recreation and resource use in the Lake Richmond, Port Kennedy Scientific Park, and the Lake Cooloongup and Walyungup areas, which all contain the sedgeland Threatened Ecological Community.
The Port Kennedy Scientific Park Conservation and Recreation Enhancement Plan (RPS Environment and Planning 2010) also provides detail about weed control and rehabilitation for the Rockingham Lakes Regional Park.

Parks and Wildlife develops and implements annual works programs in accordance with the Rockingham Lakes Regional Park Management Plan, which include:

- weed control;
- ongoing management of unauthorised vehicles, through installation and maintenance of barriers and patrols in association with the City of Rockingham;
- survey for unexploded ordnance on strategic access tracks and installation of visitor risk management signage about unexploded ordnance;
- preparation or update of subsidiary plans identified in the management plan e.g. fire response plan;
- regular and ongoing operational monitoring fencing patrols and maintenance patrols including review of signs, firebreaks and rubbish dumping.

**Groundwater management**

The two main tools used by the Department of Water to manage groundwater use are allocation limits and groundwater licences – which are the regulatory instrument under the Rights in Water and Irrigation Act. Both are informed by groundwater allocation plans.

The Becher Point Wetlands Ramsar site is located within the Churcher West subarea of the Rockingham Groundwater Area. It is downgradient from the Warnbro subarea. The Rockingham-Stakehill groundwater management plan, released in 2008, sets allocation limits for the area. The department revised allocation limits for the plan in 2007 based on PRAMS modelling and considered water requirements for recognised wetlands within the area including the Becher Point wetlands (Department of Water 2008). Current licensed entitlements in the Churcher West and Warnbro subareas are within the allocation limits.

All licence applications are individually assessed to consider potential impacts to groundwater dependent ecosystems (Department of Water, 2009) and impacts are managed through licence conditions imposed on licensees to monitor groundwater levels and water quality where possible impacts are determined.

Western Australia Golf and Beach Resorts Pty Ltd (WAGBR) undertake monitoring within the Ramsar site under the conditions of a licence to take Groundwater and Ministerial Statement No. 105 issued under the Environmental Protection Act 1986. Ministerial statement 105 requires the preparation and implementation of a groundwater management and monitoring program for the site and the licence to take Groundwater requires the production of and compliance with an Operating Strategy produced in accordance with Department of Water Operational Policy 5.08.

The objectives of the monitoring program, defined by WAGBR to inform their monitoring program, are to plan and manage the quantity and sources of groundwater abstraction for the development and to plan and manage horticultural areas in the development to ensure adequate protection of the environment, in particular to prevent water table drawdown or any deterioration in groundwater quality which could detrimentally affect wetlands and other vegetation in the conservation areas, and to
prevent any deterioration in groundwater quality which could detrimentally affect coastal water quality in the adjacent Marine Park.

As part of the monitoring program, water quality and water levels are monitored at 11 monitoring bores located within the Ramsar site. Water level, salinity and nutrient level criteria were set for two of the monitoring bores. Monitoring was undertaken since 1993. Trigger levels were set to maintain water levels within LACs if triggers are reached, appropriate action will be taken to identify if the resource can continue to supply the licenced take of water at lower water levels. Where trigger levels are reached an investigation may be carried out to determine the cause of the trigger, as part of the annual evaluation of the Rockingham – Stakehill groundwater management plan, 2008. This information will be shared with DPaW and appropriate action will be taken, depending on the severity of the triggered event, to:

- Ground-truth the measurement data to identify any impacts on the Ramsar site (species abundance, tree deaths, frog populations, etc – whatever fits here)
- Increase monitoring frequency to ascertain the exact cause of the triggered event (specify what gets increased – water quality, water levels, etc)
- Reduce the licensed entitlements by a certain amount
- Reduce the allocation limit for this location
- Cease abstraction in this location.

State Planning Policy 2.9: Water Resources requires water resources management to be integrated with land use planning decisions to achieve more sustainable development and protection of water resources. Better Urban Water Management (WAPC, 2008) is the policy mechanism by which proposals, at all levels of the state planning system, are considered with regard to water quantity and quality. The Department of Water provides advice to the Western Australian Planning Commission and the Local Government Authority to inform decision making through the state planning process.

Management is guided by the following plans -

- Rockingham-Stakehill management plan considers impacts to Becher wetlands (Department of Water 2008). Impacts are managed through licence conditions imposed on licensees to monitor groundwater levels and water quality where possible impacts are determined
- Rockingham Lakes Regional Park Management Plan (Department of Environment and Conservation on behalf of the Conservation Commission of Western Australia 2010)
3 Current condition

3.1 DATA AVAILABLE TO INFORM CONDITION ASSESSMENT

For the purposes of this Condition Statement, current condition is interpreted to be indicated by data collected after 2007 which was the end date of data collection for the drafting of the Ecological Character Description of the Becher Point Wetlands Ramsar site (V & C Semeniuk 2007).

3.1.1 Geomorphology and geology

**Geomorphology**

Current data for key components of the geomorphology that were identified by the Semeniuks (2007) as determining the ecological character of the Becher Point Wetlands Ramsar site has not been collected. However, general site information is available from ad-hoc, on site observations and aerial imagery which can be used to provide information on loss of wetland occurrence.

3.1.2 Hydrology

**Groundwater**

Western Australia Golf and Beach Resorts Pty Ltd (WAGBR) have undertaken monitoring within the Becher Point wetlands site since July 1996 under the conditions of a licence to take Groundwater and Ministerial Statement No. 105 issued under the Environmental Protection Act 1986.

The environmental criteria of the licence conditions included groundwater levels “Interim water level criteria” developed in 1994 – minimum and investigation levels – for two monitoring bores MB6 and B8. An investigation level of 0.5 m AHD and Minimum ground water level of 0.4m AHD was established for shallow bore MB6 (Figure D1) and an investigation level of 1.4 m AHD and minimum ground water level of 1.3 m for shallow bore MB8. Groundwater level graphs (mAHD), but not raw data, have been provided by Coterra Environment for ten shallow bores within the Becher Point wetlands for the 16 year period from July 1996 through July 2012.

Monthly groundwater levels (mAHD) have been provided by Coterra Environment with a majority of data collected by McMahon for the 12 month period April 2012-March 2013 as a condition of the Kennedy Bay Development that included a golf course. Data analysed in Coterra Environment Groundwater Monitoring Report 2012-2013 Kennedy Bay, April 2013 included analysis and comparison with monitoring data back to 1996. The monitoring was designed to determine if the development and water abstraction licence caused an impact to the local groundwater and hydrology of the local environment, particularly the Becher Suite of ephemeral wetlands and associated vegetation community.

The monitoring design is comprehensive for determining groundwater levels during the 2012-13 period and will allow a general analysis of trends in groundwater depth with the hydrographs supplied by Coterra Environment for the period 1996-2012. However, the data has limited value for comparison with data collected by Semeniuk (2007) for the period 1991-2007, as the Coterra shallow bores are between 20 and 200 metres from the Semeniuk monitoring points and while some of the bores may be in the same wetland, the high degree of heterogeneity of the hydrogeological parameters that
influence groundwater depths within the wetlands (Section 2.2.2), prevents conclusive analysis and caution is taken in interpretation.

3.1.3 Hydrochemistry

Western Australia Golf and Beach Resorts Pty Ltd (WAGBR) have undertaken groundwater quality monitoring within the Ramsar site since July 1996 under the conditions of a licence to take Groundwater and Ministerial Statement No. 105 issued under the Environmental Protection Act 1986.

Monthly parameters were measured from 11 shallow bores (Figure D1) within the Ramsar site of appearance, colour, temperature, pH, EC, redox, DO for the two year period April 2011- March 2013.

Quarterly water chemistry parameters were measured from 11 shallow bores (Figure D1) within the Ramsar site of TP, TN, NO$_3$-N, Ca, Na, Cl, SO$_4$, TDS for the three year period February 2010-March 2013.

The environmental criteria of the licence conditions included nutrient groundwater quality criteria developed in 1994 for maximum and investigation levels (mg/L) for total nitrogen (TN) and total phosphorus (TP) for five monitoring bores MB4, MB6, MB7, MB12 and MB14. An investigation level of 3.5 mg/L for TN and 0.12 mg/L for TP were set and a maximum level of 5.0 mg/L for TP and 0.165 mg/L for TP.

Coterra Environment in their Groundwater Monitoring Report 2012-2013 Kennedy Bay, April 2013 analysed the monitored hydrochemical data for the 12 month period April 2012-March 2013 as a condition of the Kennedy Bay Development, which included a golf course. The monitoring was designed to determine if the development and water abstraction licence caused an impact to the local groundwater and hydrology of the local environment, particularly the Becher Suite of ephemeral wetlands and associated vegetation community.

The monitoring design allows analysis of the range in hydrochemical parameters of the groundwater over a 12 month period. However, as the Semeniiks have stated in their 2007 report, the natural variability of the hydrochemical parameters of groundwater should be low and determined by rainfall events that flush nutrients from the organic layer into the water column.

3.1.4 Ecology

Plant species and physiognomies

Bennett Environmental Consulting resurveyed eight previously established vegetation monitoring transects within two wetlands on the eastern side of the Ramsar site in May 2013 (Bennett Environmental Consulting August 2013). Results were compared to previous annual surveys conducted between 2006 and 2012. Monitoring techniques are considered rigorous and result in an accurate trend in vegetation health based on severity of weed invasion, both species and cover for wetland monitoring points established by the Semeniiks (2007) 35-4 and 9-14 and TECs labelled 319, 324 and 330 (FID).

Weed cover and number of weed species is an important threatening process of the natural vegetation existing at the Ramsar site and is used as an indicator of native vegetation condition. Information on weed invasion has been collected by the development company for the adjacent Port Kennedy site as part of development conditions. Weed mapping across the Ramsar site has been
conducted by the Natural Area Management & Services consultancy on behalf of the RPS Group for the land owner, Mirvac WA in preparation of an environmental weed control and revegetation plan for the Port Kennedy Scientific Park, northern portion (RPS 2010).

**TEC**

Results from the Bennett Environmental Consulting (August 2013) report include analysis from six transects that are within three occurrences of the Sedgelands in Holocene dune swales of the southern Swan Coastal Plain TEC. This represents a rigorous sample of TEC occurrences on the eastern side of the Ramsar site, which are those occurrences closest to the groundwater production bores used by the Kennedy Bay golf course and those most at risk of being impacted by alteration of hydrological regimes and resultant vegetation loss and degradation.

Information from the mapping of weed species presented in the Weed Control and Rehabilitation Plan (RPS 2010) has also been used to assess the condition of the TEC occurrences at the Ramsar site.

**Fauna**

Fauna were not identified as ‘critical ecosystem components’ within the draft ECD (V & C Semeniuk 2007) as there was insufficient information to confirm whether their presence is pivotal in determining the ecological character for the Ramsar site, and they are not considered important for supporting the Ramsar criteria. Formal monitoring of fauna is not conducted at the Becher Point Wetlands Ramsar site, although opportunistic records of fauna are made.

### 3.2 CURRENT CONDITION

#### 3.2.1 Geomorphology and geology

**Size, shape, number and distribution of wetland basins**

The wetland nearest the point, identified as TEC occurrence 1083 and Semeniuk monitoring point BP 01 was breached during a storm surge in the winter of 2010, thus altering its geomorphological characteristics. However, this was noted as an event that had occurred on previous occasions (Semeniuk 2007) and therefore unlikely to be reflective of a growing threat at this stage from sea level rise or increased storm severity. As there are five chains and approximately 60 wetland basins and 16 other occurrences of the TEC within the Ramsar site, the significant degradation of this wetland/TEC was not interpreted as a significant trend in condition of the geomorphology across the Ramsar site. However, the event is noted and because the Semeniiks (2007) have described this wetland as one of only two, which belong to the Cooloongup Suite, having been formed most recently (<100 years), the significance is elevated on the representative value of this morphological type.

**Sediment components**

Data not collected.
3.2.2 Hydrology

Eleven shallow bores across the northern half of the Ramsar site have been monitored for groundwater level and hydrochemical parameters by consultants for the proponents of the Port Kennedy development since July 1996 (Figure D1). This has permitted analysis of trends in groundwater levels across that portion of the site that has potential to be impacted by the water abstraction licences granted for the Port Kennedy development including the golf course, just north of the Ramsar site.

![Graph of groundwater levels](image)

**Figure** D4 and indicate that the sharpest decline in groundwater took place in 2009/10 and 2010/11 that corresponded to declining rainfall years.

![Graph of groundwater levels](image)

**Figure** D4) and may be an indication that the current licensed groundwater abstraction is impacting on the shallow aquifer expressed within this wetland. The link between rainfall and groundwater levels in this shallow aquifer is strong and groundwater levels do not fully recover to average levels following dry rainfall years and this has led to cumulative declines in groundwater levels. Given that the declines in groundwater levels in bores in the central and south-western has not been as apparent, it is possible that groundwater abstraction for the golf course is exacerbating the impact from declining rainfall. Importantly, the levels are still within LACs and impacts on vegetation health are not yet observed.

![Graph of groundwater levels](image)

**Figure** D3) is within the range recorded by Semeniuk (2007) with the exception of the 2009/10 period. The range for all three shallow bores on the eastern side (MB4, MB6 and MB8) are generally also within the Limit of Acceptable Change (LAC) established by Semeniuk (2007) of 1.26 m for the groundwater levels below the wetlands of 35-4 (Table D8).
Figure D3: Groundwater level measurements in shallow bores MB4, MB6 and MB8 on the eastern side of the Becher Point Wetlands Ramsar site for period July 1996 - March 2015.

Figure D4: Maximum and minimum groundwater levels tracked against rainfall for shallow bores MB6 and MB8 collected over the period July 1996-March 2013 (Coterra 2013).
Shallow groundwater bores MB7, MB9 and MB10 (Figure D5) are located within the central suite of wetlands in the Ramsar site (Figure D1). Water levels in these bores have not experienced the significant declines in groundwater recorded for the wetlands on the northern perimeter of the Ramsar site. However all three bores indicate small declines in minimum and maximum levels in between peaks reached in the wet years of 1999 and 2009 and any noted declines are likely due to reduced rainfall. Groundwater levels in these bores in dry to medium rainfall years remained within the seasonal fluctuations reported by Semeniuk (2007) and generally within the groundwater depth range identified as the LAC of 1.18 m for this wetland suite 9-6 (Semeniuk 2007).

Figure D5 : Groundwater level measurements in shallow bores MB7, MB9 and MB10 in the centre of the Becher Point Wetlands Ramsar site for period July 1996 - March 2015 (Coterra).
The peaks in groundwater levels recorded in shallow bore MB7 in 2009 and 2012 (2.2 m) exceeded the range established as the LAC for this suite (Figure D5). The levels in the other two bores within the same suite (Figure D5), reflected similar patterns, but as they were not repeated for the 2013/14 period (Figure D6), they have not been interpreted as a valid indicator of groundwater trends, but rather outliers, or conditions that may occur in very wet years, not reflecting a potential threat to the wetland ecology.

Figure D6: Groundwater levels in shallow bores MB7, MB9 and MB10 collected over the period April 2013-March 2014 (Coterra 2014-unpublished).

The significant drop in the minimum groundwater level in 2011 is likely to be an outlier, rather than an indication of trend, as it was not repeated in following years (Figure D8). Generally the water levels are steady over the 18 year period 1996-2014 and do not reflect the significant declines in groundwater recorded for the wetlands on the northern perimeter of the Ramsar site. Seasonal fluctuations for the south-west suite are within the range reported by Semeniuk (2007) for wetland suite swi (Figure D2) and generally within the groundwater depth range identified as the LAC for wetlands of this wetland suite 9-6 (Semeniuk 2007) of 0.92 m.
Figure D7: Groundwater level in shallow bore MB11 in the south-west side of the Becher Point Wetlands Ramsar site for the period July 1996-July 2012.

Figure D8: Groundwater levels in shallow bores MB11 and MB12 collected over the period April 2013-March 2014 on the west side of Becher Point (Coterra 2014-unpublished).

Shallow groundwater bore MB12 is located within the western tip suite of wetlands, adjacent to TEC occurrence 1083 and Semeniuk wetland BP2 in the Ramsar site (Figure D1). Water levels in this bore (Figure D9) show a similar pattern to all bores within the central suite (Figure D5) with significant above average maximum levels in 1999 and 2008/09 and a period of declining groundwater levels in between these years. The significant drop in the minimum groundwater levels in
2003 and again in 2005 (Figure D9) are likely to be outliers, rather than an indication of trend as it was not repeated in following years, including 2013/14 (Figure D8, Figure D9).

Generally the water levels are static over the 18 year period 1996-2014 in Bore MB12 and do not reflect the significant declines in groundwater recorded for the wetlands on the northern perimeter of the Ramsar site. Seasonal fluctuations for the south-west suite are within the range reported by Semeniuk (2007) for wetland suite swi (Figure D2) and generally within the groundwater depth range identified as the LAC for this wetland suite BP2 (Semeniuk 2007) of 0.93 m.

**Hydrochemistry**

*Wetland groundwater and soil water salinities*

The Becher Suite wetlands are classed as freshwater (Semeniuk 2007); the salt content in the groundwater from sampling up to 2007 for the draft ECD was predominantly below 1,970 us/cm (1,000 ppm) and varied seasonally between 516 us/cm (250 ppm) and 1,970 us/cm (1,000 ppm). Although there was a slight increasing trend in the salinity of two of the bores on the north-east side of
the Ramsar site between 2011-2013 (Figure D10), the range for all bores with the exception of the last sample of March 2013 for shallow bore MB14 were within the range of values identified within the draft ECD (Semeniuk 2007). The March 2013 sample in shallow bore MB14 was 2,380 us/cm (1,221 ppm) and in the brackish range, but just below the maximum criteria established within the licence conditions placed on the Kennedy Bay golf course of 2,408 us/cm (1,221 ppm), and just within the range of salinity identified for the LAC for the wetlands monitored by the Semeniiks that are closest to this bore (Table D8).

![Figure D10](image)

*Figure D10: Groundwater conductivity in shallow bores MB4, MB6, MB8 and MB14 on the north-east side of the Becher Point Wetlands Ramsar site for period April 2011-February 2013 (Coterra 2014-unpublished).*

The conductivity of the central wetlands of the Becher Suite remains within freshwater limits, varying between 490 us/cm and 1,500 us/cm (Error! Reference source not found.). The range for the central bores were within the range of values identified as the LAC (Table D8) for wetlands in the central suite of 520 – 4,400 ppm (815-6,880 us/cm) in the draft ECD (Semeniuk 2007).

The groundwater sampled from the shallow bore MB11 is representative of the groundwater within the wetlands on the west (coastal) side of Becher Point in wetlands labelled by Semeniuk 2007 as swi and swii (Table D1). Groundwater conductivity remained below the upper limit identified in the ECD of 1,400 ppm (2,190 us/cm see Table D8) and varied very little over the sampling period April 2011 through February 2013 (Figure D12).
The groundwater conductivity measured in shallow bore MB12 demonstrated an upwards trend (Figure D12) from 1,500 us/cm up to a maximum of 5,000 us/cm, which is brackish, indicating contact with seawater. These levels of conductivity are still well within the limits established by the draft ECD (5,000-60,000 ppm–7,810-93,800 us/cm - Table D8).

Figure D12: Groundwater conductivity in shallow bores MB11 and MB12 collected over the period April 2011-February 2013 on the north-west side of Becher Point (Coterra 2014-unpublished).
Nutrient concentrations in the groundwater

Total Nitrogen

Limits for total nitrogen content in groundwater were not established within the draft ECD (Semeniuk 2007). However, a maximum level of 5 mg/L was set within licence conditions for bores down gradient of the Kennedy Bay golf course and residential area. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality establish a trigger level of 1.5 mg/L (ANZECC and ARMCANZ 2000). The nitrogen content in groundwater from shallow bores MB4, MB6 and MB14 were well below the maximum licence criteria and generally below the ANZECC trigger level for the monitoring period April 2011 through February 2013 (Figure D13). However, levels measured within shallow bore MB8 exceeded the licence criteria on two occasions during the monitoring period, in December 2011 (6.2 mg/L) and again in October 2012 (5.5 mg/L) and on both occasions were well above the ANZECC trigger level of 1.5 mg/L. The monitoring results indicate an upwards trend in total nitrogen concentration and the strong likelihood that nitrogen is leaking into the groundwater from fertiliser application from the Kennedy Bay golf course and surrounding urban development.

![Figure D13: Groundwater total nitrogen (mg/L) in shallow bores MB4, MB6, MB8 and MB14 on the north-east side of the Becher Point Wetlands Ramsar site for period February 2010-October 2012 (Coterra 2014-unpublished).](image)

The nitrogen content in groundwater from shallow bores MB9 and MB10 from the central wetlands were well above the maximum licence criteria established for the Kennedy Bay golf course in the first half of 2010. However, from this period through until the end of the monitoring period in October 2012, the levels were below the maximum criteria of 5 mg/L. Both bores were above the ANZECC trigger of 1.5 mg/L for the entire period of monitoring. The total nitrogen content in the groundwater monitored on the shore side (north-west) were below the maximum criteria established for the Kennedy Bay golf club but were consistently above the ANZECC trigger level of 1.5 mg/L in the extreme north-west point of Becher Point. These values are of some concern as they indicate a widespread contamination of nitrogen in the groundwater. However, further investigation is required before generalised conclusions can be made regarding the level of nitrogen contamination in these wetlands and the impact that it is having on their function.
Figure D14: Groundwater total nitrogen (mg/L) in shallow bores MB7, MB9 and MB10 in the central wetlands of the Becher Point Wetlands Ramsar site for period February 2010-October 2012 (Coterra 2014-unpublished).

Total Phosphorus

Limits for total phosphorus content in groundwater were not established within the draft ECD (Semeniuk 2007). However, a maximum level of 0.165 mg/L was set within licence conditions for bores down gradient of the Kennedy Bay golf course and residential area. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality establish a trigger level of 0.06 mg/L TP (ANZECC and ARMCANZ 2000). The total phosphorus content in groundwater from shallow bores MB4, MB6 and MB14 were generally well above the maximum licence criteria and above the ANZECC trigger level for the entire monitoring period February 2010 through October 2012 (Figure D15). Levels measured within shallow bore MB6 exceeded the licence criteria by five times in April 2011 with a level measured of 0.99 mg/L. The monitoring results indicate a strong likelihood that phosphorus is leaking into the groundwater from fertiliser application from the Kennedy Bay golf course and surrounding urban development.

The phosphorus content in groundwater from shallow bores MB7, MB9 and MB10 from the central wetlands were well above the maximum licence criteria (0.165 mg/L) established for the Kennedy Bay golf course peak periods towards the end of summer in 2010 and again in 2012 (Figure D16). All three bores were above the ANZECC trigger of 0.06 mg/L for a majority of the sampling period. Similarly, the concentrations of total phosphorus were generally above the maximum criteria level of 0.165 mg/L in shallow bore MB12 on the extreme north-west point of the Ramsar site and both shallow bores MB11 and MB12 were above the ANZECC trigger value of 0.06 mg/L during a majority of sampling occasions (Figure D17). These values are of some concern as they indicate a widespread contamination of phosphorus in the groundwater throughout most of the Ramsar site. However, these values need further investigation before generalised conclusions can be made regarding the level of phosphorus contamination in these wetlands and the risk to wetland function.
Figure D15: Groundwater total phosphorus (mg/L) in shallow bores MB4, MB6, MB8 and MB14 on the north-east side of the Becher Point Wetlands Ramsar site for period February 2010-October 2012 (Coterra 2014-unpublished).

Figure D16: Groundwater total phosphorus (mg/L) in shallow bores MB7, MB9 and MB10 in the central wetlands of the Becher Point Wetlands Ramsar site for period February 2010-October 2012 (Coterra 2014-unpublished).
Groundwater total phosphorus (mg/L) in shallow bores MB11 and MB12 collected over the period February 2010-October 2012 on the north-west side of Becher Point (Coterra 2014-unpublished).

**Groundwater pH**

Although there was a slight increasing trend in the pH of two of the bores on the north-east side of the Ramsar site between 2010-2012 (Figure D18), the range for all bores were only slightly outside the range of values identified for these wetlands of pH 7.0-8.3 within the draft ECD (Semeniuk 2007). All other bores demonstrated similar pH ranges and do not indicate any trends suggesting a threat to the wetland system function.

Figure D18: Groundwater total phosphorus (mg/L) in shallow bores MB4, MB6, MB8 and MB14 on the north-east side of the Becher Point Wetlands Ramsar site for period February 2010-October 2012 (Coterra 2013).
3.2.4 Ecology

*Plant species and physiognomies*

Vegetation composition, floristics and condition have been monitored annually between 2006 through 2013 from eight transects on the north-west side of the Ramsar site (Figure D1). Condition of the vegetation in this portion of the Ramsar site was described as ‘Very Good to Excellent’. Furthermore, the monitoring has concluded that during the survey years (2006-2013), there has been no evidence to suggest any significant trend in floristic composition (native species versus weed species) (Table D5 from Bennett Environment 2013).

<table>
<thead>
<tr>
<th>Flora</th>
<th>Survey Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
</tr>
<tr>
<td>Native</td>
<td>28(62%)</td>
</tr>
<tr>
<td>Weed</td>
<td>19(38%)</td>
</tr>
<tr>
<td>Total</td>
<td>47</td>
</tr>
</tbody>
</table>

The percentage cover graphs (Bennett Environment 2013) presented in Figure D19 (Transect 1, Wetland 35-4, TEC 286) and Figure D20 (Transect 4, wetland 9-14, TEC 290) are typical across all eight transects monitored between 2006 and 2013. The results indicate that there are no significant trends to suggest that weed species are becoming a greater threat to the wetland or TEC function. Fire appears to open up areas for recruitment of weed species and appropriate management of fire is the most effective action to ensure that weeds do not become a significant threat. Transect 1 samples across a stand of overstorey of paperbark, *Melaleuca rhaphiophylla* with a dominant understorey of sedge species, *Ficinia nodosa*, *Baumea juncea* and *Juncus kraussii* subsp. *australiensis*. Vegetation condition of this transect was described as ‘Very Good’ with a reduction in weed cover from a maximum recorded in 2008 following a fire of 28% to 2% in 2013. Transect 4 samples across sedgeland community with a vegetation condition of ‘Excellent’ (Bennett Environment 2013). Weed cover is stable and around 2% with good recruitment of native species.
Figure D19: Native and weed species cover from transect 1 identified as being within wetland 35-4 (Semeniuk 2007) and TEC 286 (Bennett Environment 2013).

Figure D20: Native and weed species cover from transect 4 identified as being within wetland 9-14 (Semeniuk 2007) and TEC 290 (Bennett Environment 2013).

TEC

There is no dedicated monitoring program for the TEC occurrences at the Becher Point Wetlands Ramsar site. However, the Bennett Environment 2013 report assessed the eight years of monitoring vegetation condition and weed cover data of the eight transects on the north-east side of the Ramsar site. The transects included three TEC occurrences (Figure D1) of type 19a and reports that the vegetation condition in these TECs was ‘Very Good’ to ‘Excellent’.

As noted in 3.2.1, the wetland nearest the point, identified as TEC occurrence 1083 (Type 19b) and Semeniuk monitoring point BP 01 was breached during a storm surge in the winter of 2010, thus altering its vegetation condition (approximately 60% of the vegetation was washed away or degraded...
from inundation with seawater). However, this was noted as an event that had occurred on previous occasions (Semeniuk 2007) and therefore unlikely to be reflective of a growing threat at this stage from sea level rise or increased storm severity. As there are five chains and approximately 60 wetland basins and 16 other occurrences of the TEC within the Ramsar site, the significant degradation of this wetland/TEC was not interpreted as a significant trend in condition of the geomorphology across the Ramsar site. However, the event is noted and because the Semeniuks (2007) have described this wetland as one of only two, which belong to the Cooloongup Suite, having been formed most recently (<100 years), the significance is elevated on the representative value of this morphological type.

**Fauna**

No data collected

### 3.2.5 Social and cultural values

The area is still used for recreational beach fishing and for driving of four-wheel drive vehicles.

**Scientific and Educational values**

Unlikely to have altered.
### 3.3 ASSESSMENT OF CURRENT CONDITION AGAINST RAMSAR VALUES

This section addresses the current condition of the site relative to the criteria it was listed against. The table below (replicated from Section 2.1 with an additional column) may be useful.

Table D6: Ramsar listing criteria and justification.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Justification</th>
<th>Assessment against current condition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near natural wetland type found within the appropriate biogeographic region.</strong></td>
<td>The Becher Point Wetlands Ramsar site comprises an example of shrub swamps and seasonal marshes formed in an extensive sequence of interdunal depressions that have arisen from seaward advancement of the coastline over recent millennia. This geomorphological sequence of Holocene wetlands is rare in the South-West Coast bioregion and is one of the youngest wetland systems on the Swan Coastal Plain. Examples of this type of geomorphological sequence in equally good condition and within a protected area are considered rare globally (Semeniuk 2007). In addition to the presence of a nationally endangered sedgeland community, the conservation values of the wetlands are primarily related to the geomorphic significance of the site and the respective location of the wetlands along the evolutionary time sequence. When conserved as a representative unit, the relative youth of the wetlands, and the range of wetlands of different ages in association with their geomorphic history, provide important opportunities for research on wetland evolution (V &amp; C Semeniuk Research Group 1991).</td>
<td>This criteria is still met as the Becher Point wetlands still exist as an example of shrub swamps and seasonal marshes formed in an extensive sequence of interdunal depressions in good condition. The geomorphic history of the site and the respective location of the wetlands along the evolutionary time sequence have been preserved within a nature conservation reserve and available to the public for research purposes and recreation.</td>
</tr>
<tr>
<td><strong>2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or Threatened Ecological</strong></td>
<td>The Becher Point Wetlands Ramsar site supports a nationally listed Threatened Ecological Community 'Sedgelands in Holocene dune swales of the southern Swan Coastal Plain'. The sedgeland</td>
<td>This criteria is still met as the nationally listed Threatened Ecological Community 'Sedgelands in Holocene dune swales of the southern Swan Coastal Plain' remains intact with at least 16...</td>
</tr>
<tr>
<td><strong>Communities.</strong></td>
<td>community is nationally listed as Endangered under the Australian Government Environment Protection and Biodiversity Conservation Act (1999). The sedgeland community has a restricted distribution and is almost entirely located within linear wetland depressions (swales) occurring between parallel sand ridges of the Rockingham-Becher Plain in south-west Western Australia. The best record of the sedgeland community occurs along a linear transect from the Ramsar site through to the hinterland, which spans the last 8,000 years of the Holocene Epoch (Department of Environment and Conservation 2011). The sedgeland community within the Ramsar site is particularly important for the outstanding demonstration of a continuous depositional history of sediment during the last 3,000 years.</td>
<td>occurrences of subtype 19a (17.5 ha within the Ramsar boundary) and two occurrences of subtype 19b, one of which has been part degraded by being breached with sea water, but still present.</td>
</tr>
</tbody>
</table>
4 Limits of acceptable change

4.1 INTRODUCTION

Limits of acceptable change were defined by Phillips (2006) as:

“...the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. This may include population measures, hectares covered by a particular wetland type, the range of certain water quality parameter etc. The inference is that if the particular measure or parameter moves outside the ‘Limits of Acceptable Change’ this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed. In most cases, change is considered in a negative context, leading to a reduction in the values for which a site was listed.”

Limits of acceptable change make it easier to determine when the ecological character is likely to change or when it has changed as a result of technological development, pollution or other human interference. This is particularly important for Australian wetlands given that they often have a large range in natural variability. These limits can help site managers determine appropriate activities, monitor the site, and take action to maintain ecological character.

Limits of acceptable change and the natural variability in the parameters for which limits are set are inextricably linked. Phillips (2006) suggested that Limits of Acceptable Change should be beyond the levels of natural variability. However, setting limits in consideration with natural variability is complicated. Wetlands are complex systems and there is both spatial and temporal variability associated with all components and processes (Hale and Butcher 2007). Defining trends that are not within a ‘natural’ range that can be detected with sufficient time to instigate management actions to prevent an irrevocable change in ecological character is therefore particularly difficult (Hale and Butcher 2007).

It is not sufficient to simply define the extreme measures of a given parameter and to set Limits of Acceptable Change beyond those limits. There are many examples where a parameter could change in ways that are detrimental to the ecological character of the site but do not result in a change in the maximum or minimum values. If the Limits of Acceptable Change are set to be outside the extremes of natural variability then this will only capture a change in maximum or minimum values. Situations that involve a shift in the baseline values, an increase in the number of peak events or a seasonal shift will not be captured (Hale and Butcher 2007).

The Ramsar definition of an unacceptable change in ecological character indicates that it is a human induced adverse alteration of wetland components, processes and benefits/services that is of concern.

Although it is desirable to give quantitative bounds to define limits of acceptable ecological change (sensu Phillips 2006), the reality is that quantitative data are often not available. However, the changes listed above can be recognised, and identified fairly readily using pre-existing thresholds (e.g. for eutrophic and hypertrophic systems) or expert knowledge.

The recognition of dynamic regimes (Mayer and Rietkerk 2004) which involve non-linear responses to disturbance is considered to be a more realistic construct than linear models for ecosystem management across a number of ecosystem types, including shallow lakes and wetlands. Growing pressures from drivers such as nutrient loading, invasive species and climate change may be pushing
wetland ecosystems towards thresholds that they may otherwise not have encountered (Millennium Ecosystem Assessment 2005b). The possibility that hysteresis might occur, where an adverse change in ecological character cannot be remedied by reversing only the factor that triggered the change, increases the need to be able to predict, and where possible, prevent regime shifts. Monitoring a wetland to detect when an identifier is shifting from its acceptable state towards the unacceptable can alert managers to the earlier stages of ecological regime shift when prevention or reversal of changes may be achieved.

Limits of acceptable change for the Becher Point Wetlands Ramsar site have been established for the key components and processes of ecological character identified in Section 2. The defined limit of acceptable change is the tolerance considered acceptable without indicating a change of ecological character is occurring (Phillips et al. 2006). Use of this concept requires good knowledge of natural variations, the boom and bust cycles that can occur naturally in these species or communities. Where this is lacking, the precautionary principle is applied.

### 4.1.1 Justification for the Limits of Acceptable Change

Some of the components and processes identified in the draft ECD for the Becher Point Wetlands Ramsar site do not have Limits of Acceptable Change identified. Generally this has been due to limited monitoring data being available to quantify limits of variability that would normally be expected for Holocene interdunal swale wetlands. Interim limits have been established for major components such as the occurrences of the Holocene interdunal swale wetlands and the associated vegetation communities listed nationally as Threatened Ecological Communities.

Some components have interim Limits of Acceptable Change identified in the draft ECD (V & C Semeniuk 2007) that have yet to be verified and are unlikely to be retained in the final version, due to the complexity of measurement in monitoring programs. Examples include stratigraphy and organic matter. The variability evident in some components and processes at the Ramsar site has surpassed the Limits of Acceptable Change specified in Table D7. The high total nitrogen and total phosphorus concentrations are greater than the ‘natural’ variability and are the likely consequence of anthropogenic impacts, such as the application of fertilisers on the Kennedy Bay golf course and surrounding urban precinct. Therefore, the Limits of Acceptable Change specified in Table D7 are not necessarily set around the variability recorded in the past. The limits specified are those, which if exceeded, are likely to result in a deleterious change in condition of the wetland. Justification for the specified limits includes the licence criteria that were established for the Kennedy Bay golf course and surrounding urban development (licence to take Groundwater and Ministerial Statement No. 105 issued under the Environmental Protection Act 1986).

For several components and processes, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) have been used to assist in setting the Limits of Acceptable Change. The objective of these guidelines is for the protection of aquatic ecosystems, that is, 'to maintain and enhance the ecological integrity of freshwater and marine ecosystems, including biological diversity, relative abundance and ecological processes'. Ecological integrity, as a measure of the ‘health’ or ‘condition’ of an ecosystem, is defined by Schofield and Davies (1996) as “the ability of the aquatic ecosystem to support and maintain key ecological processes and a community of organisms with a species composition, diversity and functional organisation as comparable as possible to that of natural habitats within a region”.
### 4.2 LIMITS OF ACCEPTABLE CHANGE

Limits of acceptable change for Becher Point Wetlands Ramsar site are provided in Table D7.

**Table D7: Limits of acceptable change for the Becher Point Wetlands Ramsar site**

<table>
<thead>
<tr>
<th>Component</th>
<th>Baseline/supporting evidence</th>
<th>Limit of acceptable change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratigraphy</td>
<td>In-situ cores and detailed logs from hand augering forms the baseline for this limit</td>
<td>No change is acceptable</td>
</tr>
<tr>
<td>Organic matter in sediments</td>
<td>Data obtained from carbon analyses of samples of the mud faction every 10 cm down profile from the surface to a maximum depth of 70 cm</td>
<td>15-20% variability occurred naturally, however, too much organic matter will change the pH, the orthophosphate content of the soils and the water holding capacity – therefore change is accepted only within the range of natural variability</td>
</tr>
<tr>
<td>Total Phosphorous in sediments</td>
<td>Data obtained from selected sampling of four sites. Further sampling and analyses could refine this limit</td>
<td>In the surface soils the limit of acceptable change would be ± 200 mg/kg</td>
</tr>
<tr>
<td>Seasonal fluctuation</td>
<td>Monthly data from 1991-2008 forms the baseline for this limit</td>
<td>The measure of fluctuation for wetlands in the Becher Suite ± 17 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The measure of fluctuation for wetlands in the Cooloongup Suite ± 10 cm</td>
</tr>
<tr>
<td>Peaks and troughs</td>
<td>Monthly data from 1991-2008 forms the baseline for this limit</td>
<td>The timing of seasonal water level peaks and troughs should coincide with the baseline data in Table D9, however, a difference of one month either way in a very wet or very dry year would be within acceptable limits</td>
</tr>
<tr>
<td>Water levels</td>
<td>Monthly data from 1991-2008 forms the baseline for this limit</td>
<td>The Limits of Acceptable Change are different for each wetland. Figures in brackets indicate the range of acceptable variation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland 35-4: (9 to -117 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland 9-6: (39 to -79 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland 9-14: (35 to -85 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland swi: (0 to -92 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland swii: (-12 to -104 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland swiii: (22 to -67 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland 1N-1: (-66 to -168 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland 1N-2: (-53 to -146 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland BP1-4: (21 to -42 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wetland BP2-3: (59 to -34 cm)</td>
</tr>
<tr>
<td>Component</td>
<td>Baseline/supporting evidence</td>
<td>Limit of acceptable change</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Inundation frequency</td>
<td>Hydrographs from 1991-2001 form the baseline for this limit</td>
<td>For sumplands and damplands in the Becher and Cooloongup Suites, the frequency of inundation could vary up to 20% for any decade, but should not persist for longer</td>
</tr>
<tr>
<td>Groundwater salinity</td>
<td>Monthly sampling of groundwater from 1991-1994 forms the baseline for this limit</td>
<td>The Limits of Acceptable Change are different for each wetland. Change should only be permitted within the limits provided below:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland 35-4: (310 &lt; x &lt; 1,000 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland 9-6: (520 to 4,400 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland 9-14: (450 to 2,000 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swi: (0 to -92 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swii: (440 to 1,400 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swiii: (620 to 3,000 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swiv: (0 to 92 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swv: (440 to 1,400 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swvi: (620 to 3,000 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swvii: (0 to 92 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swviii: (620 to 3,000 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swix: (0 to 92 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swi: (440 to 1,400 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swii: (620 to 3,000 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swiii: (100 to 1,300 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swiv: (0 to 92 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swv: (440 to 1,400 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swvi: (620 to 3,000 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swvii: (0 to 92 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swviii: (620 to 3,000 ppm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swix: (0 to 92 ppm)</td>
</tr>
<tr>
<td>Cation content in groundwater</td>
<td>Monthly sampling of groundwater from 1991-1994 forms the baseline for this limit</td>
<td>Acceptable change for cation content in groundwaters for all wetlands except swi: should be within the following limits:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ca: 40-360 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mg: 20-170 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Na: 40-500 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K: 1-30 ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For swi, Mg and Na are higher (25-204 and 100-1,300 ppm) and K is lower (1-10 ppm)</td>
</tr>
<tr>
<td>Groundwater pH</td>
<td>Monthly sampling of groundwater from 1991-1995 forms the baseline for this limit</td>
<td>The Limits of Acceptable Change are different for each wetland. Change should only be permitted within the limits provided below:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland 35-4: pH 7.2-8.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland 9-6: pH 7.1-8.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland 9-14: pH 7.0-7.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for wetland swi: pH 7.3-8.0</td>
</tr>
<tr>
<td>Component</td>
<td>Baseline/supporting evidence</td>
<td>Limit of acceptable change</td>
</tr>
<tr>
<td>-----------</td>
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<td>---------------------------</td>
</tr>
</tbody>
</table>
| Orthophosphate levels in groundwater | Event based sampling (4 times per year) from 1992-1994 forms the baseline for this limit | The Limits of Acceptable Change are different for each wetland. Change should only be permitted within the limits provided below:  
  - wetland 35-4: (0.1 to 1.2 ppm)  
  - wetland 9-6: (0.01 to 0.1 ppm)  
  - wetland 9-14: (0.02 to 0.07 ppm)  
  - wetland swi: (0.03 to 0.8 ppm)  
  - wetland swii: (0.001 to 0.2 ppm)  
  - wetland swiii: (0.04 to 0.6 ppm)  
  - wetland 1N-1: (0.07 to 0.6 ppm)  
  - wetland 1N-2: (0.002 to 0.5 ppm)  
  - wetland BP1-4: (0.01 to 0.4 ppm)  
  - wetland BP2-3: (0.07 to 0.7 ppm) |

<table>
<thead>
<tr>
<th>Condition</th>
<th>Confidence</th>
<th>Trend (since ECD drafted - 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 – LAC always met</td>
<td>5 – Highly confident, data available in peer reviewed journals; conference papers</td>
<td>Improving</td>
</tr>
<tr>
<td>3 – LAC met in a majority of years</td>
<td>4 - Data available through published reports, expert panels, peer reviewed agency monitoring evaluation</td>
<td>Stable</td>
</tr>
<tr>
<td>2 – LAC not met in a majority of years</td>
<td>3 - Data available through agency monitoring evaluation</td>
<td>Degrading</td>
</tr>
<tr>
<td>1 – LAC not met since ECD published</td>
<td>2 – Anecdotal information</td>
<td>Insufficient data</td>
</tr>
<tr>
<td>1 – Data not available</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table D9 : Condition Assessment for the Becher Point Wetlands Ramsar Site Against Limits Of Acceptable Change

<table>
<thead>
<tr>
<th>Geomorphology</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td>Extensive geological sequence of linear interdunal swales with calcareous/quartzose sediments.</td>
<td>Sea level rise/beach erosion.</td>
<td>None established but provisional is that there should be no loss of interdunal swale occurrences.</td>
<td>All occurrences of interdunal swales (5 chains and 60 wetland basins) inside the Ramsar site boundary are intact except on the far north-west tip of Becher Point where the partial loss of TEC # 1083 (subtype 19b) (wetland BP1) has occurred through breaching by seawater during a storm event in 2012.</td>
<td>Condition score = 3 Confidence score = 3 Trend = Stable (breaching of BP1 was reported from previous occasions and has recovered Semeniuk 2007).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrology</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water levels</td>
<td>Seasonal rainfall, rise in groundwater and reduced evaporation facilitate seasonal wetting of dunal swales.</td>
<td>Abstraction of groundwater.</td>
<td>The Limits of Acceptable Change are different for each wetland. “x” denotes the range of acceptable variation.</td>
<td>All recorded groundwater levels in MB8 with the exception of September and October were below the investigation level and seven out of the 12 events recorded levels below the minimum level. Water levels in MB6 have declined approximately 0.2 m since August 1996 and MB8</td>
<td>Condition score = 2 Confidence score = 4 Trend = Degrading</td>
</tr>
</tbody>
</table>
### Geomorphology

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Range=92cm wetland swii : (-12&gt;x&gt;104)cm</td>
<td>almost 1 m (needs further investigation). Minimum water levels in other monitoring bores are generally stable.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Range=116cm wetland swiiii : (22&gt;x&gt;67)cm</td>
<td>(MB10) Range = 39cm</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Range=89cm wetland 1N-1 : (-66&gt;x&gt;-168)cm</td>
<td>(MB2) Range = 207cm</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Range=102cm wetland 1N-2 : (-53&gt;x&gt;-146)cm</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Range=93cm wetland BP1-4 : (21&gt;x&gt;42)cm</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Range=63cm wetland BP2-3 : (59&gt;x&gt;34)cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period of inundation</td>
<td>Period each year where water level reaches long term mean maximum (1991-2008 ECD).</td>
<td>Abstraction of groundwater. Reduced rainfall and higher temperatures.</td>
<td>LAC needs developing.</td>
<td></td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Hydrochemistry

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (groundwater)</td>
<td>Measured as Total Dissolved Solids - combined content of all inorganic and organic substances contained in seawater intrusion as a result of over abstraction of groundwater.</td>
<td>The Limits of Acceptable Change are different for each wetland. Change should only be permitted within the limits provided below for surface</td>
<td>MB6 = 1,088 mg/L Max MB6 = 1,235 mg/L, three of the four TDS samples were above the investigation level (1,088 mg/L) with two samples</td>
<td>Condition score = 3 Confidence score = 3 Trend = Stable (seasonally and annually variable, but...</td>
<td></td>
</tr>
<tr>
<td>Geomorphology</td>
<td>Description</td>
<td>Threats</td>
<td>Limits of Acceptable Change (LAC)</td>
<td>Data Analysis</td>
<td>Condition</td>
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<tr>
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</tr>
<tr>
<td>Component</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Surface Water</td>
<td>the surface water.</td>
<td></td>
<td>water:</td>
<td>(October 2012 and January 2013) above the maximum criteria (1,235 mg/L)</td>
<td>generally within Limits of Acceptable Change)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>wetland 35-4 : (310&gt;x&gt;1,000mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td>wetland 9-6 : (520&gt;x&gt;4,400mg/L)</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>wetland 9-14 : (450&gt;x&gt;2,000mg/L)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>wetland swi : (0&gt;x&gt;-92mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>wetland swii : (440&gt;x&gt;1,400mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>wetland swiii : (620&gt;x&gt;3,000mg/L)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>wetland 1N-1 : (380&gt;x&gt;1,700mg/L)</td>
<td></td>
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</tr>
<tr>
<td></td>
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<td></td>
<td>wetland 1N-2 : (420&gt;x&gt;2,000mg/L)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>wetland BP1-4 : (900&gt;x&gt;4,800mg/L)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>wetland BP2-4 : (5,000&gt;x&gt;60,000mg/L)</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td>MB8 = 460 mg/L, three out of four sampling events recorded TDS levels above the investigation level (460 mg/L) and the July 2012 event showed that TDS levels at MB8 were above the Maximum levels (532 mg/L). Max MB8=532 mg/L</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Groundwater salinity within monitoring bores associated with the golf course/ residential development is generally within the range of acceptable limits.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Geomorphology

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
</table>
| pH (groundwater) | Disturbance of Acid Sulfate Soils in the catchment could be expected to lead to oxidation of sulphur containing sediments and showing as lowered pH. | Excavation of wetlands in immediate catchment. | The Limits of Acceptable Change are different for each wetland. Change should only be permitted within the limits provided below: | Specific sites not monitored however all monitoring bores within the Ramsar site monitored by the golf course are within the range of acceptable limits. | Condition score = 3  
Confidence score = 3  
Trend = Stable |
| Total P (groundwater) | TP in groundwater | Increased nutrient leakage into groundwater from urbanisation of the catchment. Eutrophication/algal blooms. | The Limits of Acceptable Change are different for each wetland. ANZECC TP = 60 ug/L Change should only be permitted within the limits provided below: | | Condition score = 2  
Confidence score = 3  
Trend = Interim Degrading |
| | | | wetland 35-4: pH 7.2-8.0  
wetland 9-6: pH 7.1-8.3  
wetland 9-14: pH 7.0-7.9  
wetland swi: pH 7.3-8.0  
wetland swii: pH 7.1-8.0  
wetland swiii: pH 7.1-8.0  
wetland 1N-1: pH 7.0-8.0  
wetland 1N-2: pH 7.0-8.0  
wetland BP1-4: pH 6.9-8.1  
wetland BP2-3: pH 7.2-8.2 | Mean TP=120 ug/L  
Max TP=165 ug/L  
The total phosphorus content in groundwater from shallow bores MB4, MB6 and MB14 were generally well above the maximum licence criteria and above the ANZECC trigger level for the entire monitoring period February 2010 through October 2012 (Figure D16). Levels | |
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomorphology</td>
<td></td>
<td></td>
<td>wetland swiii : (40 &gt; x &gt; 600 ug/L)</td>
<td>measured within shallow bore MB6 exceeded the licence criteria by five times in April 2011 with a level measured of 0.99 mg/L. The monitoring results indicate a strong likelihood that phosphorus is leaking into the groundwater from fertiliser application from the Kennedy Bay golf course and surrounding urban development. However, the interim limits established by Semeniuk 2007 included a maximum of 1.2 mg/L which has not been exceeded.</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>TN in groundwater</td>
<td>Increased nutrient leakage into groundwater from urbanisation of the catchment. Eutrophication/algal blooms.</td>
<td>ANZEC TN = 1,500 ug/L</td>
<td>Mean TN = 3,500 ug/L Max TN = 5,000 ug/L Eutrophic from ANZECC levels. The nitrogen content in groundwater from shallow bores MB4, MB6 and MB14 were well below the maximum licence criteria and generally below the ANZEC trigger level for the monitoring period April 2011</td>
<td>Interim Condition score = 2 Confidence score = 3 Trend = Interim Degrading</td>
</tr>
</tbody>
</table>
### Geomorphology

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>through February 2013 (<a href="#">Figure D14</a>). However, levels measured within shallow bore MB8 exceeded the licence criteria on two occasions during the monitoring period, in December 2011 (6.2 mg/L) and again in October 2012 (5.5 mg/L) and on both occasions were well above the ANZECC trigger level of 1.5 mg/L. The monitoring results indicate an upwards trend in total nitrogen concentration and the strong likelihood that nitrogen is leaking into the groundwater from fertiliser application from the Kennedy Bay golf course and surrounding urban development.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Sedgelands in Holocene dune swales of the southern Swan Coastal Plain

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Strategic Assessment for the Perth and Peel Regions

### Sedgelands TEC

Nationally listed Threatened Ecological Community ‘Sedgelands in Holocene dune swales of the southern Swan Coastal Plain’.

<table>
<thead>
<tr>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weed invasion Fire Off-road vehicles Sudden alteration of groundwater levels</td>
<td>Abundance cover &gt; 25%</td>
<td>Vegetation average percentage cover has been greater than 25% on each monitoring occasion. Even monitoring following wildfire a percentage cover of 62.7% of native species was recorded (Brown et al, in prep)</td>
<td>Condition score = 3 Confidence score = 2 Trend = Stable</td>
</tr>
</tbody>
</table>

Coterra 2013 assessed the eight years of monitoring vegetation condition and weed cover data of the eight transects on the north-east side of the Ramsar site. The transects included three TEC occurrences (Figure D1) of type 19a and reports that the vegetation condition in these TECs was ‘Very Good’ to ‘Excellent’.

Interim condition score = 3
Confidence score = 2
Trend = Interim Stable

### Wetland vegetation

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native species cover</td>
<td>Interdunal swale wetlands are naturally vegetated and reductions in cover indicate a loss of condition</td>
<td>Weed invasion Fire Off-road vehicles Sudden alteration of groundwater levels</td>
<td>Abundance cover &gt; 25%</td>
<td>Vegetation average percentage cover has been greater than 25% on each monitoring occasion. Even monitoring following wildfire a percentage cover of 62.7% of native species was recorded (Brown et al, in prep)</td>
<td>Condition score = 3 Confidence score = 2 Trend = Stable</td>
</tr>
</tbody>
</table>

Fire (surrogate indicator)
The 2011 Interim Recovery Plan for the TEC states that on currently available data, the minimum inter-fire interval should be at least six years, but with additional time to allow for the current dry climate, a more conservative burn regime is required.

Fire events within individual reserve portions < 1 per 6 years.

Central Reserve 4 fires in 15 years
North Reserve 5 fires in 15 years
East Reserve 6 fires in 15 years

Condition score = 2
Confidence score = 2
Trend = Degrading
<table>
<thead>
<tr>
<th>Geomorphology</th>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weed cover</td>
<td>The wetlands within this Ramsar site face significant threats from weed invasion which is being exacerbated by decreasing water levels and frequency of wildfire. Eighteen species of weeds have been identified (NAMS 2008), including Bridal Creeper, <em>Asparagus asperagoides</em>, a declared weed and three species that are a concern because of the area that they cover – Geraldton Carnation Weed <em>Euphorbia terracina</em>, Rose Pelargonium <em>Pelargonium capitatum</em> and Dune Onion Weed <em>Trachyandra divericata</em>.</td>
<td>Any presence of a declared weed Single weed species cover &gt; 15%</td>
<td>Central Reserve: Geraldton Carnation Weed, Rose pelargonium, and Dune Onion Weed restricted to &lt;5% cover and only along access tracks. Bridal Creeper found at one location covering &lt;1% North Reserve: Geraldton Carnation Weed occurring on 20% and along access tracks; Dune Onion Weed occurs on 30% and along access tracks. Other weed along access tracks East Reserve: Geraldton Carnation Weed occurring on 50% of the reserve and Dune Onion Weed covering 10% South Reserve: Dune Onion Weed covering 10% along access tracks West Reserve: Dune Onion Weed occurring on 30%, concentrated along access</td>
<td>Condition score = 3 Confidence score = 2 Trend = Stable to improving</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Geomorphology

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>tracks</td>
</tr>
</tbody>
</table>

#### 4.2.1 Summary and conclusions for LACs

**Table D10** provides a summary of the condition against each of the LACs.

**Table D10 : Summary of the condition against each of the LAC**

<table>
<thead>
<tr>
<th>Components And Processes</th>
<th>Limits Of Acceptable Change (LAC)</th>
<th>Condition Score</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geomorphology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occurrence of dunal swales</td>
<td>LAC not established, but there should be no loss of interdunal swale occurrences.</td>
<td>3-4</td>
<td>stable to degrading</td>
</tr>
<tr>
<td><strong>Hydrology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water levels</td>
<td>wetland 35-4: (9 to -117 cm)-MB4, MB6, MB8</td>
<td>2-north-east wetlands</td>
<td>stable to degrading</td>
</tr>
<tr>
<td></td>
<td>LACs established for each wetland group</td>
<td>3-other wetlands</td>
<td>stable</td>
</tr>
<tr>
<td><strong>Hydrochemistry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity (groundwater)</td>
<td>LACs established for each wetland group</td>
<td>3</td>
<td>Stable, but slight increasing trend in MB6, MB8, MB12</td>
</tr>
</tbody>
</table>
### pH
- LACs established for each wetland group
- 4
- stable

### Total-N (groundwater)
- LAC not established but use ANZECC value 1.5 mg/L and maximum licence criteria 5 mg/L
- 2-3
- degrading

### Total-P (groundwater)
- LAC not established but use ANZECC value 0.06 mg/L and maximum licence criteria 0.165 mg/L
- 2-3
- degrading

### Ecology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LAC not established, but taken as</th>
<th>Value</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Plant cover</td>
<td>no decline in native species cover</td>
<td>3</td>
<td>stable</td>
</tr>
<tr>
<td>Weed cover</td>
<td>no increase in weed cover</td>
<td>3</td>
<td>stable</td>
</tr>
<tr>
<td>Fire interval</td>
<td>&lt; 1 event per 6 years</td>
<td>2</td>
<td>degrading</td>
</tr>
<tr>
<td>TEC</td>
<td>LAC not established, but taken as no loss of occurrences</td>
<td>3 (1 occurrence lost out of 30)</td>
<td>stable</td>
</tr>
</tbody>
</table>
The overall condition of the Becher Point Wetlands Ramsar site remains good with the two criterion for listing, still being met (representative, rare or unique example of a natural wetland type and it supports the Threatened Ecological Community “Sedgelands in Holocene dune swales of the southern Swan Coastal Plain”). All of the critical ecosystem components and processes identified in the draft ECD (Semeniuk Research Group 2014) still function and the full suite of ecosystem benefits and services are still provided.

Serious threats exist at the Ramsar site, the most significant being fire frequency which combined with declining groundwater levels in the northern and eastern sectors of the site and continued access by off-road vehicles has led to weed invasions along the access tracks and in cases these have spread to significant areas, particularly in the northern and eastern sectors, closest to urban infrastructure. Beach erosion has removed one occurrence of the TEC (BP1) in the last 5 years and sea level rise will likely become the most significant threat in future years.

Groundwater levels are fairly stable, although those closest to urban infrastructure have declined and are below levels recommended in the LAC and below trigger levels for the licensing of water abstraction for the Port Kennedy golf course. The annual monitoring of vegetation condition has not indicated that vegetation has been altered by the decline in groundwater levels. The site would benefit from having a dedicated monitoring program that was designed to facilitate reporting of condition of the key values of the site, including the nationally listed Threatened Ecological Community and the processes that maintain these values including expression of water in the interdunal swales.

Elsewhere in the site, groundwater levels remain static. Nutrient loads are within eutrophic levels as a result of nutrient leakage within the catchment, but is not resulting in algal growth. The pH and conductivity are within acceptable limits and not identified as threats.
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Tauss C (2002), *Surveying Western Australia’s Land Edge. Reference transects in coastal vegetation at Geraldton, Port Kennedy, Bunbury and Esperance, Western Australia*. Published by Coastwest/Coastcare and WA Herbarium, Perth.


Western Australian Planning Commission (2008), *Better urban water management*, Western Australian Planning Commission, Perth, Western Australia.

CONDITION STATEMENT – FORRESTDALE AND THOMSONS LAKES RAMSAR SITE

EXECUTIVE SUMMARY

Forrestdale and Thomsons lakes were nominated as one site by the Western Australian Government as meeting criteria to be recognised as a “Wetland of International Importance” under the Ramsar Convention on Wetlands. In June 1990, the system was designated under the Ramsar Convention as the Forrestdale and Thomsons lakes System Ramsar site.

The lakes are approximately 8.5 km apart, separated by medium density urban development, rural and rural residential land. Forrestdale and Thomsons Lakes are class A nature reserves vested in the Conservation Commission of Western Australia and managed by the Department of Parks and Wildlife. Thomsons Lake Nature Reserve also forms part of the Beeliar Regional Park.

Forrestdale Lake is located approximately 25 km south east of Perth, in the City of Armadale and Thomsons Lake is located approximately 34 km south west of Perth in the City of Cockburn both of which lie within the southern Perth metropolitan area, in Western Australia. Forrestdale and Thomsons Lakes are fresh/brackish, seasonal wetlands, predominately fed by groundwater with little surface drainage. Forrestdale Lake usually dries out by mid-summer whereas Thomsons Lake retains water longer, as it receives water supplementation via the South Jandakot Branch Drain. These lakes remain as the best remaining examples of brackish, seasonal lakes with extensive fringing sedgeland, typical of the Swan Coastal Plain. The lakes are weakly coloured, generally clear and both have a neutral to slightly alkaline pH. The lakes are moderately enriched and occasional algal blooms have been recorded.

The designation of the Forrestdale and Thomsons Lakes Ramsar site in 1990 recognised three of the then six criteria for listing as a wetland of international importance which included the site’s:

- representativeness of natural or near-natural wetland, characteristic of those that were once widespread on the Swan Coastal Plain;
- importance for maintaining the genetic and ecological diversity of the region; and
- importance in regularly supporting more than 1 % of the individuals of the known Australian population of the Long-toed Stint (*Calidris subminata*).

A review of the waterbird data recorded for the lakes in 2003 lead to the addition of a forth listing criteria being accepted which was that the site had more than one waterbird count that was greater than 20,000. However, in an extensive review of the waterbird counts for the 2009 publication of the Ecological Character Description (ECD), two criteria, criteria 5 (regularly supports 20,000 or more waterbirds) and criteria 6 (regularly supports 1% of the individuals in a global population of waterbirds), were shown not to meet the definition of “regularly supports” and these were removed from the listing description.
The evaluation conducted in this condition statement is the most extensive conducted since the publication of the 2009 ECD. Since listing in 1990, many of the components, processes, benefits and services critical to the ecological character of the site have been maintained including water quality - the lakes are still fresh/brackish, weakly coloured, generally clear, have a neutral to slightly alkaline pH and are moderately nutrient enriched. Invertebrate species richness has remained relatively stable. This indicates that conditions remain that support the faunal species, including waterbirds and turtles.

However, there have also been a number of changes to the wetlands, the most significant being substantially lower maximum water depths, reduced period of inundation and earlier annual drying. The altered hydrological regime has been attributed to reduced rainfall from climate change, groundwater abstraction and urban development. Wetland vegetation has generally declined in condition since monitoring commenced, though in recent years there have been improvements in canopy condition at both lakes.

*Typha orientalis* now covers expansive areas of the water’s edge and is encroaching across the lake beds. *Typha* is displacing and changing riparian vegetation, which appears to be altering waterbird habitat. The invasion of *Typha* is facilitated by drier conditions and some active control measures have been implemented. These measures have been successful in reducing coverage of *Typha* around parts of the lakes.

The number of waterbirds and number of species recorded at Forrestdale and Thomsongs Lakes have been variable, but overall have declined in recent years. Numbers of migratory shorebirds have also declined, likely due to loss of suitable habitat from the encroachment of riparian vegetation across the lake floor.

The Forrestdale and Thomsons Lakes Ramsar site retains those values recognised in the two listing criteria when the ecological character was described in 2009. The two lakes are used for passive recreation; Thomsons Lake Nature Reserve has a fox proof fence around it which generally limits access to walkers only, while Forrestdale Lake Nature Reserve contains a bridle path which is actively used.

The condition assessment against the LACs highlights that many of the LACs are being met in the majority of years. However, the assessment also shows that LACs for a number of key components and processes are either never being met or not being met in the majority of years. These components and processes include:

- annual maximum water depth;
- period of inundation/drying;
- salinity;
- nutrients; and
- waterbirds.

The LACs that have never been met, particularly some set for annual maximum water depth and nutrients may no longer be appropriate. Under the current climate in the south west of Western Australia, where annual average rainfall has reduced significantly since the lakes were listed as a Ramsar site, it is very unlikely that surface water levels will ever be greater than 0.9 m for 2 months during spring or greater than 1.6 m for at least once every 10 years. However it should be noted that the last 10 years of rainfall, particularly 2006 and 2010, have been particularly dry in comparison to historical records. These extremely dry years mean the period may even be considered dry in the
context of future climate predictions that indicate rainfall will continue to reduce in the south-west of Western Australia.

The supplementation program at Thomsons Lake has helped to mitigate the effect of reduced rainfall on lake depth, but depths at the lake have still not met LACs. Under the current management of the supplementation program, surface levels will never be greater than 1.6 m as the management plan states water will be pumped out of the lake if a level of 1 m is reached until the lake is returned to a level of 0.8 m. It also seems unlikely that total nitrogen concentrations will ever meet the LAC set for nutrients, given nitrogen have remained above the LAC despite very dry conditions that seem to have led to reduced phosphorus levels since 2002–03.

Despite some of the LACs for annual maximum water depth and nutrients never being met, the lakes have not experienced unacceptable change in ecological character. The lakes have not become:

- permanently wet;
- permanently dry;
- deep (>3 m);
- saline or hypersaline;
- acidic;
- eutrophic or hypertrophic;
- dominated by invasive plants; or
- unsuitable as a habitat for aquatic biota, especially waterbirds.

Though annual maximum water depth LACs have not been met, peak levels at both lakes in 2013 and 2014 were the highest for a number of years and local Superficial Aquifer levels have remained relatively stable since monitoring commenced. The relatively stable groundwater levels mean there is still potential for the lakes to fill well in years of good winter rainfall. Water quality and macroinvertebrate species richness at the lakes has generally been maintained. The stable macroinvertebrate species richness indicates that conditions at the lakes can still support the faunal species, including waterbirds and turtles.

Importantly, Thomsons and Forrestdale Lakes are the still the best remaining examples of brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain and still provide important habitat for waterbirds on the Swan Coastal Plain including migratory species listed under the EPBC Act, meaning they still meet two Ramsar criteria.

While the sites still meet these criteria there are on-going threats, including reduced rainfall and higher temperatures, together with abstraction of groundwater and land use change, that have the potential to negatively impact on the ecological character of the lakes. Future urbanisation could, to some extent, offset the effects of reduced rainfall with the increasing presence of impervious surfaces leading to a higher percentage of rainfall entering the Superficial Aquifer as recharge than would occur under native vegetation. In the current climate of diminished rainfall, increased evaporation and a reduction in recharge to groundwater, increased recharge associated with impervious surfaces could help maintain water levels at the lakes. However urbanisation can also increase nutrient concentrations in the Superficial Aquifer. As such, as urban development increases in the catchments of the lakes, so does the threat of nutrient enrichment.
While surface water supplementation is an option that is being used for Thomsons Lake to maintain depths and duration of inundation events, a suitable drainage supplementation option is yet to be identified for Forrestdale Lake. Given the very shallow maximum depths recorded at the Forrestdale Lake since 2006, and the success of the supplementation program at Thomsons, a suitable drainage supplementation option should be investigated for Forrestdale. The investigation should assess whether local authority or private drains in the area are restricting maximum groundwater levels and in turn impacting on lake levels. It should also identify drainage or land use adjacent to the lake that may be contributing to its nutrient concentrations.
1 Introduction

1.1 INTRODUCTION TO THIS REPORT

The purpose of this technical report is to provide a Condition Statement for the Forrestdale and Thomsons Lakes Ramsar Site. It will be used to inform the development of Draft Commonwealth Impact Assessment Report (CIAR) and the Draft Strategic Conservation Plan for the Strategic Assessment of the Perth and Peel Regions (SAPPR).

The report is arranged with an overview of the Forrestdale and Thomsons Lakes Ramsar Site in Section 1, followed by a listing and justification of the criteria that were used in the designation of the site as a Wetland of International Importance under the Ramsar Convention on Wetlands in Section 2. Section 2 also contains a description and information on the condition of ecosystem components and processes that was included in the Ecological Character Description (ECD) of 2009 (Maher and Davis 2009). This follows with a description of the past, existing and future threats to the ecosystem’s components and processes and information on the existing management arrangements for the site. Section 3 contains information on the current condition of key ecosystem components and processes at the site and uses data collected since publication of the ECD, to assess current condition against the criteria used in the designation of the site as a Wetland of International Importance. Section 4 contains a description of the Limits of Acceptable Change (LACs) that are listed in the ECD and an assessment of the condition of the key ecosystem components and processes against the LACs.

This report has been developed collaboratively by a number of Western Australian State Government Agencies, as the technical experts regarding the Ramsar site. Agencies authors include:

- Department of Water.
- Department of Parks and Wildlife.

The content of this report is based on:

- Ecological Character Description for the Forrestdale and Thomsons Lakes Ramsar Site (Maher and Davis 2009).
- Information Sheet on Ramsar Wetlands (RIS)
- Monitoring data:
  - Surface water and groundwater levels (Department of Water/Water Corporation).
  - Water quality (Department of Water/Water Corporation/Water Corporation).
  - Vegetation (Department of Parks and Wildlife/Department of Water).
  - Invertebrates (Department of Water).
  - Waterbirds (Department of Water).

1.2 FORRESTDALE AND THOMSONS LAKE RAMSAR SITE OVERVIEW

Forrestdale Lake is located approximately 25 km south-east of Perth, in the City of Armadale and Thomsons Lake is located approximately 34 km south-west of Perth in the City of Cockburn both of
which lie within the southern Perth metropolitan area, in Western Australia. The lakes are approximately 8.5 km apart, separated by medium density urban development, rural and semi-rural (rural residential) land (Figure D21). Forrestdale and Thomsons Lakes are Class A nature reserves vested in the Conservation Commission of Western Australia. Thomsons Lake Nature Reserve also forms part of the Beeliar Regional Park.

Forrestdale and Thomsons Lakes are fresh/brackish, seasonal wetlands, predominately fed by groundwater with little surface drainage. Forrestdale Lake usually dries out by mid-summer whereas Thomsons Lake retains water longer. These lakes are the best remaining examples of brackish, seasonal lakes with extensive fringing sedgeland, typical of the Swan Coastal Plain. The lakes are weakly coloured, generally clear and both have a neutral to slightly alkaline pH. The lakes are moderately enriched and occasional algal blooms have been recorded.

Forrestdale and Thomsons Lakes are situated in sand dune systems and, when inundated, contain large areas of open water that are dominated by submerged and floating macrophytes and fringed by rushes and bulrushes, behind which are trees tolerant of seasonal waterlogging. The higher ground around the lakes supports open woodland. Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain with 85 species of waterbird occurring at the two lakes, including 29 migratory species listed under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). In addition, 27 waterbird species have been recorded breeding at the lakes. The Ramsar site contains rich and diverse communities of aquatic invertebrates that are representative of relatively undisturbed, large, shallow Swan Coastal Plain wetlands dominated by submerged macrophytes. Macroinvertebrates are an important component of wetland food webs, comprising much of the diet of many faunal species, including migratory waders and other waterbirds, as well as turtles. There are 339 recorded taxa; including two Western Australian listed Threatened Ecological Communities, (SCP08 – Herb rich shrublands in claypans and SCP10a – Shrublands on dry clay flats), 19 species listed under international agreements, seven threatened species and four priority species within 1.5 km of the centre of Forrestdale Lake. There are 302 recorded taxa, including the Western Australian listed Threatened Ecological Community (SCP24 Northern Spearwood shrublands and woodlands), 11 taxa listed under international agreements, four threatened species and nine priority species within 2 km of the centre of Thomsons Lake.

Although Thomsons Lake was one of few known breeding localities for Baillon’s Crane, and the last wetland within the Perth metropolitan area where Swamp Harrier was recorded breeding, these species have not been recorded breeding at this lake since the mid-1980s. Forrestdale Lake was traditionally an important turtle hunting site for indigenous peoples from as far away as Pinjarra, 50 kilometres to the south. Contemporary uses of the Ramsar site include bird watching, nature walks, horse riding and general recreation.
Figure D21: The Forrestdale and Thomsons Lakes Ramsar Site
2 Ramsar listing

2.1 LISTING CRITERIA

When the Forrestdale and Thomsons Lakes Ramsar Site was originally nominated as a Wetland of International Importance in 1990, it was considered to meet three of the six possible criteria:

Criterion 1: The site is a particularly good representative example of a natural or near natural wetland, characteristic of those that were once widespread on the Swan Coastal Plain.

Criterion 3: The site is of special value for maintaining the genetic and ecological diversity of the region because of the qualities and peculiarities of its flora and fauna.

Criterion 6: The site regularly supports more than 1% of the individuals of the known Australian population of the Long-toed Stint (*Calidris subminata*).

A review was undertaken in 2003 and the site was also considered to meet a fourth criterion:

Criterion 5: More than 20,000 waterbirds have been recorded on both Thomsons Lake (21,083 in February 1987) and Forrestdale Lake (22,196 in January 1986).

It is important to appreciate that the criteria for listing a wetland as a Ramsar site have been developed and refined over the years. When this site was listed in 1990, there were six criteria. There are now nine current criteria, with considerable explanation of the terminologies used.

Ramsar Criteria no longer met

Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.

In 2003, it was considered that the Ramsar site met the criterion now referred to as Criterion 5. The Ramsar Information Sheet (2003) for the site stated that “More than 20,000 waterbirds have been recorded on both Thomsons Lake (21,083 in February 1987) and Forrestdale Lake (22,196 in January 1986). Annual data on water depth indicates that conditions at both lakes are suitable for use by more than 20,000 waterbirds at least several times within a 25 year period; in the context of wetland availability in Western Australia, this is considered sufficient evidence of regular use by 20,000 waterbirds.”

It appears that these two counts alone were used as justification to support Criterion 5. Single counts are used at some Ramsar sites where little information is known, to establish the importance of the site for a species, particularly if the areas are remote or there are other constraints in undertaking regular waterbird surveys. However, in this case, there are a sufficient number of waterbird surveys to apply the current Ramsar definition of “regularly” under this criterion (see definition below). The existing waterbird data for the site does not support the current Ramsar definition of “regularly” and in 2009 the decision was made to remove Criterion 5 as being met.

Criterion 6: A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

In 1990, the Ramsar site was considered to meet then Criterion 3c, which is similar to current Criterion 6. At the time of listing, the site was considered to support more than 1% of the individuals of
the known Australian population of the Long-toed Stint (*Calidris subminata*). However, current Ramsar Guidelines specify that it is not a correct justification to list populations with numbers in the site >1% of their national population, except when the population is endemic to that country. The Fourth Edition of Waterbird Population Estimates (Wetlands International 2006) estimate the Long-toed Stint population, which occurs in the Asia and Oceania biogeographic regions, at around 25,000, and thus the 1% level as 250. Eighty birds were observed in summer 1980, and up to 26 have been observed since 1981. Therefore, the Long-toed Stint did not fulfil the 1% criteria at this Ramsar site in 1990 and numbers continue to be insufficient to meet Criterion 6.

Forrestdale and Thomsons Lakes have supported more than 1% of the population of four waterbirds in several years: Australasian Shoveler, Black-winged Stilt, Blue-billed Duck, and Red-capped Plover. However, the wetlands have not “regularly” supported 1% of the population, particularly in recent years. Therefore Forrestdale and Thomsons Lakes do not meet the current requirements for listing under Criterion 6.

Ramsar guidelines (Ramsar Convention 2008) define regularly – as in supports regularly – a population of a given size if:

- The requisite number of birds is known to have occurred in two-thirds of the seasons for which adequate data are available, the total number of seasons being not less than three; or
- The mean of the maxima of those seasons in which the site is internationally important, taken over at least five years, amounts to the required level.

The listing criteria, taken from the Ramsar Information Sheet (RIS) for the site are presented in Table D11.

**Table D11 : Ramsar listing criteria and justification**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near natural wetland type found within the appropriate biogeographic region.</td>
<td>Thomsons and Forrestdale Lakes are the best remaining examples of brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain. While these types of wetland were formerly common, extensive development of the Swan Coastal Plain has resulted in the loss of many of these wetlands, and most of the remaining wetlands of this type have been degraded through drainage, eutrophication and the loss of fringing vegetation.</td>
</tr>
<tr>
<td>3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.</td>
<td>Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain with 85 species of waterbird occurring at the two lakes, including 29 migratory species listed under the EPBC Act. In addition, 27 waterbird species have been recorded breeding at the lakes. The Ramsar site contains rich and diverse communities of aquatic invertebrates that are representative of relatively undisturbed, large, shallow Swan Coastal Plain wetlands dominated by submerged macrophytes. There are two WA listed Threatened Ecological Communities at Forrestdale Lake Nature Reserve, two ‘Declared Rare Flora’ species listed under WA legislation and nine Priority taxa. Thomsons Lake Nature Reserve contains one ‘Declared Rare Flora’ species listed under WA legislation and three Priority taxa.</td>
</tr>
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</table>
Thomsons Lake is one of the last remaining refuges within the Swan Coastal Plain for the threatened Australasian Bittern *Botaurus poiciloptilus*, is one of few known breeding localities for Baillon’s Crake *Porzana pusilla*, and was the last remaining wetland within the Perth metropolitan area where the Swamp Harrier *Circus approximans* was known to breed; however, these species have not been recorded breeding at this lake since the mid-1980s.

2.2 RAMSAR SITE VALUES

The values of the Forrestdale and Thomsons Lakes Ramsar Site are described in detail in the Ecological Character Description of the site (Maher and Davis 2009). These are summarised below.

2.2.1 Geomorphology and geology

In the Perth region, the Swan Coastal Plain is about 34 km wide in the north, 23 km in the south, and is bounded to the east by the Gingin and Darling Fault Scarps, which rise to over 200 m above sea level. The scarps represent the eastern boundary of Tertiary and Quaternary marine erosion. The Swan Coastal Plain consists of a series of distinct landforms, roughly parallel to the coast i.e. in an approximately north-south direction.

The youngest sediments in the Perth Basin are collectively termed the ‘superficial formations’ and include (from oldest to youngest) the Ascot Formation, Yoganup Formation, Guildford Clay, Bassendean Sand, Tamala Limestone, Becher Sand and Safety Bay Sand. The superficial formations consist mainly of sand, silt, clay and limestone in varying proportions. Along the eastern margin of the coastal plain the sediments are more clayey than those in the central area, which are predominantly sandy. To the west, the sandy sediments pass laterally into limestone, which borders the coastal strip (Davidson 1995).

The superficial formations adjacent to Forrestdale Lake are around 35 m thick, consisting predominantly of Bassendean Sand that inter-fingers with Guildford Clay as you move east towards the Darling Scarp (Davidson 1995). At Thomsons Lake the superficial formations are around 30 m thick. The lake is situated on the junction between the Bassendean Sand to the east and the Tamala Limestone to the west. (Davidson 1995).

The soils of Forrestdale and Thomsons Lakes are considered infertile. The Bassendean Dunes comprise predominantly leached grey-white siliceous sands, and are the oldest of the three Aeolian dune systems. The Spearwood dunes are younger, less leached and with higher, more rolling relief. The soils at Thomsons Lake correspond with the soils of the Karrakatta soil/landform unit, an undulating landscape with deep yellow sands over limestone (Crook and Evans 1981). Forrestdale and Thomsons Lakes are most likely underlain by pyritic peaty sediments, which are potentially acid sulfate soils. Acid sulfate soils are waterlogged soils that contain iron sulphide minerals, predominantly as the mineral pyrite. The exposure of the pyrite to air by drainage, dewatering or excavation of soil can generate sulphuric acid. Water in contact with the oxidising soil leaches metals from the soil, which then discharges into waterways and wetlands as acidic water. Both lakes have been identified as having high risk of acid sulfate soils i.e. less than three metres from the soil surface (Swan Catchment Council 2004). This means that extensive digging, dewatering or drainage has the potential to cause considerable environmental damage.
2.2.2 Hydrology

Forrestdale and Thomsons Lakes are situated on the Jandakot Groundwater Mound, which is a region of elevated groundwater table beneath the Swan Coastal Plain. Groundwater discharges from the mound into low lying depressions that support groundwater dependant vegetation and wetland systems. The majority of lakes are flow-through lakes that are in direct connection with the Superficial Aquifer (Townley et al. 1993, Turner and Townley 2006). Forrestdale Lake acts as drainage basin that captures local groundwater discharge from the Superficial Aquifer, rather than relying on regional groundwater through-flow, as well as some surface water inflow (Bourke and Paton 2010). Thomsons Lake is supported by regional groundwater through-flow of the Superficial Aquifer which is predominantly east to west (Davidson 1995).

A drainage scheme diverts water from residential subdivisions to the east of Thomsons Lake, away from the lake in order to minimise changes to water levels and protect it from nutrient loading. The lake receives drainage water through a supplementation program that was initiated in winter 2004 and has continued every winter since. With agreement from the Water Corporation, water is diverted from the South Jandakot Branch Drain into Thomsons Lake by means of adjustable weir boards (Department of Conservation and Land Management 2006). Agricultural drains are used to direct drainage into Thomsons Lake from Kogolup South Eye and the area east of the lake. The drain from Kogolup South is still present but was blocked when pipes were laid between the two lakes (GB Hill & Partners Pty Ltd and WAWA 1990).

The Water Corporation maintains a network of main drains in the Forrestdale area Forrestdale Main Drain and Berriga Main Drain. Forrestdale Lake is connected to Forrestdale Main Drain through an overflow outlet and water only flows rarely during flood events (Bourke and Paton 2010). There is also an extensive network of local authority and private drains in the area which were developed to reduce periods of inundation and water logging by restricting maximum groundwater levels. By restricting maximum groundwater levels these drains could also be impacting on lake levels. James Drain flows towards Forrestdale Lake for three to four months of the year and drains surface water and groundwater (Coffey 2008). Skeet Drain also flows into Forrestdale Lake from Skeet Oval however the volumes of water are very low. Road drains in the area (Weld, Fisher and Moore) discharge to groundwater and do not flow directly into the lake (ERM 2000). According to locals of the area, the expansion of the Wungong dam in the late 1970s was largely responsible for reducing water levels in Forrestdale Lake, by reducing overflow from Wungong brook. Diversion of other surface water away from the lake during urbanisation and groundwater abstraction have also been cited as causes of lower lake levels since the 1970s (Giblett 2006).

Thomsons Lake is a shallow, almost circular lake and has an area of open water covering approximately 151 ha when full. Forrestdale Lake is also shallow, oval in shape and has an area of open water covering approximately 221 ha when full. The water levels of wetlands on the Jandakot Mound are strongly influenced by annual rainfall, lake morphometry, location relative to groundwater contours and annual evaporation rates (Davis et al. 2008). Maximum water depths in the wetlands of the Swan Coastal Plain occur during spring, typically in September or October.

Wetlands in the south-west of Western Australia are influenced greatly by the Mediterranean climate, and seasonal drying is a feature of the lakes. The duration and time of drying depends on evaporation rates and the amount of water entering the lake during winter and spring. In wetter years, the lakes do not tend to dry completely, whereas in drier years they dry completely, i.e. no free surface water is present in summer and autumn for months at a time. The average annual evaporation in Perth is
about twice the average annual rainfall (Bureau of Meteorology 2008). This process contributes significantly to the rapid decline in water level over summer.

**Water depth**

Average maximum water depths from 1980 to 1999, the decades before and after the Ramsar site was listed, were 105 cm (range 38–206 cm) at Thomsons Lake, and 103 cm (range 47–187 cm) at Forrestdale Lake. In 1990, when Forrestdale and Thomsons Lakes were designated as a Ramsar site, the water depth at Thomsons Lake ranged from a minimum of 59 cm in May to a maximum of 98 cm in October, and at Forrestdale Lake ranged from 35 cm in March to 65 cm in September. Maximum water depths in Forrestdale and Thomsons Lakes were much greater in the 1950s and 60s in both wetlands, with average annual maximum depths of 274 cm at Thomsons Lake and 216 cm at Forrestdale Lake. The relatively high water levels at Thomsons Lake during the 1960s and 70s may have been the result of excessive inundation caused by clearing of the surrounding Banksia woodland for cattle grazing and market gardening (Crook and Evans 1981). Maximum water levels have generally been declining in both lakes since the 1960s, though were relatively high in the early 1990s when the lakes were listed as a Ramsar site. Water level declines at the lakes are attributed to reduced rainfall and recharge as well as abstraction and land use changes.

In 1992, Environmental Water Provisions (EWPs) were set for a number of wetlands, including Forrestdale and Thomsons Lakes, for the management of abstraction for public and private water supply from the Jandakot Mound. These were updated in 2004. The EWPs include a preferred minimum water level and an absolute minimum level, and were set to ensure the maintenance of the lakes’ habitat value for migratory birds and rare, threatened and priority flora and fauna. The preferred minimum water level of Thomsons Lake is 11.3–11.8 m AHD, with an absolute minimum of 10.8 m AHD (Minister for the Environment 2005). The lake bed level used by the Department of Environment in setting EWPs is 11.8 m AHD. This lake bed level was used to calculate water depth in this Condition Statement. This equates to a preferred minimum water level that is at the lake bed surface to 0.5 m below the lake bed, and an absolute minimum water level of 1.0 m below the lake bed surface. The absolute minimum level is the point at which emergent macrophytes can no longer access water (Townley et al. 1993). However, the length of time at which groundwater remains at or near this level is critical. If groundwater does not exceed this level for more than 3–4 months each year, most species of emergent macrophyte would not survive for longer than 1–2 years (Froend et al. 1993).

The current criteria for the Jandakot Mound, limit the allowances for water levels to fall between the preferred and absolute minimum values for no more than two in six years. The ‘two in six year’ approach was adopted as a simplistic means of accounting for and mimicking the occurrence of drier years, during which water levels would be expected to be lower as a direct consequence of lower rainfall. The criterion effectively requires that, on average, water levels should not be below the preferred minima for more than one-third of years, and for no longer than two consecutive years in any six year period (Minister for the Environment 2005).

It is important to note the maximum permitted water level at Thomsons Lake is 12.8 m AHD, at which time water is pumped out to a level of 12.6 m AHD (CALM 2005b). As the lake bed level is at approximately 11.8 m AHD, water can no longer reach depths of more than 1.0 m for an extended period of time. The maximum levels were developed with the Environment Protection Authority’s (EPA) approval, as an environmental condition on the rezoning of land to the east of Thomsons Lake from rural to urban (CALM 2005b).
At Forrestdale Lake the preferred summer minimum is 21.2–21.6 m AHD with an absolute summer minimum of 21.1 m AHD (Minister for the Environment 2005). The lake bed level used by the Department of Environment in setting EWP s is 21.6 m AHD. This equates to a preferred minimum water level that is at the lake bed surface to 0.4 m below the lake bed, and an absolute minimum water level of 0.5 m below the lake bed surface. A level of 21.5 m AHD has been used as the lake bed level for the purposes of calculating water depth in this report.

It should be noted that the staff gauges at both lakes are not located at the absolute lowest point of the lake bed. Therefore, a dry reading may be recorded from the staff gauge when some water (shallow) may still be present on other areas of the lake bed.

**Annual period of inundation/drying**

Forrestdale and Thomsons Lakes have experienced phases of annual drying and permanent water presence since monthly measurements of water depth began. Both lakes have experienced two phases where water was present permanently (in most years): 1972–1977 and 1989–1995 at Thomsons Lake; and 1972–1982 and 1989–1993 at Forrestdale Lake. The lakes have also experienced two periods of annual drying (in most years): 1978–1988 and 1996–present at Thomsons Lake; and 1983–1988 and 1994–present at Forrestdale Lake. Neither lake dried completely in 1990 when they were designated as a Ramsar site, but have dried completely in most years since that time.

**Timing of inundation/drying during dry phases**

In addition to drying for longer periods of time, Forrestdale and Thomsons Lakes are also drying out earlier than in previous years. During the annual drying phase in the 1980s, both lakes tended to dry completely in January, February or March. Since 2000, the lakes have been drying mostly during December and January.

**2.2.3 Physio-chemistry**

**Temperature, mixing and thermal stratification**

Wind-mixing processes dominate the physical structure of Forrestdale and Thomsons Lakes, preventing the formation of thermally stratified layers for prolonged periods of time. This general low stability indicates that these lakes can be classified as continuous or discontinuous warm polymictic lakes (Davis et al. 1993). The major mixing force in the lakes is produced by the shearing effect of the wind at the surface of the water body. Forrestdale and Thomsons Lakes would be completely mixed by winds less than 5 m s\(^{-1}\) because they are less than 2 m deep and have large surface area relative to their depth. Mean annual wind speeds in Perth are greater than 5 m s\(^{-1}\) in the afternoon (Bureau of Meteorology 2008), and wind speeds are higher during the summer months when thermal stratification is more likely to occur.

**Light, colour and turbidity**

Davis et al. (1993) found that turbidity, colour (gilvin) and chlorophyll concentration had the most significant effects on light attenuation in wetlands on the Swan Coastal Plain, including Forrestdale and Thomsons Lakes. Light is of great importance to biological processes in wetlands, in particular to
photosynthesis, and can influence whether a wetland is dominated by submerged and emergent macrophytes or phytoplankton.

Coloured compounds mostly consist of the breakdown products from plant material and phytoplankton, largely humic and fulvic acids. The lakes have historically been weakly coloured and generally clear, probably because there is little inflow of surface water, other than the drainage that Thomsons Lake has received through the supplementation program since 2004. The turbidity of Thomsons Lake was high in spring 1990 (75.0 NTU) due to the large standing crop of phytoplankton in the lake. However both lakes have generally maintained low turbidity levels during spring.

**Salinity and pH**

The major factors that control the salinity of freshwaters are the catchment geology, atmospheric precipitation and evaporation-precipitation processes. There are also a number of pollutants such as wastewater from septic systems, roads, and agricultural areas that may contribute salts. Lakes that are very shallow and have a large surface area, such as Forrestdale and Thomsons, tend to evaporate rapidly in summer and reach high salinities as a result of evapoconcentration (Davis et al. 1993). Such seasonal patterns were evident at both lakes, but have been much stronger at Forrestdale Lake. From May 1985 to May 1990, the salinity of Thomsons Lake ranged from fresh in winter (as low as 1,290 mS cm⁻¹) to brackish in summer (up to 8,350 mS cm⁻¹). Forrestdale Lake was also fresh during winter (as low as 1,200 mS cm⁻¹) but reached much higher salinities in summer before the lake dried out (up to 19,900 mS cm⁻¹). Salinity levels have remained relatively stable in both lakes over the longer term. Salinity is a major factor influencing the invertebrate species composition of wetlands (Davis et al. 1993). Apart from wetlands in the western Beeliar chain, which are naturally saline (due to a prior marine influence), anthropogenic salinisation does not seem to have affected wetlands on the Swan Coastal Plain. The flora and fauna that have evolved in these wetlands are able to cope with moderate levels of salinity, but few can survive unnaturally high salinities. Increased salinity levels in the wetlands would cause the invertebrate communities to shift to more salt tolerant species and so reduce the number of species present (Balla 1994).

Both lakes have historically had a neutral to alkaline pH. pH appears to be the most important correlate for the potential presence and proliferation of cyanobacteria in wetlands of the Swan Coastal Plain during the warmest months (Davis et al. 1993). Cyanobacteria or blue-green algae tend to form large scums that are aesthetically unpleasant and release noxious odours on decay. They release toxins that are harmful and potentially fatal to a wide range of fauna. Wetlands with a pH greater than nine have been associated with highly nutrient enriched conditions and algal blooms (Davis et al. 1993).

**Nutrients**

Both lakes have been moderately enriched since measurements began in the early 1970s. Phosphorus is of great importance in freshwater ecosystems because it is often the nutrient limiting primary production (Davis et al. 1993). In their natural state, Forrestdale and Thomsons Lakes probably received and lost most of their phosphorus through groundwater flow and sedimentation. However, since European settlement, these wetlands have had artificial drains entering or leaving them and these drains have probably largely altered the dynamics of phosphorus budgets in these wetlands. Drainage and land use adjacent to Forrestdale Lake contributes to phosphate and nitrate concentrations in the lake (ERM 2000, Department of Water 2009). These nutrients originate from a variety of point and diffuse sources associated with rural and urban land use (CALM 2005). High phosphate concentrations in the area are thought to be primarily from fertiliser, detergent use and
sewerage, and nitrate from septic tank effluent, fertiliser and animal manure (Department of Water 2009).

Nutrients that enter the lake tend to accumulate and become trapped in the sediment. Large reservoirs of nutrients can be held in the sediments and under certain conditions these may be released and recycled to the water column, providing a potentially major source of nutrients. The release of phosphorus from lake sediments into the water column is reduced with the current summer drying regime at Forrestdale and Thomsons Lakes.

Nutrient export during such dry phases occurs through a variety of mechanisms including use of nutrients by plants and animals, volatilisation of the nutrients to the atmosphere, wind blowing the nutrients (in the form of dead plant and animal material) out of the dry lake, and oxidation of nutrients so that they are accessible and used as soon as the lake floods instead of accumulating over time (CALM 2005a, b). Nutrient enrichment can result in the loss of submerged macrophytes and their replacement with green algae and cyanobacteria (blue-green algae). Such algal blooms have been recorded occasionally at the lakes. Large algal blooms can result in foul odours, low oxygen levels, and can have toxic effects on invertebrates and birds (Balla 1994). Low dissolved oxygen concentrations result in a reduction in invertebrate diversity, with only the most tolerant of species surviving in large numbers. Low oxygen levels and elevated water temperatures result in conditions favourable to growth of the bacterium, *Clostridium botulinum*, and subsequent outbreaks of botulism among waterfowl (Balla 1994). A small outbreak of botulism occurred at Forrestdale Lake in 1984; however no further outbreaks have been recorded (Bartle et al. 1987). Decaying algal blooms also provide an extensive food source for larval midges (Pinder et al. 1991). Concentrations of total phosphorus above 100µg/L are often associated with poor water quality and midge swarms.

### 2.2.4 Ecology

**Fauna**

**Mammals**

Seven species of mammal have been recorded at Forrestdale and Thomsons Lakes though surveys for mammal species within the reserves have been limited. Six species of mammal have been recorded at Thomsons Lake including the Quenda (*Isoodon obesulus fusciventer*) (Priority 5: conservation dependent species); the Western Grey Kangaroo (*Macropus fuliginosus*), Western Brush Wallaby (*Macropus irma*) (Priority 4: rare, near threatened and other species in need of monitoring); the Brush-tailed Possum (*Trichosurus vulpecula*); the Numbat (*Myrmecobius fasciatus*) (specially protected under the *Wildlife Conservation Act 1950* as a threatened species with a ranking of vulnerable), although not recorded in the reserve since 1984; and the Native Water Rat (*Hydromys chrysogaster*) (Priority 4). The Swan Coastal Plain has nine species of insectivorous bats, some of which are likely to use the reserve for occasional foraging, if not permanently (CALM 2001). Four mammal species have been identified at Forrestdale Lake including the Quenda; Western Grey Kangaroo; the White-striped Mastiff Bat (*Tararida australis*); and the Western Brush Wallaby (*Macropus irma*) (Priority 4), although few have been recorded since the 1960s and are believed to no longer inhabit the area. Introduced mammal fauna that occur at the Reserves include mice, rats, foxes, feral and domestic cats, dogs and rabbits.
**Reptiles and Amphibians**

Seven frog species have been recorded at Forrestdale and Thomsions Lakes. Tschudi's Froglet (*Crinia georgiana*), the Moaning Frog (*Heleioporus eyrei*), Banjo Frog (*Limnodynastes dorsalis*), Western Sign-bearing Froglet (*Crinia insignifera*), Slender Tree Frog (*Litoria adelaidensis*) and Motorbike Frog (*Litoria moorei*) have been recorded at both wetlands. Gunther's Toadlet (*Pseudophryne guentheri*) has also been recorded at Forrestdale Lake (Bartle et al. 1987). The Turtle Frog (*Myobatrachus gouldii*) was recorded at Thomsions Lake in the 1970s (Crook and Evans 1981), but has not been recorded since (CALM 2005b). No native fishes have been recorded. The introduced *Gambusia holbrooki* was present under a permanent water regime in the early 1990s but disappeared when the lake reverted to a seasonal drying regime (Davis and Brock 2008).

Long-necked turtles (*Chelodina oblonga*) are present in both lakes. Other reptile species comprising 12 lizard species and three species of snake have been recorded at Thomsions Lake Reserve (Crook and Evans 1981). Nine lizard species and five snake species have been recorded at Forrestdale Lake Reserve (Bartle et al. 1987). Three of the reptile species are significant because they are scarce or rare in the area and have relatively localised distributions: the Swamp Skink (*Acritoscincus trilineatum*); Lined Skink (*Lerista lineata*) (Priority 3: Poorly known species, some on conservation lands) and; Crowned Snake (*Notechis coronatus*) (State of Western Australia 2000).

**Aquatic Invertebrates**

Aquatic invertebrates are responsible for a significant proportion of secondary production occurring in wetlands and form two interconnected food chains: a grazing food chain and a detrital food chain. Both food chains play important roles in the functioning of wetland ecosystems. Grazers maintain good water quality by feeding upon algae while decomposers process the organic material of the lake bed (Davis and Christidis 1997). Macroinvertebrates are an important component of wetland food webs, comprising much of the diet of many faunal species, including migratory waders and other waterbirds, and turtles (CALM 2001).

Seasonal wetlands have high invertebrate species richness compared to permanent wetlands and this appears to be related to the higher biomass and diversity of aquatic plants present (Balla 1994). When the wetlands dry, many terrestrial plants temporarily colonise the bed of these wetlands. When this vegetation is flooded, it decomposes and releases nutrients, which supports the growth of aquatic plants and provides a food source for detrital-feeding invertebrates. Vegetation also offers suitable habitats for invertebrates to live and avoid predators.

The aquatic invertebrate fauna of the wetlands on the Swan Coastal Plain is diverse and abundant. Over 280 invertebrate species have been collected from 40 wetlands on the Swan Coastal Plain (Davis et al. 1993). Macroinvertebrates have been the subject of several studies at Thomsions Lake and Forrestdale Lake (Davis and Rolls 1987; Rolls 1989; Pinder et al. 1991; Balla and Davis 1993, 1995; Davis et al. 1993; McGuire and Davis 1999; Wild et al. 2003; Wild and Davis 2004; Davis et al. 2008). A large diversity of species exists within the Ramsar site. Macroinvertebrates from a total of 59 families and three taxa identified only to order, were collected at Thomsions Lake from 1985–2007, including two annelids, 4 molluscs, 15 crustaceans, 8 arachnids and 33 insects. Macroinvertebrates from a total of 40 families and three taxa identified only to order, have been collected at Forrestdale Lake from 1986–2007, including two molluscs, 12 crustaceans, 7 arachnids and 22 insects. Fewer invertebrate families have been recorded at Forrestdale Lake, most likely because less frequent sampling has been carried out than at Thomsions Lake.
Forrestdale Lake is one of only three sites in the world which are known to support the Critically Endangered (EPBC Act) Short-tongue bee *Leioprotactus dougaliius*. Forrestdale Lake is also one of only a few known locations of the Critically Endangered (EPBC Act) native bee, *Neopasiphae simplicior*.

**Terrestrial Birds**

The margins of both lakes support diverse and abundant terrestrial bird life; 66 species have been recorded at Thomsons Lake and 81 species at Forrestdale Lake. Both lakes provide habitat for Carnaby’s Black-cockatoo (*Calypnorhynchus latirostris*), which is listed as endangered under the EPBC Act, as rare or is likely to become extinct under the Wildlife Conservation Act 1950 (Wildlife Conservation (Specially Protected Fauna) Notice 2008) and as endangered on the IUCN Red List of Threatened Species. Three species are listed under Australian Migratory Bird Agreements, the Fork-tailed swift (*Apus pacificus*) has been recorded once at Forrestdale Lake in March 2000, while the Rainbow Bee-eater (*Merops ornatus*) and the White-bellied Sea Eagle (*Haliaeetus leucogaster*) are regular visitors to both Forrestdale and Thomsons Lakes and have been recorded in most bird surveys. Other species that are listed under the Western Australian Wildlife Conservation Act 1950, that are infrequent visitors include the specially protected Peregrin Falcon (*Falco peregrinus*) and the rare, near threatened Red-tailed Tropicbird (*Phaethon rubricauda*).

**Waterbirds**

Waterbirds depend on wetlands for a variety of activities including feeding, breeding, nesting and moulting. Waterbirds are often found at seasonal wetlands but move to permanent lakes and estuaries in summer and autumn when seasonal wetlands are dry (Balla 1994). The annual cycle of waterbird usage at Forrestdale and Thomsons Lakes is marked and noticeably regular as a result of winter filling, spring summer drying and as a function of annual migrations by shorebirds. A small peak in numbers of individuals using the Ramsar site occurs in early winter due to the persistence of shallow mud flats as the lakes slowly fill. In summer, bird numbers reach their maximum. The summer peak is attributed to the availability of ideal feeding conditions for many species and includes influxes of waterbirds from drying wetlands in the surrounding district (Jaensch, 1988). Jaensch (2002) described a series of guilds, grouping species that share a common set of ecological requirements or behaviour patterns.

For the purposes of the Condition Statement for the Forrestdale and Thomsons Lakes Ramsar Site, the discussion has been limited to birds that are considered wetland dependant and so excludes terrestrial birds recorded in adjacent landscapes. Wetland dependant in this context is defined as birds that are dependent on the habitats and vegetation that are considered to require periods of inundation (Hale and Butcher 2007).

Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain with 85 species of waterbird occurring at the two lakes and 27 have been recorded breeding. Twenty-nine of the recorded species are protected by the Japan-Australia Migratory Bird Agreement (JAMBA), the China-Australia Migratory Bird Agreement (CAMBA), Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA) and the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention). Seventy-three waterbird species have been recorded at Thomsons Lake, including 20 species that are protected by JAMBA, CAMBA, ROKAMBA and Bonn Convention. Seventy-six waterbird species have been recorded at Forrestdale Lake, with 23 of these
protected by JAMBA, CAMBA, ROKAMBA and Bonn Convention. All migratory species listed under JAMBA, CAMBA, ROKAMBA and Bonn Convention are protected by the EPBC Act.

**Diversity and abundance**

Monitoring of waterbirds over the period 1999–2008 showed the abundance of waterbirds at Forrestdale Lake fluctuated widely but decreased in the most recent years monitored, while species richness remained relatively constant (Figure D22). There has been no monitoring since 2008. Abundance declined since 2005, following a period of often low but occasionally very high counts, leading to a running mean that increased by a series of steps before trending downwards (Figure D22). Lake Forrestdale has experienced influxes of Black-winged Stilts but migratory shorebirds have been virtually absent since the early years of surveys.

Over the same monitoring period the abundance and species richness remained relatively at Thomsons Lake. The wide fluctuations in abundance in early years were due to fluctuations in numbers of migratory shorebirds and large numbers of Grey Teal and Silver Gulls in the late 1990s and early 2000s (Figure D23).

![Figure D22](image) : Running mean abundance of waterbirds (black line) and species (grey line) counted at Lake Forrestdale
When last conducted in 2008, monitoring of waterbirds at lakes Thomsons and Forrestdale showed (Bancroft and Bamford 2009):

- species richness and abundance of migratory shorebirds has declined, probably because of habitat change due to the encroachment of riparian vegetation across the lake floor;
- encroachment of riparian vegetation across the lake floor has favoured Black Swans. They now breed in moderate numbers at both lakes whereas they did not do so previously; and
- the lakes are important for foraging by ducks and waders, although this effect has declined due to plant invasion of the wetland floor.

Variations and declines in the abundance of many waterbird species on the Jandakot wetlands from 1996–2006 could largely be explained by the availability of alternative coastal and inland sites. Cyclones that created extensive ephemeral wetlands in inland areas occurred in 1997, 2001 and 2005/2006, and resulted in falls in the abundance of many waterbird species in individual wetland sites, while maintaining abundance of waterbird species over the whole region (Bamford et al. 2010). Migratory waterbirds are subject to threats and conditions existing at all of their landing sites in their flyway.

The number of surveys conducted at each lake has ranged from 0 to 50 per year since 1981. Some caution must be applied to the interpretation of the survey data because the differences in the number of surveys conducted each year, and in monitoring methods, will have had an impact on some bird records. However, consistent monitoring of waterbirds at the lakes was undertaken as part of the monitoring program for the Public Environmental Review and Environmental Management Program of the Jandakot Groundwater Scheme Stage 2 from 1996 to 2008 by Bamford Consulting Ecologists.

Forrestdale and Thomsons Lakes provides important habitat for waterbirds on the Swan Coastal Plain. The highest number of waterbirds counted at Thomsons Lake was 21,083 in February 1987, and more than 10,000 waterbirds have been recorded in several years. Species occurring in significant numbers at Thomsons Lake include:
Australasian Shoveler 2,000 Mar 1982
Australian Shelduck 1,600 Nov 1982
Black-winged Stilt 3,000 Feb 1986
Curlaw Sandpiper 2,500 Mar 1983
Eurasian Coot 7,000 Feb 1987
Grey Teal 6,000 Feb 1986
Hoary-headed Grebe 1,500 Nov 1982
Pacific Black Duck 4,500 Dec 1985
Red-capped Plover 1,000 Feb 1986
Red-necked Avocet 2,000 Mar 1983
Red-necked Stint 2,500 Mar 1983
Sharp-tailed Sandpiper 1,000 Jan 1986

The highest number of waterbirds counted at Forrestdale Lake was 22,196 in January 1986 and at least 10,000 have been recorded in several years. Species occurring in significant numbers at Forrestdale Lake include:

- Australasian Shoveler 2,000 Jan 1984
- Australian Shelduck 1,650 Jan 1985
- Black Swan 1,416 Feb 1987
- Black-winged Stilt 3,840 Dec 1985
- Curlaw Sandpiper 2,000 Jan 1983
- Eurasian Coot 7,670 Jan 1987
- Grey Teal 9,000 Mar 1987
- Hardhead 1,053 Oct 1982
- Hoary-headed Grebe 1,890 Jan 1987
- Pacific Black Duck 5,500 Mar 1987
- Red-capped Plover 1,300 Mar 1987
- Red-necked Stint 3,000 Mar 1982

A review of the Ramsar Information Sheet in 2003 determined that the Ramsar site was also considered to meet the criterion now referred to as Criterion 5. The justification stated that “More than 20,000 waterbirds have been recorded on both Thomsons Lake (21,083 in February 1987) and Forrestdale Lake (22,196 in January 1986). Annual data on water depth indicates that conditions at both lakes are suitable for use by more than 20,000 waterbirds at least several times within a 25 year period; in the context of wetland availability in Western Australia, this is considered sufficient evidence of regular use by 20,000 waterbirds.”

It appears that these two counts alone were used as justification to support Criterion 5. Single counts are used at some Ramsar sites where little information is known, to establish the importance of the site for a species, particularly if the areas are remote or there are other constraints in undertaking
regular waterbird surveys. However, in this case, there are a sufficient number of waterbird surveys to apply the current Ramsar definition of “regularly” under this Criterion. The existing waterbird data for the site does not support the current Ramsar definition of “regularly” and it in 2009 the conclusion was made during a review of the Ramsar Information Sheet that the site does not meet Criterion 5.

In the 1998 update of the Ramsar Information Sheet, the criteria applicable to the site included the finding that Forrestdale Lake was an important area for the Long-toed Stint (*Calidris subminuta*) in south-western Australia and supported over 1% of the regional population. The current Ramsar Guidelines state that it is important to recognise that Criterion 6 must be applied to the biogeographic population of a species or subspecies of waterbird, which is in most cases larger than the territory of one Contracting Party. The Guidelines also specify that it is not a correct justification to list populations with numbers in the site >1% of their national population, except when the population is endemic to that country. The Long-toed Stint population, which occurs in the Asia and Oceania biogeographic regions, is estimated at around 25,000, and thus the 1% level as 250 (Wetlands International 2006). Eighty birds were observed in summer 1980, and up to 26 have been observed since 1981. Therefore, the Long-toed Stint does fulfill the current requirements for listing under Criterion 6. However, as noted previously, some caution needs to be applied to this interpretation because the reduced frequency of surveys in recent years may have resulted in insufficient count data.

Forrestdale and Thomsons Lakes have supported more than 1% of the population of four waterbirds in several years: Australasian Shoveler, Black-winged Stilt, Blue-billed Duck, and Red-capped Plover. However, for listing under Criterion 6, the wetland must “regularly” support 1% of the population. Since Forrestdale and Thomsons Lakes have not supported 1% of the population of these waterbirds in recent times (from 4 to 18 years) the Ramsar site does not meet the requirements for listing under Criterion 6.

Thomsons Lake was considered one of the last remaining refuges within the Swan Coastal Plain for the threatened Australasian Bittern *Botaurus poiciloptilus*. One to two Australasian Bittern were recorded at Thomsons Lake in six consecutive years 1981–1987 (one in four years and two in three years) inhabiting tall sedgeland with enclosed areas of shallow open water or low sedges. They were not recorded to be breeding, however conditions were probably suitable. The Australasian Bittern population size is estimated to be around 500 (Wetlands International 2006), and this species is listed as a vulnerable species in the IUCN Red List of Threatened Species. However, this species has not been recorded at Thomsons Lake since 1991.

Pectoral Sandpiper *Calidris melanotos* (up to 4) and Ruff *Philomachus pugnax* (one) occur at Thomsons Lake in some years. Forrestdale Lake is one of the few sites in Western Australia where Little Ringed Plover *Charadrius dubius* and Little Stint *Calidris minuta* have been recorded more than once, and it is the only location in Western Australia where White-rumped Sandpiper *C. fuscicollis* have been recorded. None of these species have been recorded since the 1980s. However, the species recorded at Forrestdale Lake in particular are vagrants and it is remarkable they were ever recorded. Very few Ruff and Pectoral Sandpipers have been recorded in south-western Australia and although are not considered to be as vagrant as the Little Stint, they are rare migrants and also unpredictable. It is therefore unsurprising that these species have not been recorded since the 1980s.

**Variability**

Large, open wetlands on the Jandakot Mound support maximum numbers of waterbirds when water levels are low, declining in early summer. Waterbird numbers are especially high on Forrestdale and
Thomsons Lakes when they are extremely shallow and appear to be important for foraging by ducks and waders. These wetlands are usually dry by late summer. Waterbird numbers on wetlands of the Swan Coastal Plain are determined both by local conditions, such as rainfall, and by the availability of wetlands elsewhere in the state.

The maximum number of waterbirds appears to have declined at Forrestdale and Thomsons Lakes since the mid-1980s and the number of species recorded at each lake has been variable. However there has been no systematic survey and reporting of abundance, species composition or breeding. The number of surveys conducted each year has varied dramatically, and appears to affect the maximum number of birds and species recorded. The data used in this report are conservative and additional species including the Sharp-tail Sandpiper, Curlew Sandpiper, Sanderling, Red-necked Stint and Grey Plover, have been recorded at the lake recently (Pickering, pers. comm.).

Twelve wetlands on the Jandakot Mound in the Perth region, including Forrestdale and Thomsons Lakes, have been surveyed in autumn/winter, spring and early summer from 1996 to 2008. Bamford and Bancroft (2007) found that since 1996, waterbird numbers were variable but generally tended to decline. They found that low counts of many species and low total counts occurred in years of low water levels, and attributed the generally high numbers of 2005 to high water levels. However, variations and declines in the abundance of many waterbird species on the Jandakot wetlands from 1996–2008 could largely be explained by the availability of alternative coastal and inland sites. Cyclones that created extensive ephemeral wetlands in inland areas occurred in 1997, 2001 and 2005/2006, and resulted in falls in the abundance of many waterbird species in individual wetland sites, while maintaining abundance of waterbird species over the whole region (Bamford and Bancroft 2007).

In their study of wetlands on the Jandakot Mound, Bamford and Bancroft (2007) found that local conditions were particularly important for diving waterbirds that do not use inland wetlands and migratory waders (shorebirds). Blue-billed and Musk Ducks have declined in abundance on the Jandakot wetlands, probably because successive years of low water levels have led to poor breeding success (Bamford and Bancroft 2007). As these waterbirds require deep permanent water (Frith 1957; Braithwaite and Frith 1968), their reduced abundance is expected to some degree during annual drying phases that do not favour these, or other, diving species. The Eurasian Coot, a primarily herbivorous species that forages on submerged aquatic plants, has also decreased in abundance in recent years, which suggests that such vegetation has decreased in abundance (Bamford and Bancroft 2007). Seasonal drying generally favours wading birds that require shallow water or exposed mudflats; however these species have also dramatically declined in abundance (Bamford and Bancroft 2007).

The general decline in the number of migratory waterbird individuals and number of species recorded at Forrestdale and Thomsons Lakes is also evident when all available data are pooled. The decline in the abundance of migratory waterbirds is particularly noticeable, despite similar numbers of observations having been conducted in some years. For example, many more migratory waders were recorded at Forrestdale Lake in 1991 and 1997 than any year since 1998, despite a similar or greater number of surveys having been conducted each year. Although the number of surveys conducted each year has varied, increased sampling effort does not appear to have as strong an effect on the number of birds or species recorded. Bamford and Bancroft (2007) attributed the ‘virtual disappearance’ of migratory waders to loss of habitat due to the encroachment of riparian vegetation across the lake floor, which has covered the open muddy shallows utilised by migratory shorebirds.
Vegetation

Phytoplankton

Relatively little is known about the phytoplankton communities of Forrestdale and Thomsons Lakes. Davis et al. (1993) identified phytoplankton at 41 wetlands on the Swan Coastal Plain in 1989–1990, the most common genera being the cyanobacteria *Anabaena* and *Microcystis*. Excessive growth of phytoplankton and cyclic algal blooms are usually indicative of severe eutrophication in wetlands. The abundance of phytoplankton in Forrestdale and Thomsons Lakes may be an important indicator of the ecological state of the wetlands.

Aquatic Plants

Extensive stands of the submerged macrophyte *Myriophyllum salusigenium* have been recorded in open water at Thomsons Lake (Halse et al. 1993). The floating macrophyte *Lemma spp* has also been recorded in this lake (Balla 1992). The submerged macrophytes *Ruppia polycarpa* and *Potamogeton pectinatus* sometimes form dense stands at Forrestdale Lake and 26 species of algae, notably *Chara spp*, have also been recorded (Bartle et al. 1987). However, the extent of aquatic plant communities of Forrestdale and Thomsons Lakes has not been mapped, and has not been monitored regularly. Like phytoplankton, the abundance of aquatic plants may also be an important indicator of the ecological state of the wetlands.

Littoral Vegetation

The littoral vegetation of Forrestdale and Thomsons Lakes has been mapped using aerial photographs, with limited ground checking (Arnold 1990). *Typha orientalis* and *Baumea articulata* grow around the edge of Thomsons Lake. As water levels drop, *Bolboschoenus caldwellii* becomes established on the newly exposed mudflats inside the fringing zone. In 2008, the small perennial herb *Suaeda australis* was abundant across much of the dry lake bed at both Forrestdale and Thomsons Lakes. This plant is more commonly found at coastal sites, saline swamps and creeks.

Behind the fringing zone is a belt of *Baumea juncea* and *B. articulata* with emergent *Viminaria juncea* and *Acacia saligna* shrubs. This gives way to a belt of trees, *Eucalyptus rudis* and *Melaleuca preissiana*, and the shrub *Jacksonia furcellata*. As the ground rises these are replaced by open forest or woodland dominated by *Eucalyptus marginata*, *Banksia menziesii* and *B. attenuata*. Keighery (2002a) surveyed the vascular flora of Thomsons Lake and identified 491 taxa, including 360 native and 131 introduced species. Previous flora surveys at Thomsons Lake Nature Reserve identified one Priority taxa *Dodonaea hackettiana* (State of Western Australia 2000). Keighery (2002a) further identified one ‘Declared Rare Flora’ species listed under the Wildlife Conservation Act 1950, *Caladenia huegelii*, and two Priority taxa, *Cardamine paucijuga* and *Eryngium pinnatifidum subsp. palustre ms.*

Around the water's edge at Forrestdale Lake there is an almost continuous belt of *Typha orientalis*, behind which *Baumea articulata*, *B. juncea*, *Juncus pallidus*, *Bolboschoenus caldwellii* and *Gahnia trifida* sometimes grow. Beyond these is a belt of trees, principally *Melaleuca rhaphiophylla*, with some *M. preissiana*, *M. incana*, *M. cuticularis*, *M. lateritia* and *Banksia littoralis* also present. *Acacia saligna* and *Eucalyptus rudis* occur on the landward side of this zone. The higher sandy ground on the eastern side of Forrestdale Lake supports open woodland dominated by *Banksia attenuata*. 

There are two Threatened Ecological Communities within Bush Forever site 345 (Forrestdale Lake and adjacent bushland, Forrestdale) approximately 60 m east of Forrestdale Lake Nature Reserve and the Ramsar site boundary (State of Western Australia 2000): (1) ‘herb rich shrublands in clay pans’ are listed as vulnerable in Western Australia and consist of clay pan communities that can be dominated by *Viminaria juncea*, *Melaleuca viminea*, *M. lateritia* or *M. uncinata* but occasionally by *Eucalyptus wandoo* and aquatic annuals are also common (Gibson et al. 1994) and; (2) ‘shrublands on dry clay flats’ are listed as endangered in Western Australia and form on the most rapidly drying of the clay flats. Both communities are included under the nationally listed TEC ‘Claypans of the Swan Coastal Plain’, which is listed as Critically Endangered under the EPBC Act. They contain aquatic annuals and geophytes such as *Schoenus natans*, *Crassula natans* and *Amphibromus neesii* (Gibson et al. 1994). A Priority Ecological Community ‘Northern Spearwood shrublands and woodlands’ (Priority 3: poorly known ecological communities) is located within Thomsons Lake Nature Reserve and the Ramsar site boundary.

The introduced Bulrush *Typha orientalis* first appeared at Forrestdale Lake in 1976 and at Thomsons Lake in the 1980s. Since that time it has established and now covers expansive areas of the water’s edge. Although plant colonisation of dry wetlands is a naturally occurring event, the presence of a large number of weed species is likely to have been influenced by the drier conditions and the proximity of urban and rural land use activities (Davis et al. 2008). After a prolonged drying phase in recent times, colonies of *Typha* have invaded both lakes, and this seems likely to continue while drier conditions persist (Davis et al. 2008). *Typha* has the potential to further significantly reduce the area of open water and displace and change riparian vegetation at these lakes and hence alter waterbird habitat. Low counts of migratory wader species in recent years has been attributed to encroachment of riparian vegetation across the lake bed at Forrestdale and Thomsons Lakes, which has decreased the amount of mudflats available for wading birds (Bamford and Bancroft 2007). Pampas grass *Cortaderia selloana* and Arum Lily *Zantedeschia aethiopica* have also established at both lakes and are problematic weeds.

### 2.2.5 Social and cultural values

**Indigenous heritage**

At the time of colonisation, three Aboriginal communities occupied Perth, one of which was the Beeliar community (Seddon 1972). The wetlands of the eastern and western chain of what is now Beeliar Regional Park, including Thomsons Lake, were part of the Beeliar District, which extended south of the Swan River. Beeliar Regional Park is significant to the local Aboriginal people, as parts of it were important camping and food source areas (Polglaze 1986). The eastern chain, and hence Thomsons Lake, is said to have been part of a major trade route between Aboriginal people in the Swan and Murray River areas. The lakes of Beeliar Regional Park also hold importance as spiritual
and mythological locations and the wetlands provided an important link to the natural context, cultural traditions, spiritual life and history of the Aboriginal people of the Swan Coastal Plain (Polglaze 1986).

According to Noongar tradition, wetlands, waterways and lakes are said to be the home of the powerful water serpent figure, the Waugal. The Waugal is spiritually and mythologically important to Aboriginal people who believe that it created rivers and lakes, and maintains the flow of waters that feed its resting places. According to Noongar beliefs, these places are described as winnatch, (an area that is avoided, usually for reasons of cultural or religious significance) and consequently require the highest respect and reverence in the way they are considered, used and valued.

As well as the mythological status, the lakes were a source of turtles for people from Pinjarra, Mandurah and Armadale. Seasonal camps were usually established under the shelter of surrounding melaleuca scrub in Forrestdale Lake’s northwestern edge, and some groups set up semi-permanent camps for extended periods on their way from the Darling Plateau to the coast (O’Conner et al. 1989; Gray 1994). Thus, the lake has significance both as a turtle hunting site, and for these campsites at the lake.

In Western Australia, the *Aboriginal Heritage Act 1972* (Aboriginal Heritage Act) protects places and objects customarily used by, or traditional to, the original inhabitants of Australia. Five sites within Thomsons Lake Nature Reserve and two within Forrestdale Lake Nature Reserve are listed on the Department of Indigenous Affairs’ Register of Aboriginal Sites. The sites at Thomsons Lake include a ceremonial, mythological and historical site, a hunting site, and three sites with archaeological artefacts. The sites at Forrestdale Lake include a hunting site, and a site containing archaeological artefacts. Both reserves are covered by one registered native title claim by the Combined Swan River and Swan Coastal Plains Native Title Claimant Group.

**Non-indigenous heritage**

**Thomsons Lake**

In the late 1800s, during the gold rushes, market gardens were established on the land surrounding many of the wetlands of the Swan Coastal Plain. At Thomsons Lake, a proposed grazing lease was rejected in 1954 based on the area’s value as habitat for native fauna, and in 1955 the reserve’s purpose was changed from ‘Drainage’ to ‘Drainage and Conservation of Fauna’. During this time, and into the 1960s, the as yet unvested reserve was being used by adjoining landholders for cattle grazing and the vegetation was being cut for firewood, with both practices having an impact on the reserve’s vegetation (Crook and Evans 1981). Land was excised from the reserve in 1962 for a prison site and again in 1969 for the University of Western Australia’s Marsupial Breeding Station. The development of land around the reserve mainly occurred during the 1960s, and by 1968, most of the private land to the east and southwest had been subdivided (Crook and Evans 1981). The managing agency at the time, the Department of Fisheries and Fauna, sought vesting of the reserve. This was agreed to on the proviso that the lake could still be used as required for drainage purposes: consequently the reserve was vested in the then WA Wildlife Authority for its current purpose of ‘Fauna Conservation and Research and Drainage’ (Crook and Evans 1981). At the time the reserve was transferred to the Wildlife Authority, the lake was used for water skiing. Since then, the Nature Reserve has become increasingly popular with the local community as a place for nature appreciation, in particular birdwatching and bushwalking.
**Forrestdale Lake**

The first non-Aboriginal settlement at Forrestdale Lake (then known as Lake Jandakot) occurred in 1885, when William and Alfred Skeet were granted a ‘Special Occupation’ licence for 100 acres adjoining the Lake, as well as licences to cut and sell timber. Early settlers in the Forrestdale Lake area commenced farming in 1893 on the edge of Commercial Road. Large areas of land were soon utilised for farming around Taylor Road. Other settlers soon followed and the Lake Jandakot settlers cleared their land, experimented with crops and ran dairy cattle and poultry as viable commercial ventures (Popham 1980). By 1898, the area surrounding the Lake had been set aside as a Townsite Reserve. The Jandakot region soon became a thriving community, producing vegetables, apiary products and in later years, dairy produce for the Fremantle Markets. The prosperity of the region encouraged the construction of a railway between Fremantle and Jandakot, which in July 1907 was extended to Armadale for the purpose of transporting goods to the Fremantle Markets (Bartle et al. 1987).

From the 1920s, intensive agriculture gave way to sheep and cattle grazing, which continued over the next 50 years. During the 1940s, the west side of Forrestdale Lake was heavily grazed by sheep and cattle, particularly during the drier summers when land owners used the fringing vegetation to supplement feed from their paddocks. In 1957 interest developed in creating a Class A reserve around and including Forrestdale Lake, with the intention that the reserve be used for recreation, particularly sailing. Thus the reserve was gazetted for the ‘Protection of Flora and Fauna and Recreation’ (Bartle et al. 1987). Boating in hand-made canoes and catamarans was an important recreation activity at the lake. A Sailing Club was opened in the late 1950s to early 1960s when the lake rarely dried completely and regattas were held regularly (Giblett 2006). However, sailing could not continue as water levels declined and the lake dried more frequently. Recreation was removed from the purpose of the reserve in 1998, when it was changed to ‘Conservation of Flora and Fauna’.

The population in the Forrestdale area rapidly increased in the latter half of the 1960s as the townsite blocks to the northwest of the lake were taken up. Since that time, the population has slowly increased. The Friends of Forrestdale Lake has collected and transcribed a large number of oral histories about Forrestdale Lake (Giblett 2006).

**Aesthetic, recreation, science and education values**

The lakes now provide an attractive natural environment within a metropolitan region that people can view, enjoy, or otherwise appreciate. Forrestdale and Thomsons Lakes are the best remaining examples of large brackish, seasonal lakes with extensive fringing sedgeland characteristic of the Swan Coastal Plain. While these types of wetland were formerly common, extensive development of the Swan Coastal Plain has resulted in the loss of many of these wetlands, and most of the remaining wetlands of this type have been degraded through drainage, eutrophication and the loss of fringing vegetation.

Although Forrestdale and Thomsons Lakes are primarily reserved for nature conservation purposes, passive recreation that does not impact on natural values or ecosystems of the reserve is permitted. Considering the importance of Thomsons Lake as waterbird and shorebird habitat, it is not surprising that it is a popular destination for bird watchers, and that bird watching represents one of the main visitor activities at the site. Bushwalking is also a popular pursuit within the reserves. Horse riding is an historical use in both areas and the local community has identified horse riding as a key recreational value. However, horse riding is only allowed to occur outside the predator proof fence at
Thomsons Lake. This activity will be continually reviewed in light of environmental impacts, the demand for horse riding and conflicts of use with other visitors.

Research is included in the purpose for Thomsons Lake Nature Reserve and there are many opportunities for research within both reserves including studies of the lakes’ water quality and levels, groundwater interaction, invertebrates, waterbirds, and of terrestrial flora and fauna. Murdoch University has undertaken research into the macroinvertebrate community structure (which can be used as an indicator of wetland health) at Forrestdale and Thomsons Lakes since the 1980s.

Forrestdale and Thomsons Lakes provide an array of educational opportunities, and are popular with school and community groups, particularly in relation to learning about wetland ecology, as well as flora and fauna and indigenous heritage (CALM 2005a, b). The Cockburn Wetlands Education Centre also plays an important role in environmental education within the regional park, which includes Thomsons Lake.

### 2.3 PAST, EXISTING AND FUTURE THREATS

#### 2.3.1 Changes to hydrological regimes

Wetland water regimes have been under considerable pressure over recent years due to a combination of an increasingly dry climate, groundwater abstraction and the influence of drainage. Other factors contributing to pressures on the groundwater include changes in vegetation cover and the increasing presence of impervious surfaces associated with urbanisation. A CSIRO investigation of climate change (Bates et al. 2010), along with relevant global climate change models, predict a continuation of rainfall reduction in the south-west of Western Australia. The likely continued reduction in rainfall is a significant threat to the future of the Forrestdale and Thomsons Ramsar site.

Maximum water levels have generally been declining in both lakes since the 1960s, though were relatively high in the early 1990s when the lakes were listed as a Ramsar site. Since 1992, Forrestdale and Thomsons Lakes have experienced a general trend of declining peak lake levels, reduced hydroperiods and earlier drying, despite local Superficial Aquifer levels remaining relatively stable. However, peak levels at both lakes in 2013 and 2014 were the highest for a number of years.

Impacts of declining water levels include:

- Earlier drying has resulted in the encroachment of vegetation (predominantly *Typha orientalis*) onto the lake bed, subsequently decreasing the amount of mudflats available for wading birds. Encroachment has the potential to significantly displace and change fringing vegetation and hence alter waterbird habitat.

- Declining water levels have affected fringing vegetation around the lake, including *Melaleuca rhaphiophylla* and *Eucalyptus rudis* (Ladd 2001), and threaten the health and persistence of the surrounding vegetation.

- Lower peak water levels and shorter periods of inundation has resulted in poor breeding of waterbirds, especially swans, across the wetlands on the Jandakot Mound (Bamford and Bancroft 2007). Breeding typically occurs when water levels are high in late winter/early spring and a high winter/spring peak water level appears to be required to trigger breeding or allow breeding to be successful.
• The premature drying of Thomsons Lake has resulted in cygnets, which have not matured to a stage where they can fly, being trapped inside the predator proof fence while trying to find an alternative water source. Water supplementation has helped to alleviate this problem by diverting stormwater into the lake during winter so that water is present in November and December. This allows the cygnets to mature to a stage where they can fly to other water bodies (such as the Swan River Estuary) as Thomsons Lake dries up. The supplementation program is discussed in Section 2.4.2.

• The premature drying has also reduced the suitability of these lakes for migratory waterbird species, often arriving in November-December.

• Macroinvertebrates are greatly influenced by water depth and lower species richness has been recorded in dry years. Macroinvertebrates are an important component of wetland food webs, comprising much of the diet of many faunal species, including migratory waders and other waterbirds, and turtles (CALM 2001).

2.3.2 Urban development

Future urbanisation could, to some extent, offset the effects of reduced rainfall with the increasing presence of impervious surfaces leading to a higher percentage of rainfall entering the Superficial Aquifer as recharge than would occur under native vegetation. In the current climate of diminished rainfall, increased evaporation and a reduction in recharge to groundwater, increased recharge associated with impervious surfaces could help maintain water levels at the lakes. However urbanisation can also increase nutrient concentrations in the Superficial Aquifer. As such, as urban development increases in the catchments of the lakes, so does the threat of nutrient enrichment.

Nutrient enrichment (eutrophication) is an issue of ongoing concern at both lakes (Wild and Davis 2004) and their biological value may decline if high levels of nutrient loading continue. Forrestdale Lake, in particular, has a history of nutrient enrichment and poor water quality resulting from catchment activities including intensive animal feed-lots, commercial crop and domestic garden fertilisers, and possibly sewage leaching from septic tanks.

Nuisance swarms of non-biting midges (Chironomidae) occur seasonally at some wetlands on the Swan Coastal Plain as a response to warmer temperatures and poor water quality, especially nutrient enrichment. High densities of larval midges (in excess of 2,000 larvae/m²) are usually a response to an abundant algal food resource, which, in turn, is a response to elevated concentrations of nutrients. Davis and Christidis (1997) identified Forrestdale Lake as a problem site for midges. Large swarms of emerging adults are blown by prevailing south-westerly breezes into the Forrestdale townsite (which is located on the north-east corner of the lake). The need to use pesticides to control chironomids at Forrestdale Lake is a potential threat to aquatic invertebrate and bird life.

The City of Armadale began aerial spraying of Forrestdale Lake in 1975 to control larval midges. Since that time, the lake has been treated on an as-needs basis, as often as two or three times a year during spring and summer, using a granulated organophosphate known as Temphos. To help address the midge problems occurring at Forrestdale Lake, a monitoring program conducted by Murdoch University commenced in 1987, and a District Control Plan for treatment was put in place in 1991. There is some concern about the impact of Temphos, both on macroinvertebrates and the entire food chain. As a precaution, and to ensure waterbirds do not ingest Temphos granules, the lake is not treated if the water level is less than 30cm in depth. Large swarms of midges have not been evident at Forrestdale Lake in recent years because the lake has been dry over the summer period.
However, if the climate becomes wetter again, this could lead to a sharp increase in nutrient enrichment and issues with odours, toxic algae and midges.

Thomsons Lake is not currently identified as a midge problem area due to the wide vegetation buffer around the lake and the lack of residential development in close proximity to the reserve (CALM 2001). However, rapid urban expansion in a corridor immediately to the east of Thomsons Lake is now occurring. The nuisance midge problems that have been experienced by residents living near Forrestdale Lake suggest that similar problems may potentially occur at residential developments near Thomsons Lake under similar conditions (deeper water levels and eutrophic conditions).

Threats to wetland values can be mitigated by vegetative or other buffers, which are vital in maintaining the health of the system and habitat diversity (Bowen et al. 2002). The wide buffer of vegetation around Thomsons Lake helps to maintain water quality by reducing the influx of nutrients through filtration and storage, and acts as a physical impediment to the movement of midges. The vegetation buffer surrounding Forrestdale Lake is relatively narrow, hence the problems of midge swarms during wetter climatic regimes. Frequent fires will reduce the effectiveness of the buffer at Thomsons Lake by reducing the structure and cover of the vegetation canopy and understorey.

2.3.3 Fire

Unplanned fire is a significant threat to the natural values of the lakes. Infestations of *Typha orientalis* are fire hazards because fires in these bulrushes are difficult to control and can cause damage to fringing vegetation. Frequent wildfire in wetland areas will also prevent the establishment of paperbark vegetation and will lead to an even greater domination of *Typha*. Fire activity also encourages the invasion of *Typha* in wetland areas because it regenerates more rapidly than local rush species (CALM 2001).

2.3.4 Problem species – native and introduced

Over the past 20 years the area of *Typha orientalis* in the fringing vegetation of both lakes has increased substantially and poses a threat to their ecological character by changing floristics and reducing the amount of open water. Exposed mudflats around the lake are essential habitat and feeding ground for migratory waders. Furthermore, as the lake dries in summer, *Typha* dries off presenting a significant fire hazard. To ensure the continued presence of such birds it is essential that the amount of *Typha* and, where appropriate, native emergent rushes and sedges be controlled to prevent encroachment onto the lake bed. This will ensure that exposed mudflats remain available for utilisation by wading birds. The Department of Parks and Wildlife has undertaken *Typha* mapping at Thomsons Lake, which guides the *Typha* control program that has been implemented within the Ramsar site. This program is ongoing but intensity of control activities varies from year to year, depending on the on-ground priorities for the site.

Foxes and cats are considered to be a threat to wildlife at both lakes; however, the extent of their impact is currently unknown. Predation by foxes has, in the past, been identified as a threatening process for breeding waterbirds and other native fauna (Mawson 2002). In recent drier years, foxes have been seen preying on young cygnets at Forrestdale Lake (CALM 2005a). The potential of cats to prey on waterbirds, particularly hatchlings, is also a significant concern. In 1993, a predator proof fence was constructed around Thomsons Lake to protect native fauna by preventing feral animals from entering the reserve. A fox eradication program was also implemented. The fence does inhibit the movement of some native fauna (e.g. kangaroos, turtles and cygnets). However, the benefits of
the fence in protecting migratory waders, other fauna and their habitats, are considered to outweigh
the negative impacts. It is a proposed action to improve fencing to better manage access to
Forrestdale Lake but it is unlikely to include predator proof fencing as it is a larger lake with higher
public usage including a bridle path. Construction of a fence of the dimension that was constructed at
Thomsons Lake that would be effective in preventing cats and foxes from entering the site would
require extensive public consultation and currently budgets do not exist for such infrastructure
projects and their ongoing maintenance.

In some instances native fauna can also have adverse impacts on their environment. Thomsons Lake
Nature Reserve has a population of Western Grey Kangaroos confined within the predator proof
fence. Before the fence was constructed, in 1993, it was estimated that the kangaroo population of
the reserve was approximately 20–30 animals. A survey in April 2002 by Mawson (2002) counted 141
animals, comprising 67 adult males, 10 juveniles and 64 adult females and sub-adults, which has
further increased. In 2006/07 a culling program was carried out and 1,032 kangaroos were culled
initially (P. Mawson pers. comm.). This is far in excess of the kangaroo population at the reserve prior
to construction of the fence. Consequently, the biodiversity values of the reserve have been
significantly affected. Vegetation within the reserve, including the riparian zone, has been overgrazed,
habitat destroyed, flora values diminished and naturally occurring regeneration and plant succession
inhibited. Anecdotal evidence suggests that the number of orchid plants and species have decreased,
possibly as a result of over-grazing by kangaroos. In order to maintain the population at a sustainable
level, subsequent ongoing culling by shooting has occurred as necessary, with culling initiated
whenever the population reaches approximately 50 animals.

The Australian Raven (Corvus coronoides) at Thomsons Lake Nature Reserve has been found to raid
the nests of smaller birds and consequently drive them out (P. Jennings, pers. comm.). DEC has a
culling program in place, which may continue periodically at times when the species is considered a
problem (CALM 2006).

2.3.5 Disease

The disease known as ‘dieback’, caused by the pathogen Phytophthora cinnamomi, has been
recorded in the southeast section of Thomsons Lake Nature Reserve and the southeast section of
Forrestdale Lake Nature Reserve. Once infected by P. cinnamomi, susceptible plants are killed. As
many as 2,000 of the estimated 9,000 native plant species in the south-west of Western Australia are
susceptible to this pathogen. In field studies of south-western plant communities the families with the
highest proportion of susceptible species were Proteaceae (92 per cent), Epacridaceae (80 per cent),
Papilionaceae (57 per cent) and Myrtaceae (16 per cent) (Wills 1993; Wills and Keighery 1994). The
spread of this disease could lead to permanent changes to some native plant communities and their
dependent fauna. The Dieback Working Group undertook mapping of the dieback zone in 2014 and
when the results are available they will serve to assist in quarantining certain areas and managing
those areas that are currently infected. Of particular concern is the potential threat posed to the
Threatened Ecological Communities that occur in Forrestdale Lake Nature Reserve. However,
comprehensive surveys have not been conducted of the entire area. Therefore, the extent of the
current area of infection and impact on flora and fauna present in the area is currently unknown.
2.3.6  Acid sulfate soils

Both lakes have been identified as having high risk of acid sulfate soils, i.e. less than three metres from the soil surface (Swan Catchment Council 2004). This means that extensive digging, dewatering or drainage has the potential to cause considerable environmental damage.

2.3.7  Recreation

Although Forrestdale and Thomsons Lakes are primarily reserved for nature conservation purposes, passive recreation that does not impact on natural values or ecosystems of the reserve is permitted. The greatest threats to the values of the lakes from visitor access are from uncontrolled and unauthorised access by horse and trail bike riders. These activities may cause trampling and grazing of plants, spreading weeds and disease, disturb native fauna, and result in soil compaction and erosion. Excessive disturbance of waterbirds by humans and dogs may also occur, especially in summer and autumn when the lake is drying out. Rubbish dumping can also be an issue in these reserves.

2.4  EXISTING MANAGEMENT ARRANGEMENTS

2.4.1  Legislative protection and/or management requirements

Australia is a participant of, and signatory to, a number of important international conservation agreements that influence the management of the Forrestdale and Thomsons Ramsar site, by promoting consistent standards of management for wetlands. These are:

Convention on Wetlands of International Importance (Ramsar Convention)
CAMBA, JAMBA and ROKAMBA bilateral agreements relating to conservation of migratory birds
Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention)

At a national level the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) is the primary piece of legislation relating to Ramsar sites. This Act establishes a legislative framework for environmental protection and biodiversity conservation, including assessment and approvals of proposed actions, species and Ramsar site listing, recovery plans and management plans. The ecological character of Ramsar wetlands is one of the nine matters of national environmental significance under this Act. Any action that has had, will have, or is likely to have a significant impact on a matter of national environmental significance is required to undergo an environmental assessment and approvals process. The EPBC Act also establishes standards for managing Ramsar wetlands through the Australian Ramsar Management Principles, which are stated as Regulations under the Act and which describe the principles and guidelines for the management of Ramsar wetlands (Environment Australia 2001). The Native Title Act 1993 and Wetlands Policy of the Commonwealth Government of Australia 1997 are also relevant.

There is a suite of Western Australian legislation that is relevant to Ramsar sites, both in terms of protecting and managing the sites, but also for regulating potential impacts. The relevant legislation is listed below.

There are also a number of state, regional and local policies and planning schemes that relevant to Ramsar sites. These include:

- **Wetlands Conservation Policy for Western Australia 1997.** This policy outlines the WA Government’s commitment to identifying, maintaining and managing the State’s wetland resources, including the full range of wetland values, for the long term. It provides broad objectives for wetlands, waterways, estuaries and shallow marine areas, and provides an implementation strategy specifically for the management of wetlands in Western Australia. It also identifies the agencies involved and their responsibilities.

- **State Planning Policy 2.8 Bushland Policy for the Perth Metropolitan Region.** This policy provides a framework to ensure bushland protection and management issues in the Perth Metropolitan Region are appropriately addressed in the planning process, while also seeking to integrate and balance wider environmental, social and economic considerations. This will secure long term protection of biodiversity and associated environmental values of significant bushland areas. This policy provides the policy and implementation framework for Bush Forever areas shown in the Metropolitan Region Scheme. Thomsons Lake forms part of Bush Forever site 391 ‘Thomsons Lake Nature Reserve and Adjacent Bushland, Beeliar’ and Forrestdale Lake forms part of Bush Forever site 345 ‘Forrestdale Lake Nature Reserve and Adjacent Bushland, Forrestdale’.

- **Metropolitan Region Scheme.** The Forrestdale and Thomsons Lakes Ramsar Site is within this scheme and is reserved as Parks and Recreation.

- **Local Government Planning Schemes.** Local government authorities are responsible for planning for local communities by ensuring appropriate planning controls exist for land use and development. Thomsons Lake is located in the City of Cockburn and Forrestdale Lake is located in the City of Armadale.

### 2.4.2 Current management of the Ramsar site

**Land management**

The Department of Parks and Wildlife manages the Forrestdale and Thomsons Lakes Ramsar Site. Forrestdale and Thomsons Lakes are Class A nature reserves vested in the Conservation Commission of Western Australia. Thomsons Lake Nature Reserve also forms part of the Beeliar Regional Park.

Management of the Ramsar site is guided by the:

- **Forrestdale Lake Nature Reserve Management Plan (CALM 2005a);**
Strategic Assessment for the Perth and Peel Regions

- Thomsons Lake Nature Reserve Management Plan (CALM 2005b); and
- Beeliar Regional Park Management Plan (CALM 2006).

The Department of Parks and Wildlife develops and implements annual works programs in accordance with the management plans and prepares updates of subsidiary plans identified in the management plans e.g. fire response plans. In accordance with the Thomsons Lake Nature Reserve Management Plan and the Department's Policy Statement 3: Management of Phytophthora disease (DPaW 2014), in 2014 the Dieback Working Group provided signage and undertook mapping for management of Phytophthora dieback within Thomsons Lake.

Regular and ongoing operational monitoring is undertaken with fencing patrols and maintenance patrols including review of signs, fences, firebreaks and rubbish dumping. Regular monitoring of the Western Grey Kangaroo population is undertaken to determine if management actions are required. The Thomsons Lake Nature Reserve Management Plan states that the preferred population is approximately 22 kangaroos. To reduce the numbers to a sustainable level a culling program was undertaken with a total number of 1,032 kangaroos culled between May 2006 and March 2007. Another cull is being planned for late 2014/early 2015 with the current kangaroo population being in excess of 300.

Predation by foxes has been identified as a threatening process for the breeding waterbirds and other native fauna within Forrestdale Lake and Thomsons Lake nature reserves. In 1993, a vermin proof fence was constructed around Thomsons Lake Nature Reserve and fox control programs are being implemented at both reserves (Department of Conservation and Land Management 2005).

Parks and Wildlife manages walking paths, boardwalks, interpretative signs and a viewing platform to educate and facilitate visitor use while limiting disturbance to the nature reserves.

Groundwater management

The two main tools used by the Department of Water to manage groundwater use are allocation limits and groundwater licences – which are the regulatory instrument under the Rights in Water and Irrigation Act 1914.

Groundwater allocation limits and licensing on the Jandakot Groundwater Mound are managed in line with conditions and commitments in Ministerial Statement No. 688 set under the Environmental Protection Act that aim to protect significant environmental values supported by the mound – including Forrestdale and Thomsons Lakes (Minister for the Environment 2005).

Allocation limits are based on sustainable yield – i.e. the quantity of water that can be drawn over a period of time that will be replaced by recharge. Allocation limits for the Jandakot Groundwater Area, which covers most of the Jandakot Groundwater Mound, have recently been reviewed to consider the drying climate (DoW 2013b). The review was triggered by the continued non-compliance with Ministerial water level criteria at a number of high value wetlands despite groundwater abstraction being managed within existing allocation limits. The review has resulted in the reduction of allocation limits in all subareas in the Jandakot Groundwater Area. Total volumes of groundwater licensed from the Jandakot Groundwater Mound have reduced in recent years (DoW 2013a).

Forrestdale Lake is located in the City of Armadale Subarea in the Perth South Groundwater Area. There is no groundwater allocation plan for the Perth South Groundwater Area and the current limits were determined through an allocation limit review in 2008 (DoW 2008). Current licensed entitlements
in the City of Armadale Subarea are within the allocation limits. Licensed entitlements in other subareas in the Jandakot Groundwater Area near Forrestdale Lake are also within allocation limits.

Thomsons Lake is located in the Thomsons Subarea of the Cockburn Groundwater Area. The Cockburn Groundwater Area Allocation Plan, released in 2007, set the current allocation limits (DoW 2007). Current licensed entitlements in the Thomsons Subarea are within the allocation limits. Licensed entitlements in other subareas in the Jandakot Groundwater Area near Thomsons Lake are also within allocation limits. All licence applications, even in subareas that are not fully allocated, are individually assessed to consider potential impacts to groundwater dependent ecosystems (DoW 2009b) and impacts are managed through licence conditions including the requirement to monitor groundwater levels and water quality where possible impacts are determined.

Ministerial Statement No. 688 sets Environmental Water Provisions (EWPs) in the form of water level criteria at 23 sites on the Jandakot Mound, located in the Jandakot, Perth and Cockburn groundwater areas. The EWPs at Forrestdale and Thomsons Lakes include a preferred minimum water level and an absolute minimum level, and were set to ensure the maintenance of the lakes’ habitat value for migratory birds and rare, threatened and priority flora and fauna (Minister for the Environment 2005). The Department of Water aims to manage abstraction from the Jandakot Groundwater Mound to meet water level criteria and to minimise environmental impacts associated with abstraction.

At Forrestdale Lake the preferred summer minimum is 21.2–21.6m AHD and the absolute summer minimum is 21.1m AHD (Minister for the Environment 2005). The preferred minimum water level at Lake Thomsons is 11.3–11.8m and the absolute minimum is 10.8m AHD (Minister for the Environment 2005). Minimum Superficial Aquifer levels at Forrestdale Lake have been non-compliant since 2010-11, though levels improved marginally in the last 2 years and have been relatively stable since monitoring commenced in 1996. Minimum Superficial Aquifer levels at Thomsons Lake are currently compliant with the absolute minimum water level criteria (DoW 2013a) and have been relatively stable since 1996.

Both sites are currently non-compliant with other conditions from Ministerial Statement No. 688 relating to minimum peak lake levels and climate variability (DoW 2013a). Increased rainfall variability and reduced recharge to groundwater associated with the drying climate in the south-west of Western Australia has contributed to non-compliance with water level criteria at many sites (DoW 2013a). The Department of Water’s recent focus for the management of Jandakot Mound groundwater resources has been on a review of allocation limits for the Jandakot Groundwater Area that was completed in 2014. The review accounted for the drying climate and will help ensure future increases in abstraction do not adversely impact on water levels at the lakes. Allocation limits in the Jandakot Groundwater Area were reduced by around eight gigalitres per year in the review.

The Department of Water’s other ongoing response to non-compliance includes:

- adjusting the distribution of abstraction for public supply based on investigations and monitoring to limit impacts at non-compliant sites
- compliance inspections and metre audits to ensure groundwater use is within licence entitlements
- working with local governments to improve water use efficiency including design and maintenance of public open space.
Urban water and drainage management

The Department of Water is responsible for developing strategies and management plans to protect the quantity and quality of water resources, protect infrastructure from flooding, and enhance the living environment for the community.

The Department is an ‘essential partner’ in the CRC for Water Sensitive Cities. This is the major research vehicle for the implementation of the Federal and State Governments visions for better use of our water resources while delivering affordable and liveable cities and towns for expanding urban communities.

State Planning Policy 2.9: Water Resources (Government of Western Australia 2006) requires water resources management to be integrated with land use planning decisions to achieve more sustainable development and protection of water resources. Better Urban Water Management (WAPC 2008) is the policy mechanism by which proposals, at all levels of the state planning system, are considered with regard to water quantity and quality. The Department of Water provides advice to the Western Australian Planning Commission and the Local Government Authority to inform decision making through the state planning process.

Thomsons Lake’s regional drainage infrastructure is managed by the Water Corporation under the South Jandakot Drainage Management Plan (GB Hill and Partners 1990). One of the principal objectives of the plan is to ensure that the drainage system will be capable of meeting environmental objectives for the Beeliar wetlands (including Thomsons Lake). More specific objectives of the scheme are to limit the impacts of development on the water levels and water quality, primarily nutrient levels, of the lakes (GB Hill and Partners and WAWA 1990).

The drainage scheme is managed in line with conditions and commitments in Ministerial Statement No.’s 45 and 467 set under the Environmental Protection Act which include implementing relevant components of the Environmental Management Programme for the South Jandakot Drainage Scheme (GB Hill and Partners and WAWA 1990) and monitoring the environmental performance of the scheme.

The scheme has been constructed in accordance with the approved strategy, however the strategy was developed during a ‘wet climate’ period (mid-1980’s) when the objective was to prevent high lake levels and excessive inundation of the supporting flora and fauna ecosystems. With current drying climate trends the main threat to lakes is now low water levels and ecosystems declines due to lack of water. Some interim provisions have been made to divert drainage water into lakes; however there has been no formal review to date of the approved drainage strategy.

Forrestdale Lake has a high level drainage outlet which is the commencement point for the Forrestdale Main Drain. Urban development in the catchment is managed under the Southern River Integrated Land and Water Management Strategy (DoW 2009c) and the Forrestdale Main Drain arterial drainage strategy (DoW 2009a).

Implementation of these strategies is occurring progressively as urban and industrial development is occurring in accordance with the approved land use planning through the Western Australian Planning Commission.

Thomsons Lake receives water through a supplementation program that was initiated in winter 2004 and has continued every winter since. With agreement from the Water Corporation, water is diverted from the South Jandakot Branch Drain into Thomsons Lake by means of adjustable weir boards (Department of Conservation and Land Management 2006). The Water Corporation is responsible for
manually adjusting the weir boards each year in July to commence the program and in September to end the program. The program aims to ensure that the lake contains enough water in late spring and early summer to support the resident and migratory waterbird population. In addition, ensuring the lake contains water for a longer period in early summer allows cygnets to mature enough to enable them to fly over the vermin proof fence surrounding the Thomsons Lake Nature Reserve, to find alternative water sources. The timing of when to commence and stop water supplementation is based on water level criteria. If water levels are below 12.6 mAHDD on 1 July supplementation commences on 15 July and continue until 15 September, or until a level of 12.6 mAHDD has been achieved. The maximum drainage operational water level at Thomsons Lake is 12.8 mAHDD so if this level is met water is pumped out to a level of 12.6 mAHDD.

The program has been successful in improving water levels and periods of inundation at the lake and contributed to lake levels in 2013 and 2014 approaching the target level of 12.6 mAHDD. A recent review (DPaW 2013) of the program found that it is not having a detrimental impact on nutrient concentrations or macroinvertebrate family richness at the lake. Given the positive impacts of the program on water levels, the review recommended the program, and associated monitoring, should be continued.

Community group management

The Friends of Forrestdale was formed in April 1990 following a recommendation in the Forrestdale Lake Nature Reserve Management Plan. Since that time, the group has played an active role assisting the Department of Parks and Wildlife in the care and management of the Bush Forever sites and conservation reserves in the Forrestdale area. These bushland and wetland sites include Anstey-Keane damplands, Piara Nature Reserve and Gibbs Road Swamp – all within the Jandakot Regional Park – and Forrestdale Lake Nature Reserve.

The Cockburn Wetland Centre was formed in 1993 with funding from the Commonwealth government, the scouts and the City of Cockburn. Since that time the centre has played an important role in environmental education within the regional park, which includes Thomsons Lake.

The Beeliar Regional Park Community Advisory Committee (CAC) provides a forum at which issues affecting the park are discussed and the Department of Parks and Wildlife’s management decisions take into consideration advice from this group. The CAC consists of community members, representatives from Parks & Wildlife, local government and other landowners/stakeholders. Members of the public are formally involved in implementing the Beeliar Regional Park Management Plan through the CAC.
3 Current condition

The Ecological Character Description (ECD) for the Forrestdale and Thomsons Lakes Ramsar Site (Maher and Davis 2009) provides comprehensive information about the site, values and condition up until 2007. For many values there has been ongoing monitoring to understand the current condition of the lakes. Where this ongoing monitoring has happened, Section 3.2 updates the monitoring data presented in ECD to provide a more contemporary understanding of condition. Section 3.2 also notes which of the values of the lakes have remained relatively unchanged since the ECD was prepared.

3.1 DATA AVAILABLE TO INFORM CONDITION ASSESSMENT

3.1.1 Surface water and groundwater

The Department of Water (DoW) has monitored surface water levels at Forrestdale and Thomsons Lakes on a monthly basis since the early 1970s and groundwater levels at both lakes since 1996 and 1989 respectively. Monitoring of surface water levels at Thomsons Lake has been taken over by the Water Corporation as part of the monitoring program for the operation of the Southern Lakes Drainage Scheme. The data is subject to a rigorous quality assurance process.

3.1.2 Water quality

Water quality parameters have been measured at Thomsons Lake since 1996 and Forrestdale Lake since 2001 by Murdoch University, Edith Cowan University and Bennelongia on behalf of DoW as part of the Environmental Investigations for the Jandakot Groundwater Scheme Stage 2. The parameters measured include: chlorophyll a, nitrate/nitrite, orthophosphate, total nitrogen, total phosphorus, colour (gilvin or soluble humic colour) and turbidity (NTU). Monitoring occurs during spring. The objective of the monitoring program is to provide an indication of whether existing and proposed groundwater abstraction schemes together with private groundwater abstraction, are having an impact on the identified ecological values of wetlands (Wild and Davis 2004). Data on water quality and aquatic invertebrates has been collected as part of various studies undertaken by Murdoch University at Thomsons Lake (since 1985) and Forrestdale Lake (since 1989). These datasets extend the baselines back in time from the 1996 programs.

The Water Corporation monitors total phosphorus and nitrogen and water levels at Bartram Road Buffer Lakes and Thomsons Lake as part of the monitoring program for the operation of the Southern Lakes Drainage Scheme. The Bartram Rd Buffer Lakes inflow and outflow have weekly samples collected using an autosampler and Thomsons Lake is sampled fortnightly when the water level is sufficient.

3.1.3 Vegetation

Wetland vegetation has been monitored at Thomsons Lake since 1996 and Forrestdale Lake since 2004 by Murdoch University and Edith Cowan University on behalf of DoW as part of the Environmental Investigations for the Jandakot Groundwater Scheme Stage 2. Monitoring is undertaken in spring/summer and the parameters measured include: tree position and diameter; species richness; crown health; cover and abundance for all species; weediness index; and a regeneration index. The objectives of monitoring are to determine if there have been any changes in
the condition of the vegetation over time, and if this is related to alterations of the groundwater regime or to other factors affecting the wetlands (Ladd 1999).

Phreatophytic terrestrial vegetation has been monitored at Thomsons Lake since 1988 on behalf of the DoW (Mattiske 2001). Triennial monitoring takes place during spring and the objective is to relate vegetation condition to soil moisture, climate and pumping operations. The diameter of all tree species; stem numbers and condition; seedlings; and the density and cover of understorey species are recorded.

3.1.4 *Invertebrates*

Aquatic macroinvertebrates have been identified at Thomsons Lake since 1996 and Forrestdale Lake since 2001 by Murdoch University, Edith Cowan University and Bennelongia on behalf of DoW as part of the Environmental Investigations for the Jandakot Groundwater Scheme Stage 2. Monitoring occurs during spring. Dominant habitats are identified at each wetland and macroinvertebrate samples collected. Family richness counts are compiled for each sampling site and for each wetland (Wild and Davis 2004). The objective of the monitoring program is to provide an indication of whether existing and proposed groundwater abstraction schemes together with private groundwater abstraction, are having an impact on the identified ecological values of wetlands (Wild and Davis 2004).

3.1.5 *Waterbirds*

Waterbirds were monitored at Forrestdale and Thomsons Lakes from 1996 to 2008 by Bamford Consulting Ecologists on behalf of DoW as part of the Environmental Investigations for the Jandakot Groundwater Scheme Stage 2. The aim of the waterbird monitoring is to gather information on waterbird usage of wetlands that are influenced by the Jandakot Mound, so that impacts of current or future groundwater abstraction can be assessed (Bamford and Bamford 2006). Waterbird monitoring was conducted during the autumn/winter period and again during the spring/summer period, at approximately the same time each year, relative to the water cycle (Bamford and Bamford 2002). Each site survey involves a total count of all waterbird species present; the activity and habitat of waterbirds; breeding and nest records.

3.2 **CURRENT CONDITION**

3.2.1 *Climate*

Groundwater levels of the Jandakot Mound depend on recharge from rainfall. Across the south-west of Western Australia there has been a general trend of declining annual rainfall since the mid-1970s. A CSIRO investigation of climate change (Bates et al. 2010), along with relevant global climate change models, predict a continuation of rainfall reduction in the south-west of Western Australia.

Comparison of long term (1945 to 2013 = average annual rainfall of 772 mm) and ten year average rainfall (2004 to 2013 = average annual rainfall of 672 mm) for the Perth Airport station shows a decline of 100 mm per year (Figure D24). In the last ten years, the two driest years on record at Perth Airport were recorded – 480 mm in 2006 and 483 mm in 2010 (Figure D24).
3.2.2 Geomorphology

The current condition of the geomorphology is unchanged to the description given in Section 2.2.1.

3.2.3 Hydrology

At Lake Forrestdale there has been a general trend in declining peak lake levels, reduced hydroperiods and earlier drying since 1992, predominantly due to reduced rainfall. The peak lake level in 2013 of 21.96m AHD was the highest since 2008 but did not reach the preferred spring peak of 22.6m AHD which has not been reached since 1993 (Figure D25). Local levels in the Superficial Aquifer have been relatively stable since monitoring commenced in 1996, though show a slight declining trend in minimum levels (Figure D25). The minimum level in 2013 (20.85m AHD) was non-compliant with the absolute minimum water level criteria (21.1m AHD).
Figure D25: Superficial Aquifer and surface water levels at Forrestdale Lake against preferred peak and absolute minimum water level criteria

At Thomsons Lake there has also been a general trend in declining peak lake levels, reduced hydroperiods and earlier drying since 1992, predominantly due to reduced rainfall. This trend has been mitigated to some extent by the supplementation program initiated in 2004, which contributed to lake levels approaching the target level of 12.6 m AHD in 2013 and 2014 (Figure D26).

Local levels in the Superficial Aquifer have been relatively stable since 2007 (Figure D26). The minimum level in 2013 (11.13m AHD) was compliant with the absolute minimum water level criteria (10.8m AHD).

Figure D26: Superficial Aquifer and surface water levels at Thomsons Lake against preferred and absolute minimum water level criteria
**Maximum water depth**

Average maximum water depths from 1980 to 1999, the decades before and after the Ramsar site was listed, were 105 cm (range 38–206 cm) at Thomsons Lake, and 103 cm (range 47–187 cm) at Forrestdale Lake. Since 2000, average maximum water levels have declined 15 cm at Thomsons Lake (0–142 cm), and 63 cm at Forrestdale Lake (8–83 cm) (**Figure D27**). The supplementation program at Thomsons Lake, which has been running since 2004, has contributed to the smaller declines in average maximum lake levels compared to those at Forrestdale Lake.

![Annual depth variation in Forrestdale and Thomsons Lakes from 1971 to 2013](image)

**Figure D27 : Annual depth variation in Forrestdale and Thomsons Lakes from 1971 to 2013**

**Annual period of inundation/drying**

The duration of time that water is present in Forrestdale and Thomsons Lakes is currently less than in the previous dry phase in the 1980s. Since 1998 both lakes have dried for at least 5 months each year. In 2013 both were dry for 7 months (**Figure D28**). In some years since 2009 Thomsons Lake has dried for a shorter period than Forrestdale Lake. This may have been due to the influence of the supplementation program.
Figure D28: Number of months Forrestdale and Thomsons Lake were completely dry each year from 2000 to 2013

The period of inundation may be somewhat longer than the durations indicated, due to dry readings being recorded at the particular location of the staff gauges when some water (albeit very shallow) remained elsewhere in the lakes (as explained previously). For example, Jaensch et al. (1988) commented that from 1981–85 Forrestdale Lake was usually less than 0.3 m deep in summer and subsequently dry for 2 or 3 months. Similarly, the surface of the peat bed at Thomsons Lake was dry for a few weeks in late autumn in 1982 and 1983, and was dry for more than a month in autumn of 1984. The annual period of inundation recorded is therefore slightly shorter than those periods actually observed.

**Timing of inundation/drying during dry phases**

In addition to drying for longer periods of time, Forrestdale and Thomsons Lakes are also drying out earlier than in previous years. During the annual drying phase in the 1980s, both lakes tended to dry completely in January, February or March. Since 2000, the lakes have been drying mostly during December or January, and sometimes as early as November (Table D12). Since 2008, Thomsons Lake has generally dried later than Forrestdale. This is likely due to the influence of the supplementation program.

Table D12: Timing of drying at Thomsons and Forrestdale Lakes

<table>
<thead>
<tr>
<th>Year</th>
<th>Thomsons Lake</th>
<th>Forrestdale Lake</th>
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<tbody>
<tr>
<td>1980</td>
<td>January</td>
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<td>January</td>
<td>2014</td>
</tr>
</tbody>
</table>
3.2.4 Physio-chemistry

**Temperature, mixing and thermal stratification**

The current condition in terms of temperature, mixing and thermal stratification is largely unchanged to the description given in Section 2.2.3.

**Light, colour and turbidity**

From 1996 the lakes have remained weakly coloured (Thomsons Lake = 6–23 g440/m; Forrestdale Lake = 3–29 g440/m; Figure D29), and are generally clear (Figure D30), probably because there is still little inflow of surface water, other than the drainage that Thomsons Lake has received through the supplementation program since 2004. However, turbidity may increase during the first winter inflows as some sediment may be carried into the lakes (Davis et al. 1993), or as the result of wind induced re-suspension of bed sediments with shallower water depths. From 1996 the lakes have generally maintained low turbidity levels during spring (Thomsons Lake = 1–27 NTU; Forrestdale Lake = 1–34 NTU; Figure D30).

![Figure D29: Colour values recorded in spring each year at Forrestdale and Thomsons Lakes, from 1996 to 2013](image-url)
Salinity and pH

From 1996 to 2013, Thomsons Lake has remained fresh to brackish during spring when the water levels in the lakes are highest (1,693–6430 mS cm⁻¹). Forrestdale Lake has generally remained fresh to brackish during spring (1,590–5,700 mS cm⁻¹; Figure D32). However, conductivity was much higher than usual in spring 2006 (15,900 mS cm⁻¹) because the lake was drying out and water depth at the time of sampling was only 10 cm. The unusually low water depth and early drying of the lake was probably due to extremely low rainfall during winter and spring and subsequently low groundwater recharge. Conductivity returned to normal levels in spring 2007. Thomsons Lake did not
experience similarly high levels of salinity in 2006 because it was supplemented with additional water over this period of time.

From 1996 to 2013 the pH of the water at Thomsons Lake in spring ranged from 6.3 to 9.9. The slightly acidic pH of 6.3 was recorded in 2012. The pH of 8.4 recorded in 2013 showed no evidence of continued acidification (Strehlow et al. 2012). The pH of Forrestdale Lake has remained similar over time, ranging from 7.4 to 9.7 over the period 2001 to 2013 (Figure D33).

Figure D32: Conductivity levels recorded in spring each year at Forrestdale and Thomsons Lakes, from 1996 to 2013

Figure D33: Values of pH recorded in spring each year at Forrestdale and Thomsons Lakes, from 1996 to 2013
**Nutrients**

From 1996 to 2013 nutrient levels recorded in spring at Thomsons Lake have ranged from 28–300 μg/L of total phosphorus and 2,000–6,800 μg/L of total nitrogen. Nutrient levels are similar at Forrestdale Lake, ranging from 43–180 μg/L of total phosphorus and 2,200–9,500 μg/L of total nitrogen (Figure D34 and Figure D35). The level of nitrogen in Forrestdale Lake was higher than usual in spring 2006 (9,500 μg/L), most likely due to evapoconcentration effects, as the lake was drying out at the time of sampling and water depth was only 10 cm. Nitrogen levels were within the normal range at Forrestdale Lake in spring 2012.

Phosphorus levels have generally been lower since 2002–03, probably due to reduced rainfall leading to less phosphorus being mobilised and then entering the Superficial Aquifer through recharge. This has meant there have been fewer problems from midges with the lake drying out early in summer before major midge swarms develop (CALM 2005a; Figure D34). It is unclear why reduced rainfall has not had the same effect on nitrogen concentrations at the lakes, which have remained in historic ranges in recent years. One explanation could be that large reservoirs of nitrogen are held in the sediments of the lake beds, which are being mobilised when they are rewet.

![Graph showing nutrient levels](image-url)

**Figure D34**: Concentration of total phosphorus recorded in spring each year at Forrestdale and Thomsons Lakes, from 1996 to 2013
3.2.5 Ecology

Fauna

Mammals

Regular monitoring of the Western Grey Kangaroo population is undertaken to determine if management actions are required. Recent counts in 2014 of kangaroo numbers have identified an average of 200 kangaroos with the actual kangaroo population estimated to be in excess of 300 (T. Fisher pers. comm.).

Reptiles and Amphibians

There is no additional information available from that described in Section 2.2.4.

Aquatic Invertebrates

Family richness at Forrestdale and Thomsons Lakes has remained relatively stable (Figure D36 and Figure D37; note that Forrestdale was not sampled in 2001 or 2012). At Forrestdale, richness was low in spring 2006 when surface water levels were relatively low, but returned to normal levels in 2007. In 2013 the higher than normal species richness recorded was associated with the highest peak water levels for four years (Figure D36).
At Thomsons, there is a significant positive correlation between peak water levels and family richness. In 2013, water levels and family richness were the highest for four years (Sampey et al. 2014). The historic monitoring has not record abundance data.

Figure D37: Total number of invertebrate families and maximum annual water depth recorded at Thomsons Lake over the period 1996 to 2013

Terrestrial Invertebrates

There is no additional information available from that described in Section 2.2.4.
Terrestrial Birds

There is no additional information available from that described in Section 2.2.4.

Waterbirds

The only recent data available for the number of species of waterbirds at Thomsons Lake, presented in Figure D38, was collected by BirdLife Australia. The total species counts are considerably lower during the same period than those collected by Bamford and Bancroft (2007) as reported in the 2009 ECD (Maher and Davis 2009). The reason is not clear, but the increasing trend in species counts in the BirdLife Australia data may be attributed to the increasing experience of volunteers contributing to the bird counts and caution should be taken in making firm conclusions based on the data. Figure D38 indicates that species abundance has not altered since BirdLife Australia began collecting records for Thomsons Lake in 1998, if any trend can be noted, it is that maximum species abundance and minimums in The Birdlife Australia data have both tended to increase over this period. While lake depth and duration of inundation have both decreased since 1998 (Figure D27 and Figure D28), these altered conditions have appeared to have been successfully mitigated by the water supplementation program that was initiated in 2004.

![Figure D38 Species abundance for Thomsons Lake 1998-2013 (Birdlife Australia 2014)](image)

As with the BirdLife Australia data collected for Thomsons Lake, the species abundance counts for Forrestdale Lake are considerably lower for the same period than the counts by Bamford and Bancroft (2007) as reported in the 2009 ECD (Maher and Davis 2009). However, as the counts have been taken over the longer period, significant trends should be detectable (Figure D39). The figures shows no significant trend in species abundance of waterbirds at Forrestdale Lake since 1998, although the maximum counts that normally record between 20 and 30 species every one to three years, have not been recorded since 2012. The maximum number of species recorded in the 2013 to 2015 period has only been 13. This recent decline in waterbird usage should be monitored closely in future years in relation to reduced water levels and duration of inundation at the lake reducing the suitability of the site for some waterbird species.
Total bird counts are more sparing and it has been well discussed in the literature, including the 2009 ECD (Maher and Davis 2009), that the intensity of survey efforts effects the bird count recorded and any analysis of trends and conclusions of populations have to be made cautiously. The only waterbird population data that is available since 2008, collected by BirdLife Australia is shown in **Figure D40** (BirdLife Australia 2014). BirdLife Australia does not routinely gather total waterbird counts and the data can only be assumed as ad-hoc estimates. This likely explains why these counts are considerably lower than those reported in the 2009 ECD (Maher and Davis 2009), where over 10,000 waterbirds were recorded in 40% of years between 1982 and 1999 and over 5,000 waterbirds in 80% of these years at both lakes. Though analysis of these trends requires caution, the observations made suggest that there is a large amount of variation in the numbers of waterbirds that visit these wetlands over the years and it is heavily dependent on not only water availability at Forrestdale and Thomsons Lakes, but water availability across the entire south-Western Australia and in the case of migratory species, the suitability of landing sites across the entire global flyway.

The two last available waterbird counts at Thomsons Lake are for 2013 (**Figure D40**). Both counts recorded counts of 1,000 or less and while not significantly lower than many other periods, it will be important to assess data from future counts to determine if a significant trend is occurring or if the water supplementation program is successfully mitigating the drying trend.
The waterbird counts for Forrestdale Lake appear to have significantly declined since a count of over 10,000 waterbirds was recorded 2004 (Figure D41). Although the count of 3,800 waterbirds in 2012 is close to years previous to 2004, the very low numbers recorded at Forrestdale Lake between 2008 and 2011 indicate that the system is under pressure from low lake levels and longer periods of drying. The variability between years is high and counts are dependent of many factors other than conditions that exist at the lake. However, the low water levels and longer periods of drying are not conducive to some species of waterbirds and careful monitoring should be conducted as part of ongoing management of the site, relating waterbird counts to lake levels and inundation periods.

BirdLife Australia data was used to indicate trends in some of the more significant migratory shorebirds listed under Migratory Bird Agreements. Given the limitations on the data (counts are only conducted ad-hoc and not for all species on any one date), the trends are generally downwards. It is uncertain how this reflects flyway populations, or the availability of other foraging areas within the Swan Coastal Plain, but is likely at least in part to reflect earlier drying of both Thomsons and

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**Figure D40 Waterbird counts for Thomsons Lake 1998-2013 (Birdlife Australia 2014)**

**Figure D41 Waterbird counts for Forrestdale Lake 1998-2012 (Birdlife Australia 2015)**
Forrestdale Lakes (Table D12), the lower water depths and longer drying periods (Figure D27 and Figure D28). Thomsons Lake still supports Red-necked Stints, with 48 counted in 2012. This number represents approximately 8% of maximum counts in 2000 of 600 (Figure D42).

![Figure D42 Red-necked Stint Counts for Forrestdale and Thomsons Lakes 1999-2012 (Birdlife Australia 2015)](image)

Significant counts of the migratory shorebird, Sharp-tailed Sandpiper have not been recorded at Forrestdale Lake since 2004 and the same was true for Thomsons Lake except for a very significant count in 2010, which was nearly a magnitude greater than had previously been recorded (Figure D43). Interestingly, the peak water level at the Thomsons Lake in 2010 was relatively low.

![Figure D43 Sharp-tailed Sandpiper counts for Forrestdale and Thomsons Lakes 1999-2012 (Birdlife Australia 2015)](image)

The last significant counts for the Common Greenshank occurred at Forrestdale Lake in 2004 and at Thomsons Lake in 2008 (Figure D44). The variability of the numbers of this migratory bird has always been high and ongoing monitoring of this species will be required at both lakes to confirm whether the systems continue to support significant numbers.
Vegetation

Phytoplankton

There is no additional information available from that described in Section 2.2.4.

Aquatic Plants

Anecdotal observations suggest that aquatic plants have remained similar both lakes over time, however the extent of aquatic plant communities has not been mapped, and has not been monitored regularly (Maher and Davis 2009).

Littoral Vegetation

Wetland vegetation has been monitored at Thomsons Lake since 1996 and Forrestdale Lake since 2004. Monitoring is undertaken in spring/summer and the parameters measured include: tree position and diameter; species richness; crown health; cover and abundance for all species; weediness index; and a regeneration index. A summary of the changes in vegetation at Forrestdale and Thomsons Lakes based on the monitoring is given in Tables D13 and D14.

Wetland vegetation monitoring at Forrestdale Lake in 2013 showed (Table D13; Wilson et al. 2013):

- two recent tree mortalities (Melaleuca rhaphiophylla);
- decreased canopy condition compared to 2004;
- improved canopy condition over the last 3 years;
- decreased exotic cover since 2012; and
- little floristic change since 2011.

Figure D44 Common Greenshank counts for Forrestdale and Thomsons Lakes 1999-2012 (BirdLife Australia 2015)
Monitoring at Thomsons Lake in 2012 showed (Table D14; Wilson et al. 2012):

- decreased canopy condition compared to 1996;
- improved canopy condition from the previous year’s sampling and since 2009;
- increased exotic cover at one transect and decreased cover at the second transect;
- little change in native species richness; and
- moderate change in vegetation and hydrology.

Despite general declines in wetland vegetation condition at both sites since they were first monitored, condition at both was considered to be relatively stable in the most recent monitoring compared to the previous assessment.
Table D13: Changes in vegetation (transect means) and hydrological conditions for Forrestdale Lake. Comparisons are shown between 2012 & 2013, 2010 & 2013 and 2004 & 2013 (Adapted from Wilson et al. 2012).

<table>
<thead>
<tr>
<th>Site</th>
<th>Vegetation Change</th>
<th>Hydrological Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>¹Canopy Condition % change</td>
<td>²Exotic cover % change</td>
</tr>
<tr>
<td>Forrestdale Lake</td>
<td>+9 (10)</td>
<td>+14</td>
</tr>
</tbody>
</table>

¹ Values in parentheses are actual canopy vigour scores for 2013; maximum possible score is 23
² Values in parentheses show the percentage cover of exotic species on the transect in 2013.

Table D14: Changes in vegetation (transect means) and hydrological conditions for Thomsons Lake. Comparisons are shown between 2011 & 2012, 2009 & 2012 and 1996 & 2012 (Adapted from Wilson et al. 2012).

<table>
<thead>
<tr>
<th>Site</th>
<th>Vegetation Change</th>
<th>Hydrological Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>¹Canopy Condition % change</td>
<td>²Exotic cover % change</td>
</tr>
<tr>
<td>Thomsons Lake transect 1</td>
<td>+22 (11)</td>
<td>+44</td>
</tr>
<tr>
<td>Thomsons Lake transect 4</td>
<td>+14 (18)</td>
<td>+15</td>
</tr>
</tbody>
</table>

¹ Values in parentheses are actual canopy vigour scores for 2011; maximum possible score is 23
² Values in parentheses show the percentage cover of exotic species on the transect in 2011
Vegetation type and condition

A weed and rehabilitation plan was undertaken by Syrinx Environmental Pl (2006) for Beeliar Regional Park, which includes Thomsons Lake Nature Reserve. Vegetation surveys of Thomsons Lake identified eight vegetation community types with the dryland vegetation types being mostly in very good to good condition and the wetland vegetation community types in degraded to completely degraded condition (Figure D45; Syrinx Environmental Pl 2006).

Vegetation type and condition mapping has not been completed for Forrestdale Lake Nature Reserve.

Weed/Typha Mapping

The introduced Bulrush *Typha orientalis* has increased in abundance since Forrestdale Lake was listed as a Ramsar site. *Typha*, along with other exotic and native emergent rushes and sedges, now covers expansive areas of the water's edge and is encroaching across the dry lake beds (Figure D46). The invasion and expansion of *Typha* and other emergent rushes and sedges appears largely due to the prolonged drying phase in recent times (Davis et al. 2008). At Thomsons Lake, *Typha*, along with other exotic and native emergent rushes and sedges, now covers expansive areas of the water's edge and is encroaching across the dry lake beds. The extent of *Typha* at the lake has recently been mapped and results indicate an increase in *Typha* extent of 2.7 ha from 2006 to 2009.
(SCP Conservation 2009). While the extent of *Typha* has increased, the spatial distribution has also changed over the three years, that is, *Typha* expanded in some areas and contracted in others (SCP Conservation 2009). At both lakes *Typha* is displacing and changing riparian vegetation, which appears to be altering waterbird habitat.

**Thomsons Lake – *Typha* spp. (as at January 2009)**

In 2006, a weed and rehabilitation plan was produced by Syrinx Environmental Pl (2006) for Beeliar Regional Park, which includes Thomsons Lake Nature Reserve. The plan included mapping of priority weeds so that appropriate weed control programs could be developed. As well as treating and controlling *Typha* spp., the annual weed control programs such as *Beeliar Weed Control Program 2013* targeted the following priority weed species within Thomsons Lake Nature Reserve:

- Pampas grass (*Cortaderia selloana*).
- Cotton bush (*Gomphocarpus fruticosus*).
- Arum lily (*Zantedeschia aethiopica*).
- Bridal creeper (*Asparagus asparagoides*).
- Fleabane (*Conyza spp.*).
- Japanese pepper (*Schinus terebinthifolius*) (**Figure D47**).
Current weed control practices at Lake Forrestdale, while not insubstantial (including a large contribution by the Friends of Forrestdale), are not keeping pace with limiting the further spread of weeds other than *Typha*. A map of the occurrences of major weeds (other than *Typha*) at Forrestdale Lake is shown in Figure D48. For *Typha*, the current level of management maintains the status quo.
Figure D48: Weed mapping at Lake Forrestdale

Fire history

Pre-suppression fire work is carried out regularly as part of the Beeliar Regional Park, which includes Thomsons Lake Nature Reserve, annual works program and includes tree pruning, weed spraying, slashing and grading of fire access tracks.

Fire history for Thomsons Lake, is as follows:

- A 20 ha fire on east side of the reserve on 13/1/2004.
- A <2 ha fire east side of reserve on 1/1/2011.
- A <2 ha fire northwestern corner of reserve on 10/2/2014.

Figure D49 below of fire history shows that fire suppression works have been successful in mitigating the threat of too frequent fires to the lake or the fringing vegetation.

Current management practices at Forrestdale Lake have been successful in ensuring that too frequent fires do not affect adversely on the lake or its fringing vegetation. Pre-suppression works are undertaken annually and include maintaining strategic fire breaks around the boundary of the Nature Reserve, creating low fuel areas within the vegetation on the lake floor and control of weeds.

Figure D50 shows that despite many fires being present in the general area during the last 10 years, very little of the lake or its fringing vegetation burned. On 1 January 2002, 2 ha burned within the
Figure D49: Fire history at Thomsons Lake
Figure D50: Fire history at Forrestdale Lake
3.2.6 Social and cultural values

The social and cultural values are unchanged to the description given in Section 2.2.5.

3.3 ASSESSMENT OF CURRENT CONDITION AGAINST RAMSAR VALUES

The attributes that are central to maintaining ecological character and that are crucial to the maintenance of the components and processes for which the Forrestdale and Thomsons site was listed include:

- Seasonal hydrological regime.
- Inter-annual variability resulting in wet and dry cycles depending on annual rainfall and evaporation rates.
- Shallow (<3 m).
- Fresh to brackish.
- Alkaline.
- Moderately nutrient enriched.
- Provision of habitat for aquatic biota, especially waterbirds.
- Clear water, aquatic plant-dominated ecological regime.

The loss of or change to any one of these identifiers flags the likely occurrence of unacceptable ecological change.

Since Forrestdale and Thomsons Lakes were first listed under the Ramsar Convention in 1990, many of the components, processes, benefits and services critical to the ecological character of the site have been maintained including:

- Water quality has generally been maintained. The lakes are still fresh/brackish, weakly coloured, generally clear, have a neutral to slightly alkaline pH and are moderately enriched.
- Invertebrate species richness has remained relatively stable. This indicates that conditions remain that support the faunal species, including waterbirds and turtles.

However, there have also been a number of changes to the wetlands. Major changes include:

- The lakes are experiencing substantially lower maximum water depths, reduced period of inundation and earlier annual drying. The altered hydrological regime has been attributed to reduced rainfall from climate change, groundwater abstraction and urban development.
- Wetland vegetation has generally declined in condition since monitoring commenced though in recent years there have been improvements in canopy condition at both lakes.
- *Typha orientalis* now covers expansive areas of the water’s edge and is encroaching across the lake beds. *Typha* is displacing and changing riparian vegetation, which appears to be altering waterbird habitat. The invasion of *Typha* is facilitated by drier conditions and some active control measures have been implemented. These measures have been successful in reducing coverage of *Typha* around parts of the lakes.
The number of waterbirds and number of species recorded at Forrestdale and Thomsons Lakes have been variable, but overall have declined in recent years. Numbers of migratory shorebirds have also declined, likely due to loss of suitable habitat from the encroachment of riparian vegetation across the lake floor.

Forrestdale and Thomsons Lakes still meet two Ramsar criteria that were noted with its listing:

- Criterion 1 is met as Forrestdale and Thomsons Lakes are the best remaining examples of large brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain, within the South-West Coast Drainage Division.
- Criterion 3 is still met as Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain including migratory species listed under the EPBC Act. Waterbird species have been recorded breeding at the lakes and the sites still contain a rich and diverse community of aquatic invertebrates that are representative of relatively undisturbed, large, shallow Swan Coastal Plain wetlands dominated by submerged macrophytes.

However, the lakes no longer meet the following Ramsar criteria:

- Criterion 5 is not met as the lakes do not regularly support 20,000 or more waterbirds. It appears that two counts in 1986 and 1987 were used as justification for this criterion. The existing waterbird data for the site does not support the current Ramsar definition of regularly\(^1\). Therefore the site does not meet the requirements this criterion.
- Criterion 6 is not met as the lakes do not regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

The Ramsar listing criteria for Thomsons and Forrestdale Lakes and an assessment of the criteria against current conditions is given in

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\(^1\) Ramsar guidelines (Ramsar Convention 2008) define regularly – as in supports regularly – a population of a given size if:

- The requisite number of birds is known to have occurred in two thirds of the seasons for which adequate data are available, the total number of seasons being not less than three; or
- The mean of the maxima of those seasons in which the site is internationally important, taken over at least five years, amounts to the required level.
### Table D15: Ramsar listing criteria and justification

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Justification</th>
<th>Assessment against current condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near natural wetland type found within the appropriate biogeographic region.</td>
<td>Thomsons and Forrestdale Lakes are the best remaining examples of brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain. While these types of wetland were formerly common, extensive development of the Swan Coastal Plain has resulted in the loss of many of these wetlands, and most of the remaining wetlands of this type have been degraded through drainage, eutrophication and the loss of fringing vegetation.</td>
<td>This criteria is met as Forrestdale and Thomsons Lakes are still the best remaining examples of large brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain, within the South-West Coast Drainage Division.</td>
</tr>
<tr>
<td>3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.</td>
<td>Thomsons Lake is one of the last remaining refuges within the Swan Coastal Plain for the threatened Australasian Bittern <em>Botaurus poiciloptilus</em>, is one of few known breeding localities for Bailon’s Crake <em>Porzana pusilla</em>, and was the last remaining wetland within the Perth metropolitan area where the Swamp Harrier <em>Circus approximans</em> was known to breed; however, these species have not been recorded breeding at this lake since the mid-1980s.</td>
<td>This criteria is still met as Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain including migratory species listed under the EPBC Act.</td>
</tr>
</tbody>
</table>

*EPBC Act:* Environmental Protection and Biodiversity Conservation Act
4 Limits of acceptable change

4.1 INTRODUCTION

Limits of acceptable change were defined by Phillips (2006) as:

“...the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. This may include population measures, hectares covered by a particular wetland type, the range of certain water quality parameter etc. The inference is that if the particular measure or parameter moves outside the ‘Limits of Acceptable Change’ this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed. In most cases, change is considered in a negative context, leading to a reduction in the values for which a site was listed.”

Limits of acceptable change make it easier to determine when the ecological character is likely to change or when it has changed as a result of technological development, pollution or other human interference. This is particularly important for Australian wetlands given that they often have a large range in natural variability. These limits can help site managers determine appropriate activities, monitor the site, and take action to maintain ecological character.

Limits of acceptable change and the natural variability in the parameters for which limits are set are inextricably linked. Phillips (2006) suggested that Limits of Acceptable Change should be beyond the levels of natural variability. However, setting limits in consideration with natural variability is complicated. Wetlands are complex systems and there is both spatial and temporal variability associated with all components and processes (Hale and Butcher 2007). Defining trends that are not within a “natural” range that can be detected with sufficient time to instigate management actions to prevent an irrevocable change in ecological character is therefore particularly difficult (Hale and Butcher 2007).

It is not sufficient to simply define the extreme measures of a given parameter and to set Limits of Acceptable Change beyond those limits. There are many examples where a parameter could change in ways that are detrimental to the ecological character of the site but do not result in a change in the maximum or minimum values. If the Limits of Acceptable Change are set to be outside the extremes of natural variability then this will only capture a change in maximum or minimum values. Situations that involve a shift in the baseline values, an increase in the number of peak events or a seasonal shift will not be captured (Hale and Butcher 2007).

The Ramsar definition of an unacceptable change in ecological character indicates that it is a human induced adverse alteration of wetland components, processes and benefits/services that is of concern. Davis and Brock (2008) identified unacceptable adverse ecological changes to Thomsons Lake (which are also applicable to Forrestdale Lake) would include changes to the unique set of identifiers, for example, the wetland becoming:

- Permanently wet.
- Permanently dry.
- Deep (>3 m).
- Saline or hypersaline.
• Acidic.
• Eutrophic or hypertrophic.
• Dominated by invasive plants.
• Unsuitable as a habitat for aquatic biota, especially waterbirds.
• Or undergoing an ecological regime shift – for example, from clear, aquatic plant-dominated to turbid, phytoplankton-dominated.

Although it is desirable to give quantitative bounds to define limits of acceptable ecological change (sensu Phillips 2006), the reality is that quantitative data are often not available. However, the changes listed above can be recognised, and identified fairly readily using pre-existing thresholds (e.g. for eutrophic and hypertrophic systems) or expert knowledge.

The recognition of dynamic regimes (Mayer and Rietkerk 2004) which involve non-linear responses to disturbance is considered to be a more realistic construct than linear models for ecosystem management across a number of ecosystem types, including shallow lakes and wetlands. Growing pressures from drivers such as nutrient loading, invasive species and climate change may be pushing wetland ecosystems towards thresholds that they may otherwise not have encountered (Millennium Ecosystem Assessment 2005b). The possibility that hysteresis might occur, where an adverse change in ecological character cannot be remedied by reversing only the factor that triggered the change, increases the need to be able to predict, and where possible, prevent regime shifts. Monitoring a wetland to detect when an identifier is shifting from its acceptable state towards the unacceptable can alert managers to the earlier stages of ecological regime shift when prevention or reversal of changes may be achieved.

Limits of acceptable change for Forrestdale and Thomsons Lakes have been established for the key components and processes of ecological character identified in Section 2. The defined limit of acceptable change is the tolerance considered acceptable without indicating a change of ecological character is occurring (Phillips et al. 2006). Use of this concept requires good knowledge of natural variations, the boom and bust cycles that can occur naturally in these species or communities. Where this is lacking, the precautionary principle is applied.

4.1.1 Justification for the Limits of Acceptable Change

The variability evident in some components and processes at Forrestdale and Thomsons Lakes has surpassed the Limits of Acceptable Change specified in Table D16. Both lakes have experienced high total phosphorus concentrations (>300 μg L⁻¹), which has often resulted in problems with nuisance midges or algal blooms. These high levels of total phosphorus are greater than the ‘natural’ variability and are the consequence of anthropogenic impacts, such as urbanisation. Therefore, the Limits of Acceptable Change specified in Table D16 are not necessarily set around the variability recorded at the lakes in the past. The limits specified are those, which if exceeded, are likely to result in a deleterious change in condition of the wetland. Justification for the specified limits is provided below.

For several components and processes, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) have been used to assist in setting the Limits of Acceptable Change. The objective of these guidelines is for the protection of aquatic ecosystems, that is, “to maintain and enhance the ‘ecological integrity’ of freshwater and marine ecosystems, including biological diversity, relative abundance and ecological processes”. Ecological integrity, as a measure
of the ‘health’ or ‘condition’ of an ecosystem, is defined by Schofield and Davies (1996) as “the ability of the aquatic ecosystem to support and maintain key ecological processes and a community of organisms with a species composition, diversity and functional organisation as comparable as possible to that of natural habitats within a region.” The factors outlined below were taken into consideration when setting the LACs for Thomsons and Forrestdale Lake.

**Minimum water depth and period of inundation**

- Summer water stress and subsequent reduction in productivity becomes evident where the minimum level for capillary rise of water to reach the roots of emergent macrophytes (water table 0.8–1.0 m below the sediment surface) occurs. The length of time at which groundwater remains at or near this level is most critical. If groundwater did not exceed this level for more than 3–4 months each year, most species of emergent macrophytes would not survive for longer than 1–2 years (Froend et al. 1993).

- The declining watertable at Forrestdale Lake has reduced the health of fringing vegetation including *Eucalyptus rudis* and *Melaleuca preissiana* (Ladd 2001).

- Seasonal wetlands with moderate periods (< 7 months) of shallow (< 0.5 m) inundation, support the largest areas and most diverse fringing plant communities. A lowering of the water regime would most likely result in a gradual shift of the vegetation downgradient i.e. encroachment of the lake bed (Froend et al. 1993). Low counts of migratory wader species at Forrestdale and Thomsons Lakes in recent years has been attributed to encroachment of riparian vegetation, which has decreased the amount of mudflats available for wading birds (Bamford and Bancroft 2007).

- The minimum water levels should not fall below 0.5 m of the sediment surface more than once every ten years to protect the health and extent of the emergent vegetation, particularly sedge beds. The optimum water level for *Baumea articulata* is ± 0.1 m above the lake bed (Froend et al. 1993). This should in turn ensure the protection of fauna habitat, including waders and invertebrates (Davis et al. 2001).

- The richness of invertebrate families is greatly reduced if maximum annual depth is < 50 cm.

- Adult insects with aquatic larvae require healthy vegetation for resting sites and some require submerged macrophytes, particularly damselflies (Odonata: Zygoptera), for egg laying sites. Maintaining a water regime that supports submerged macrophytes is therefore also important for the maintenance of invertebrate habitat values. The requirements of aquatic invertebrates to complete their life cycles should be met if water is present for at least 4 months per year, seasonal wetlands do not dry out before December each year, and rates of wetland drying do not exceed 0.02 m day⁻¹ (Balla and Davis 1993).

- Briggs and Thornton (1999) found that waterbirds (other than ducks) needed at least 5 to 8 months inundation to successfully complete breeding when flooding commences in winter/spring in River Red Gum *Eucalyptus camaldulensis* wetlands. This included time for egg laying, as well as for incubation and fledging of young. However, these times increased by one to three months (average of two months) following autumn flooding. Therefore, 7 to 10 months inundation under the nest trees is required when flooding commences in autumn.

**Maximum water depth and period of inundation**

- Prolonged flooding (>2 years) can lead to severe degradation and possibly local extinction of fringing tree populations, including *Eucalyptus rudis* and *Melaleuca preissiana* (Froend et al.
The average annual evaporation in Perth is 2,056 mm (Bureau of Meteorology 2008), as a consequence, if the maximum water depth is >2.5 m it is unlikely that either lake would dry completely.

- The aquatic macrophyte, *Myriophyllum*, requires water that is relatively shallow. Excessive depth increases may lead to the death of macrophyte beds and favour cyanobacterial blooms (Balla and Davis 1993).
- Highest richness of aquatic invertebrates recorded at water depth >1.6 m indicating that high water levels may be preferred, provided the regime does not change to permanent for >2 years.
- Inundation of *Baumea articulata* by 0.8 m each year will prevent downslope growth i.e. encroachment of the lake bed (Froend et al. 1993).

**Seasonal drying requirements**

- The emergent macrophyte *Bolboschoenus caldwelli* requires seasonal drying: it becomes established below sedges as the lake dries (Halse et al. 1993).
- Wading birds require shallow water levels (Davis et al. 2001), however, ducks such as the Musk Duck and Blue-billed Duck require deep, permanent water (Frith 1957; Braithwaite and Frith 1968).
- Seasonal drying is linked to increased productivity of aquatic invertebrates, which should result in large numbers of waterbirds (Crome 1988).
- Seasonal drying allows for the exposure of mudflats in summer/autumn, which is required by migratory waders (Davis et al. 2001).
- Seasonal drying reduces the potential for exotic fish (*Gambusia holbrooki*) to colonise and achieve high densities, and result in an aquatic invertebrate community typical of seasonal wetlands (Davis et al. 2001).

**Salinity**

- Wetlands typically have conductivity values in the range 500–1,500 μS cm⁻¹ over winter. Higher values (>3,000 μS cm⁻¹) are often measured in wetlands in summer due to evaporative water loss. In general, freshwater wetlands would not be expected to exceed 2,475 μS cm⁻¹ during winter. However, criteria are difficult to set because of the high levels that may occur at the end of summer (ANZECC 2000).

**pH**

- Levels between 7.0 (lower limit) – 8.5 (upper limit) are required for the protection of wetland ecosystems (ANZECC 2000).
- pH > 9 generally indicates highly nutrient enriched conditions in which algal blooms are present (Davis et al. 1993).

**Chlorophyll a**

- Concentrations should not exceed 100 μg L⁻¹ for prevention of problems with nuisance midges (*Polypedilum nubifer*) (Davis et al. 1993).
**Nutrients**

- Annual maximum concentrations of total phosphorus should not exceed 100 μg L\(^{-1}\) for prevention of problems with nuisance midges (*Polypedilum nubifer*) (Davis et al. 1993).

- A shift from clear water, submerged macrophyte-dominated regime to a turbid phytoplankton-dominated regime had been observed in wetlands on the Swan Coastal Plain with low colour (< 52 g440 m\(^{-1}\)) and levels of total phosphorus greater than 100 μg L\(^{-1}\) (Davis et al. 1993).

### 4.2 LIMITS OF ACCEPTABLE CHANGE

Limits of acceptable change (LACs) for Forrestdale and Thomsons Lakes were established for the key components and processes of ecological character in the *Ecological Character Description for the Forrestdale and Thomsons Lakes Ramsar Site* (Maher and Davis 2009). The defined LACs are the tolerance considered acceptable without indicating a change of ecological character is occurring (Phillips et al. 2006). The LACs for the lakes are summarised in Table D16
<table>
<thead>
<tr>
<th>Components and processes</th>
<th>Baseline condition and range of natural variation where known (range with average in brackets)</th>
<th>Limits of acceptable change</th>
</tr>
</thead>
</table>
| **Annual minimum water depth** | Typically falls to around 0.5 m below the lake bed level.  
**Permanent water** (in most years):  
**Annual drying** (in most years):  
Forrestdale: 1983–1988 and 1994–present | At the sediment surface (wet years), or up to 0.5 m below the lake bed levels (medium years), or 0.5–1.0 m below the lake bed surface (dry years) (DoE 2004) for 3–4 consecutive months annually.  
Always < 1.0 m below the sediment surface (DoE 2004).  
Not 0.5–1.0 m below the sediment surface for longer than four consecutive months more than once every ten years or for 2 consecutive years (Froend et al. 1993). |
| **Annual maximum water depth** | 1952–2005:  
Thomsons Lake 38–371 cm (139 cm)  
Forrestdale Lake 45–266 cm (129 cm)  
1980–1999 (decades before and after Ramsar listing):  
Thomsons 38–206 cm (105 cm)  
Forrestdale 47–187 cm (103 cm) | > 0.9 m (DoE 2004) for 2 months during spring.  
> 1.6 m at least once every 10 years (for invertebrates)  
No less than 0.5 m more than once every 10 years (Froend et al. 1993).  
No greater than 2.5 m for 2 consecutive years (Froend et al. 1993). |
| **Period of inundation/drying** | 1972–2005:  
Thomsons 5–12 months (9.6 months)  
Forrestdale 5–12 months (9.9 months)  
Drying phase 1 (1980s):  
Thomsons 7–10 months (8.6 months)  
Forrestdale 9–12 months (10.2 months)  
Drying phase 2 (mid-1990s to 2005): | > 6 consecutive months annually (Balla and Davis 1993; Briggs and Thornton 1999).  
Preferred earliest drying by April (wet year), Feb–Mar (medium year) or January (dry year) (DoE 2004).  
Permanent water present for not more than two consecutive years in every ten years (Crome 1988; Halse et al. 1993; Davis et al. 2001). |
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thomsons</strong></td>
<td>5–9 months (7.3 months)</td>
<td>Forrestdale 5–9 months (6.8 months)</td>
</tr>
<tr>
<td><strong>Colour</strong></td>
<td>Colour typically 3.2–29.0 g 440 m$^{-1}$ during spring.</td>
<td>&lt; 30 g 440 m$^{-1}$ at all times</td>
</tr>
<tr>
<td><strong>Turbidity</strong></td>
<td>Turbidity typically 0.4–38.0 NTU during spring.</td>
<td>&lt; 40 NTU at all times</td>
</tr>
<tr>
<td><strong>Salinity</strong></td>
<td>Conductivity typically 1,500–7,000 μS cm$^{-1}$ during spring.</td>
<td>&lt; 2,475 μS cm$^{-1}$ during winter</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>pH typically 7.0–9.9 during spring.</td>
<td>&gt; 7.0 (ANZECC 2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 9.0 (Davis et al. 1993)</td>
</tr>
<tr>
<td><strong>Chlorophyll a</strong></td>
<td>Chlorophyll a typically 0.5–23.3 μg L$^{-1}$ during spring.</td>
<td>&lt; 100 μg L$^{-1}$ (Davis et al. 1993)</td>
</tr>
<tr>
<td><strong>Nutrients</strong></td>
<td>Total phosphorus typically 28–389 μg L$^{-1}$ during spring.</td>
<td>&lt; 100 μg L$^{-1}$ (Davis et al. 1993)</td>
</tr>
<tr>
<td></td>
<td>Total nitrogen typically 1,386–6,800 μg L$^{-1}$ during spring.</td>
<td>&lt; 1,500 μg L$^{-1}$ (ANZECC 2000)</td>
</tr>
<tr>
<td><strong>Aquatic plants</strong></td>
<td>Systems dominated by submerged macrophytes but current extent</td>
<td>&gt; 50 % cover of lake bed (Strehlow et al. 2005).</td>
</tr>
<tr>
<td></td>
<td>and biomass of submerged and floating macrophytes unknown.</td>
<td></td>
</tr>
<tr>
<td><strong>Littoral vegetation</strong></td>
<td>Current extent and biomass of native and exotic riparian</td>
<td>Baseline must be set before limits can be made.</td>
</tr>
<tr>
<td></td>
<td>vegetation unknown.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current area of lake bed encroached by <em>Typha</em> and other</td>
<td></td>
</tr>
<tr>
<td></td>
<td>riparian vegetation unknown.</td>
<td></td>
</tr>
<tr>
<td><strong>Aquatic invertebrates</strong></td>
<td>Number of aquatic invertebrate families typically 14–39.</td>
<td>&gt; 14 families during spring</td>
</tr>
<tr>
<td></td>
<td>Insufficient information to set a baseline for abundance.</td>
<td></td>
</tr>
<tr>
<td><strong>Waterbirds</strong></td>
<td>Forrestdale and Thomsons Lakes regularly support &gt; 5,000</td>
<td>Consideration should be given to climatic patterns and their</td>
</tr>
<tr>
<td></td>
<td>waterbirds and breeding of 27 species (since 1988). However,</td>
<td>potential effect on bird numbers. Generally each lake should</td>
</tr>
<tr>
<td></td>
<td>waterbird numbers are highly variable and there has been no</td>
<td>support:</td>
</tr>
<tr>
<td></td>
<td>systematic, long term monitoring of these birds to enable a</td>
<td>&gt; 5,000 total waterbirds in 4 out of 5 years.</td>
</tr>
<tr>
<td></td>
<td>numerical baseline to be set.</td>
<td>Breeding of 27 species a minimum of once every three years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(lakes combined).</td>
</tr>
</tbody>
</table>
Note: The lake bed levels (m AHD) at both Forrestdale and Thomsons Lakes need to be agreed upon, as the reported levels have varied from <11.5 to 11.8 m AHD at Thomsons Lake and 21.1 to 21.6 m AHD at Forrestdale Lake. Levels currently used by the Department of Water in setting EWPs are 11.8 m AHD at Thomsons Lake and 21.6 at Forrestdale Lake. However, measurements currently recorded at Thomsons Lake by the Water Corporation reads to a minimum level of 11.5 m AHD, which is considered to be located above the lake bed level. Agreement on these levels is important the management of both lakes for the purposes of maintaining ecological character.
### Table D17: Condition Rating Against LACs (2009–2013)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Confidence</th>
<th>Trend (since ECD publication – 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 – LAC always met</td>
<td>5 – Highly confident, data available in peer reviewed journals; conference papers</td>
<td>Improving</td>
</tr>
<tr>
<td>3 – LAC met in the majority of years</td>
<td>4 - Data available through published reports, expert panels, peer reviewed agency monitoring evaluation</td>
<td>Stable</td>
</tr>
<tr>
<td>2 – LAC not met in majority of years</td>
<td>3 - Data available through agency monitoring evaluation</td>
<td>Degrading</td>
</tr>
<tr>
<td>1 – LAC not met</td>
<td>2 – Anecdotal information</td>
<td>Insufficient data</td>
</tr>
<tr>
<td></td>
<td>1 – Data not available</td>
<td></td>
</tr>
</tbody>
</table>
4.2.1 Condition assessment against Limits of Acceptable Change

Tables D18 to D22 below provide a summary of condition assessment against the LACs. Note that there is no data available to assess condition against the LACs for aquatic plants.

Table D18: Hydrology

<table>
<thead>
<tr>
<th>Components and processes</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Forrestdale Lake data analysis</th>
<th>Thomsons Lake data analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abstraction of groundwater</td>
<td>At the sediment surface (wet years), or up to 0.5 m below the lake bed levels (medium years), or 0.5–1.0 m below the lake bed surface (dry years) (DoE 2004) for 3–4 consecutive months annually.</td>
<td>All comments based on minimum water levels measured at FORRESTDALE LAKE BORE 602 (61410714). Lake bed = 21.6 mAHD 10 years assessed: 2004 to 2013. 7 of last 10 years were dry rainfall years. 2005, 2008 and 2013 were medium rainfall years. In this time this LAC was met in all years but 2005, a medium year when minimum levels fell 0.5 m below the lake bed for 3 consecutive months. There is a general trend in declining minimum water depth since 1996, predominantly due to reduced rainfall</td>
<td>All comments based on minimum water levels measured at THOMSONS LAKE LIMNOLOGY TM14A (61410367) Lake bed = 11.8 mAHD 10 years assessed: 2004 to 2013. Note – it appears the lake bed reading is too high. Levels of 11.5 mAHD have been recorded annually since 2003. 7 of last 10 years were dry rainfall years. 2005, 2008 and 2013 were medium rainfall years. In this time the LAC was met in all year except in 2013, a medium year when minimum levels fell 0.5 m below the lake bed for 3 consecutive months.</td>
<td>Forrestdale Lake</td>
</tr>
<tr>
<td></td>
<td>Reduced rainfall and higher temperatures</td>
<td></td>
<td></td>
<td></td>
<td>Forrestdale Lake</td>
</tr>
<tr>
<td></td>
<td>Altered catchment surface and groundwater water flows</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Always &lt; 1.0 m below the</td>
<td>This LAC has been met in all of</td>
<td>This LAC has been met in all of</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Forrestdale Lake
Condition score = 3
Confidence score = 4
Trend = degrading (declining lake levels)

Thomsons Lake
Condition score = 3
Confidence score = 4
Trend = degrading (declining lake levels managed by drainage supplementation)
and for waterbirds

<table>
<thead>
<tr>
<th>Condition</th>
<th>Confidence</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomsons Lake</td>
<td>4</td>
<td>stable</td>
</tr>
<tr>
<td>Condition score</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Confidence score</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**Strategic Assessment for the Perth and Peel Regions**

In the last 10 years minimum levels have never fallen more than 1.0 m below the sediment surface.

**Abstraction of groundwater**

Reduced rainfall and higher temperatures

Altered catchment surface and groundwater water flows

<table>
<thead>
<tr>
<th>Condition</th>
<th>Confidence</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomsons Lake</td>
<td>4</td>
<td>stable</td>
</tr>
<tr>
<td>Condition score</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Confidence score</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

**Annual maximum water depth** – is a key indicator of condition of emergent macrophytes and riparian vegetation.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Confidence</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forrestdale Lake</td>
<td>1</td>
<td>degrading (declining lake levels)</td>
</tr>
<tr>
<td>Condition score</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Confidence score</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>Confidence</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomsons Lake</td>
<td>1</td>
<td>degrading (declining lake levels managed by drainage supplementation)</td>
</tr>
<tr>
<td>Condition score</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Confidence score</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

All comments based on water levels measured at LAKE FORRESTDALE STAFF GAUGE 602 (6162557).

10 years assessed: 2004 to 2013.

In the last 10 years this LAC has never been met, maximum levels have not reached 0.9 m.
<table>
<thead>
<tr>
<th>ground water flows</th>
<th>months in only 1 year (2005).</th>
<th>Trend = stable (declining lake levels managed by drainage supplementation)</th>
</tr>
</thead>
</table>
| > 1.6 m at least once every 10 years (for invertebrates) | In the last 10 years this LAC has not been met, maximum levels have not reached 1.6 m. | Forrestdale Lake  
Condition score = 1  
Confidence score = 4  
Trend = degrading (declining lake levels) |
|                     | In the last 10 years this LAC has not been met, maximum lake levels have not reached 1.6 m. Note – the supplementation management plan for Thomsons states that (Dooley and Jackson 2004): ‘Nevertheless it is important to note the maximum drainage operational water level at Thomsons Lake is 12.8 AHD (at which time water would be pumped out to a level of 12.6 AHD). As such supplementation should be stopped at 12.6 AHD.’ This means this LAC will never be met under current management arrangements. | Thomsons Lake  
Condition score = 1  
Confidence score = 4  
Trend = stable (declining lake levels managed by water supplementation) |
| No less than 0.5 m more than once every 10 years (Froend et al. 1993). | This LAC has not been met. In 8 of the last 10 years maximum levels have been less than 0.5 m. | Forrestdale Lake  
Condition score = 1  
Confidence score = 4  
Trend = degrading (declining lake levels) |
|                     | This LAC has not been met. In 3 of the last 10 years (2006, 2010 and 2012) maximum levels have been less than 0.5 m. | Thomsons Lake  
Condition score = 1  
Confidence score = 4  
Trend = degrading (declining lake levels) |
<table>
<thead>
<tr>
<th>Period of inundation/drying</th>
<th>Abstraction of groundwater</th>
<th>&gt; 6 consecutive months of inundation annually (Balla and Davis 1993; Briggs and Thornton 1999).</th>
<th>All comments based on water levels measured at LAKE FORRESTDALE STAFF GAUGE 602 (6162557). 10 years assessed: 2004 to 2013. This LAC has not been met in 4 of the last 10 years. In 2007 the lake dried for 10 consecutive months (including Nov and Dec 2006), in 2008 for 7 months (including Dec 2007, in 2010 for 8 months (including Nov and Dec 2009) and in 2011 for 7 months (including Dec 2010). There were insufficient readings in 2013 to determine if LAC was met.</th>
<th>All comments based on minimum water levels measured at LAKE THOMSON STAFF GAUGE 609 (6142517). 10 years assessed: 2003 to 2012. This LAC has not been met in 6 of the last 10 years. In 2005 the lake dried for 7 months (including Dec 2004), in 2006 for 7 months, in 2007 the lake was likely dry for 9 months (readings were missing for Feb, Mar, May and Jul), in 2008 for 7 months, in 2011 for 8 months (including Nov and Dec 2010) and in 2012 for 9 months (including Dec 2011).</th>
</tr>
</thead>
<tbody>
<tr>
<td>No greater than 2.5 m for 2 consecutive years (Froend et al. 1993).</td>
<td>Maximum lake levels have not been greater than 2.5 m in the last 10 years.</td>
<td>Maximum lake levels have not been greater than 2.5 m in the last 10 years.</td>
<td>Forrestdale Lake Condition Score = 4 Confidence Score = 4 Trend = stable Thomsons Lake Condition score = 4 Confidence score = 4 Trend = stable</td>
<td>Preferred earliest drying by April</td>
</tr>
</tbody>
</table>
and 2013 were medium rainfall years. This LAC has not been met in 6 of the last 10 years. In 2005, a medium year, the lake dried in Dec 04. In 2007, a dry year, the lake dried in Oct 06. In 2008, a medium year, the lake dried in Dec 07. In 2010, a dry year, the lake dried in Dec 09. In 2011, a dry year the lake dried in Dec 10. In 2013, a medium year, the lake dried in Jan.

Permanent water present for not more than two consecutive years in every ten years (Crome 1988; Halse et al. 1993; Davis et al. 2001).

In the last 10 years this LAC has been met each year. The lake has not had permanent water for 2 consecutive years.

Forrestdale Lake
Condition score = 4
Confidence score = 4
Trend = stable

Thomsons Lake
Condition score = 2
Confidence score = 4
Trend = degrading (declining lake levels managed by drainage supplementation)

<table>
<thead>
<tr>
<th>Components and processes</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Lake Forrestdale data analysis</th>
<th>Lake Thomsons data analysis</th>
<th>Condition</th>
</tr>
</thead>
</table>
|                        | surface water and groundwater | Turbidity – high turbidity can indicate the presence of eutrophic conditions and a proliferation of phytoplankton | Nutrient enrichment from surface water and groundwater | Condition score = 4  
Confidence score = 4  
Trend = stable  
Thomsons Lake  
Condition score = 4  
Confidence score = 4  
Trend = stable  
Forrestdale Lake  
Condition score = 4  
Confidence score = 4  
Trend = stable  
Forrestdale Lake  
Condition score = 2  
Confidence score = 4  
Trend = stable  
Thomsons Lake  
Condition score = 2  
Confidence score = 4  
Trend = stable  
Forrestdale Lake  
Condition score = 3 |
|------------------------|--------------------------------|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|
|                        |                                | In this monitoring the LAC has always been met, colour has never exceeded 30 g 440 m\(^{-1}\).  
2012.  
In this monitoring the LAC has always been met, colour has never exceeded 30 g 440 m\(^{-1}\). | Period assessed: annual monitoring in spring from 2001-2009, 2012.  
In this monitoring the LAC has always been met, turbidity has never exceeded 40 NTU. | Monitored annually in spring from 1996-2001, 2003-2012.  
In this monitoring, the LAC has always been met turbidity has never exceeded 40 NTU. | Assessment of annual monitoring in spring (not winter) from 2001-2009, 2012.  
In this monitoring the LAC was not met in 9 of the 10 years. Salinity exceeded 2475 \(\mu S\) cm\(^{-1}\) in 2001,  
Assessment of annual monitoring in spring (not winter) from 1996-2012.  
In this monitoring the LAC was not met in 11 of the 17 years. Salinity exceeded 2475 \(\mu S\) cm\(^{-1}\) in 1996- 
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Criteria</th>
<th>Monitoring Period</th>
<th>Result</th>
<th>Confidence Score</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll a</td>
<td>Nutrient enrichment from surface water and groundwater</td>
<td>Assessment of annual monitoring in spring from 2001-2009, 2012.</td>
<td>In this monitoring the LAC has never been met, chlorophyll a has never exceeded 100 μg L⁻¹.</td>
<td>3</td>
<td>Stable</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Nutrient enrichment from surface water and groundwater</td>
<td>Assessment of annual monitoring in spring from 2001-2009, 2012.</td>
<td>In this monitoring the LAC has never been met. TP was above 100 μg L⁻¹ in 3 of the 10 years (2003, 2006 and 2012) and TN was above 1500 μg L⁻¹ in all years.</td>
<td>1</td>
<td>Stable</td>
</tr>
</tbody>
</table>

In monitoring the LAC was not met in 4 of the 10 years. pH was above the required range in 2002, 2004, 2006, 2012. 2012. In this monitoring the LAC was not met in 9 of the 17 years pH was above the required range in 1996-1998, 2000, 2002, 2006, 2009 and less than required range in 2012. Assessment of annual monitoring in spring from 1996-2001, 2003-2012. In this monitoring the LAC has never been met, chlorophyll a has never exceeded 100 μg L⁻¹. Assessment of annual monitoring in spring from 1996-2001, 2003-2012. In this monitoring the LAC has never been met. TP was above 100 μg L⁻¹ in 6 of the 17 years (1996, 1997, 1999-2001, 2010) and TN was above 1500 μg L⁻¹ in all years.

**Forrestdale Lake**
Condition score = 1  
Confidence score = 4  
Trend = Stable

**Thomsons Lake**
Condition score = 1  
Confidence score = 4  
Trend = Stable

**Forrestdale Lake**
Condition score = 4  
Confidence score = 4  
Trend = Stable

**Thomsons Lake**
Condition score = 4  
Confidence score = 4  
Trend = Stable

lead to rapid declines in pH after rewetting

< 9.0 (Davis et al. 1993)
### Table D20: Littoral vegetation condition

<table>
<thead>
<tr>
<th>Components and processes</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Lake Forrestdale data analysis</th>
<th>Lake Thomsons data analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Littoral vegetation extent and condition</td>
<td>Abstraction of groundwater</td>
<td>Current extent and biomass of native and exotic riparian vegetation unknown.</td>
<td>Not monitored</td>
<td>Not monitored</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Reduced rainfall and higher temperatures</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Altered catchment surface and groundwater water flows</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current area of lake bed encroached by Typha and other riparian vegetation unknown.</td>
<td></td>
<td>Not monitored</td>
<td>Not monitored</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Table D21: Invertebrates

<table>
<thead>
<tr>
<th>Components and processes</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Lake Forrestdale data analysis</th>
<th>Lake Thomsons data analysis</th>
<th>Condition</th>
</tr>
</thead>
</table>
Condition score = 3  
Confidence score = 5  
Trend = stable  
Thomsons Lake  
Condition score = 3  
Confidence score = 5  
Trend = stable |
<p>| Reference: Strehlow et al. (2012)           | Abstraction of groundwater           |                                                                       |                               |                             |            |
|                                              | Reduced rainfall and higher temperatures                                    |                                                                       |                               |                             |            |</p>
<table>
<thead>
<tr>
<th>Components and processes</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Lake Forrestdale data analysis</th>
<th>Lake Thomsons data analysis</th>
<th>Condition</th>
</tr>
</thead>
</table>
| Waterbirds               | Abstraction of groundwater | Consideration should be given to climatic patterns and their potential effect on bird numbers. Generally each lake should support: > 5,000 total waterbirds in 4 out of 5 years. Breeding of 27 species a minimum of once every three years (lakes combined). | Assessment of counts undertaken from 1996 – 2007 (generally in winter, spring and summer). This LAC has not been met. From 1996-2007 > 5,000 total waterbirds were recorded in: 1996, 2003 and 2005. Site specific breeding counts at Forrestdale and Thomsons (lakes combined) in 2004 and 2005 recorded higher than 27 species in 2005. For other years breeding data was pooled in reports across all sites. | Assessment of counts undertaken from 1996 – 2007 (generally in winter, spring and summer). This LAC has not been met. From 1996-2007 > 5,000 total waterbirds were recorded in: 1996, 1997, 1999, 2004 and 2005. Site specific breeding counts at Forrestdale and Thomsons (lakes combined) in 2004 and 2005 recorded higher than 27 species in 2005. For other years breeding data was pooled in reports across all sites. | Forrestdale Lake  
Condition score = 2  
Confidence score = 3  
Trend = Likely degrading  
Thomsons Lake  
Condition score = 3  
Confidence score = 3  
Trend = Likely stable |

|                           |         |                                  |                                |                           |            |
| Altered catchment surface and groundwater flows |         |                                  |                                |                           |            |
### 4.2.2 Summary and conclusions for LACs

Table D23 provides a summary of the condition against each of the LAC.

**Table D23 : Summary of the condition against each of the LAC**

<table>
<thead>
<tr>
<th>Components and processes</th>
<th>Limits of acceptable change (LAC)</th>
<th>Condition Score</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual minimum water depth</td>
<td>At the sediment surface (wet years), or up to 0.5 m below the lake bed levels (medium years), or 0.5–1.0 m below the lake bed surface (dry years) (DoE 2004) for 3–4 consecutive months annually.</td>
<td>3–4</td>
<td>stable to degrading</td>
</tr>
<tr>
<td></td>
<td>Always &lt; 1.0 m below the sediment surface (DoE 2004).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not 0.5–1.0 m below the sediment surface for longer than four consecutive months more than once every ten years or for 2 consecutive years (Froend et al. 1993).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual maximum water depth</td>
<td>&gt; 0.9 m (DoE 2004) for 2 months during spring.</td>
<td>1</td>
<td>degrading</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.6 m at least once every 10 years (for invertebrates).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No less than 0.5 m more than once every 10 years (Froend et al. 1993).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No greater than 2.5 m for 2 consecutive years (Froend et al. 1993).</td>
<td>4</td>
<td>stable</td>
</tr>
<tr>
<td>Period of inundation/drying</td>
<td>&gt; 6 consecutive months of inundation annually (Balla and Davis 1993; Briggs and Thornton 1999).</td>
<td>2–3</td>
<td>degrading</td>
</tr>
<tr>
<td></td>
<td>Preferred earliest drying by April (wet year), Feb–Mar (medium year) or January (dry year) (DoE 2004).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Permanent water present for not more than two consecutive years in every ten years (Crome 1988; Halse et al. 1993; Davis et al. 2001).</td>
<td>4</td>
<td>stable</td>
</tr>
<tr>
<td>Colour</td>
<td>&lt; 30 g 440 m⁻¹ at all times.</td>
<td>4</td>
<td>stable</td>
</tr>
<tr>
<td>Turbidity</td>
<td>&lt; 40 NTU at all times.</td>
<td>4</td>
<td>stable</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Value</td>
<td>Status</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>Salinity</td>
<td>&lt; 2,475 μS cm⁻¹ during winter.</td>
<td>2</td>
<td>stable</td>
</tr>
<tr>
<td>pH</td>
<td>&gt; 7.0 (ANZECC 2000), &lt; 9.0 (Davis et al. 1993).</td>
<td>3</td>
<td>stable</td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td>&lt; 100 μg L⁻¹ (Davis et al. 1993).</td>
<td>4</td>
<td>stable</td>
</tr>
<tr>
<td>Nutrients</td>
<td>TP &lt; 100 μg L⁻¹ (Davis et al. 1993), TN &lt; 1,500 μg L⁻¹ (ANZECC 2000).</td>
<td>1</td>
<td>stable</td>
</tr>
<tr>
<td>Littoral vegetation</td>
<td>Current extent and biomass of native and exotic riparian vegetation unknown.</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>extent and condition</td>
<td>Current area of lake bed encroached by <em>Typha</em> and other riparian vegetation unknown.</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Aquatic invertebrates</td>
<td>&gt; 14 families during spring.</td>
<td>3</td>
<td>stable</td>
</tr>
<tr>
<td>Waterbirds</td>
<td>Consideration should be given to climatic patterns and their potential effect on bird numbers.</td>
<td>2–3</td>
<td>stable to degrading</td>
</tr>
<tr>
<td></td>
<td>Generally each lake should support:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 5,000 total waterbirds in 4 out of 5 years.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Breeding of 27 species a minimum of once every three years (lakes combined).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The condition assessment against the LACs highlights that many of the LACs are being met in the majority of years. However, the assessment also shows that LACs for a number of key components and processes are either never being met or not being met in the majority of years. These components and processes include:

- annual maximum water depth;
- period of inundation/drying;
- salinity;
- nutrients; and
- waterbirds.

The LACs that have never been met, particularly some set for annual maximum water depth and nutrients may not be appropriate. Under the current climate in the south-west of Western Australia, where annual average rainfall has reduced significantly since the lakes were listed as a Ramsar site, it is very unlikely that surface water levels will ever be greater than 0.9 m for 2 months during spring or greater than 1.6 m for at least once every 10 years. However it should be noted that the last 10 years of rainfall, particularly 2006 and 2010, have been particularly dry in comparison to historical records. These extremely dry years mean the period may even be considered dry in the context of future climate predictions that indicate rainfall will continue to reduce in the south-west of Western Australia.

The supplementation program at Thomsons Lake has helped to mitigate the effect of reduced rainfall on lake depth, but depths at the lake have still not met LACs. Under the current management of the supplementation program, surface levels will never be greater than 1.6 m as the management plan states water will be pumped out of the lake if a level of 1 m is reached until the lake is returned to a level of 0.8 m. It also seems unlikely that total nitrogen concentrations will ever meet the LAC set for nutrients, given nitrogen have remained above the LAC despite very dry conditions that seem to have led to reduced phosphorus levels since 2002–03. One explanation for the continued high concentration of nitrogen despite the dry conditions could be that large reservoirs of nitrogen are held in the sediments of the lake beds, which are being mobilised when they are rewet.

Despite some of the LACs for annual maximum water depth and nutrients never being met, the lakes have not experienced unacceptable change in ecological character. The lakes have not become:

- Permanently wet.
- Permanently dry.
- Deep (>3 m).
- Saline or hypersaline.
- Acidic.
- Eutrophic or hypertrophic.
- Dominated by invasive plants.
- Unsuitable as a habitat for aquatic biota, especially waterbirds.
Though annual maximum water depth LACs have not been met, peak levels at both lakes in 2013 and 2014 were the highest for a number of years and local Superficial Aquifer levels have remained relatively stable since monitoring commenced. The relatively stable groundwater levels mean there is still potential for the lakes to fill well in years of good winter rainfall. Water quality and macroinvertebrate species richness at the lakes has generally been maintained. The lakes are still fresh/brackish, weakly coloured, generally clear, have a neutral to slightly alkaline pH and are moderately enriched. The stable macroinvertebrate species richness indicates that conditions at the lakes can still support the faunal species, including waterbirds and turtles.

Though wetland vegetation has declined in condition since monitoring commenced, it is still generally intact and there have been improvements in canopy condition at both lakes in recent years. Encroachment of Typha orientalis across the lake bed is an issue though active control measures have been successful in reducing coverage around parts of the lakes.

Importantly, Thomsons and Forrestdale Lakes are the still the best remaining examples of brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain and still provide important habitat for waterbirds on the Swan Coastal Plain including migratory species listed under the EPBC Act, meaning they still meet two Ramsar criteria.

While the sites still meet these criteria there are ongoing threats, including reduced rainfall and higher temperatures, together with abstraction of groundwater and land use change, that have the potential to negatively impact on the ecological character of the lakes. Future urbanisation could, to some extent, offset the effects of reduced rainfall with the increasing presence of impervious surfaces leading to a higher percentage of rainfall entering the Superficial Aquifer as recharge than would occur under native vegetation. In the current climate of diminished rainfall, increased evaporation and a reduction in recharge to groundwater, increased recharge associated with impervious surfaces could help maintain water levels at the lakes. However urbanisation can also increase nutrient concentrations in the Superficial Aquifer. As such, as urban development increases in the catchments of the lakes, so does the threat of nutrient enrichment.

While surface water supplementation is an option that is being used for Thomsons Lake to maintain depths and duration of inundation events, a suitable drainage supplementation option is yet to be identified for Forrestdale Lake. Given the very shallow maximum depths recorded at the Forrestdale Lake since 2006, and the success of the supplementation program at Thomsons, a suitable drainage supplementation option should be investigated for Forrestdale. The investigation should assess whether local authority or private drains in the area are restricting maximum groundwater levels and in turn impacting on lake levels. It should also identify drainage or land use adjacent to the lake that may be contributing to its nutrient concentrations.
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CONDITION STATEMENT – PEEL-YALGORUP SYSTEM RAMSAR SITE

EXECUTIVE SUMMARY

The Peel-Yalgorup System Ramsar site is located in south-western Australia, approximately 80 km south of Perth within the Swan Coastal Plain bioregion. The site covers more than 26,000 hectares and spans four municipal boundaries: City of Mandurah and the Shires of Waroona, Murray and Harvey (Figure D51).

The Peel-Yalgorup System is a large and diverse system of shallow estuaries, coastal saline lakes and freshwater marshes. The site includes the Peel Inlet, Harvey Estuary, Lake McLarty, Lake Mealup to the south of Peel Inlet and ten elongated coastal saline lakes to the west of the Peel Inlet in the Yalgorup National Park. The system also includes Goegrup Lake and Black Lake on the Serpentine River, which are being considered as an extension to the Ramsar listing.

The Peel-Yalgorup Ramsar site lies within Pinjarup country, a dialect group of the Nyoongar.

In January 1990 the Peel and Harvey Estuaries and the satellite lakes of McLarty and Mealup and the Yalgorup Lakes were nominated by the Western Australian Government as meeting criteria to be recognised as a “Wetland of International Importance” under the Ramsar Convention on Wetlands. In June 1990, the system was designated under the Ramsar Convention as the Peel-Yalgorup System Ramsar site.

The designation of the Peel-Yalgorup Ramsar site recognised four of the then six criteria for listing as a Wetland of International Importance which include the site’s size and diversity of estuarine systems and other coastal wetland types in south-western Australia in a near natural condition; the site is one of only two locations in south-western Australia and one of very few in the world where living thrombolites occur in inland waters; the site is the most important area for waterbirds in south-western Australia, supporting in excess of 20,000 waterbirds with numbers as high as 150,000 recorded; the site regularly supports 1% of the global population of Red-necked Avocet, Red-necked Stint, Red-capped Plover, Hooded Plover, Black-winged Stilt, Banded Stilt, Curlew Sandpiper, Sharp-tailed Sandpiper, Fairy Tern, Musk Duck, Grey Teal, Australasian Shoveler, Australian Shelduck and Eurasian Coot.

Additional criteria were adopted by the Ramsar Convention in 1996 and again in 2005 and as a result, two further criteria were recognised as being met at the Peel-Yalgorup System in a revision of the Ramsar Information Sheet in 2007. It is now recognised that the site supports an array of species and communities during critical life stages including large numbers and species of migratory birds (44 bird species are listed under international migratory agreements), breeding of waterbirds, fish, crabs and prawns, drought refuge for waterbirds, fish and invertebrates and for Australian Shelduck during molting and the site is an important as a nursery and/or breeding ground for at least 50 species of fish as well as the Western King Prawn and commercially significant Blue Swimmer Crab and is a migratory route for the Pouched Lamprey.
The listing in December 2009 under the EPBC Act of the *Thrombolite (microbialite) Community of a Coastal Brackish Lake (Lake Clifton)* as a critically endangered Threatened Ecological Community (TEC), the listing in August 2013 of the *Subtropical and Temperate Coastal Saltmarsh* as a vulnerable TEC, and in 2011 of the Fairy Tern (*Sternum nereis nereis*) as a Vulnerable threatened species, qualifies the Peel-Yalgorup System Ramsar site as meeting a further seventh criteria i.e. Criteria # 2 - *A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or Threatened Ecological Communities*. The proposed addition of this criteria will be addressed through the next revision of the Ramsar Information Sheet in 2015.

The Peel Inlet and Harvey Estuary are mainly used for recreational and commercial fishing, and other aquatic activities. The estuary system supports the largest professional and amateur estuarine fishery in Western Australia, with a high catch of blue swimmer crabs. The Peel-Yalgorup region is one of the fastest growing residential areas in Western Australia and supports varied types of horticultural and agricultural industries which require large supplies of groundwater and combined, excerpt a significant pressure on the natural values of the wetland systems.

Re-evaluation of the Peel-Yalgorup Ramsar site in 2007 for the publication of the Ecological Character Description (ECD) and in 2011 for the Commonwealth’s Rolling Review of Ramsar sites in Australia, confirmed the criteria for listing the Peel-Yalgorup System remain and while significant pressures were recognised and gaps in knowledge and monitoring existed, the site retained the biotic components and ecological processes that were the basis for recognising the site as a wetland of international significance. The evaluation conducted in this condition report is the most extensive conducted since the publication of the 2007 ECD.

The Peel-Yalgorup System Ramsar site retains those values recognised in all six of the criteria. The wetland habitat remains suitable to support high numbers of waterbirds in all parts of the system with perhaps the exception until June 2012, being for Lake Mealup, where all species counts had declined. Recent restoration of near natural hydrological regime, water quality and aquatic vegetation through the redirection of the Mealup Main Drain into Lake Mealup should facilitate a return to expected populations of waterbirds in that wetland.

The Shorebird 20-20 data confirms that habitat within the components of the Peel-Yalgorup System remains suitable to support high numbers of waterbirds with numbers across the entire Peel-Yalgorup System Ramsar site being greater than 20,000 for all six years of monitoring 2008-2013 and a maximum count in 2013 of over 90,000 waterbirds was recorded.

Assessment against the Limits of Acceptable Change (LACs) highlights that many of the LACs are being met in the majority of years. However, the assessment also shows that LACs for a number of key components and processes are either never being met, or not being met in the majority of years. These components and processes include:

- Nutrients (Total-P, Total-N, NOx) - particularly in the Serpentine and Murray Rivers, Goegrup Lake, Yalgorup Lakes and during low water levels in Lake McLarty
- Phytoplankton – particularly significant in the Serpentine and Murray Rivers and in Goegrup Lake and in the Peel Inlet and Harvey Estuary
- Dissolved Oxygen-particularly in bottom waters and in the Serpentine and Murray Rivers
- Salinity- particularly in the Yalgorup Lakes
Littoral Vegetation – particularly along fringes of the Peel Inlet and Harvey Estuary and lower reaches of its tributaries.

The areas of most concern at the present time are the Serpentine River and Murray River where the greatest proportions of water samples exceed the LAC for Total-P and for Dissolved Oxygen and consequently where the greatest number of fish kills occurs. If the apparent linear trend of declining dissolved oxygen continues, within about 15 years, all channel systems, including the Peel-Harvey Estuary will be anoxic with concentrations of dissolved oxygen below levels tolerated by fish i.e. < 4 mg/L.

The steady increase in salinity and nutrient concentrations in the Yalgorup Lakes is important and particularly the salinity is likely to lead to the deterioration of the Thrombolite formed processes responsible for these communities is the trend is not able to be managed effectively.

Evaluation of the available data for the biotic and abiotic components and processes for the Peel-Yalgorup System Ramsar site confirms that the ecological character has not been significantly altered since it was designated a wetland of international significance in 1990. However, significant pressures exist, including reduced rainfall and higher temperatures, together with abstraction of groundwater and land use change, that have the potential to negatively impact on the ecological character of the wetlands that make up this system.

Pressures will continue from the effects of climate change including declines in rainfall, changes to seasonal patterns of rainfall, increasing temperatures, high wind events and evaporation and sea level rise. Wetland systems are already undergoing significant alteration of hydrological regimes from reduced recharge of groundwater and river flows. Future sea level rise will increase the incidence of coastal erosion and flood events, leading to significant degradation of low lying areas. Future management actions should focus on the adaptation of these wetland systems to climate change and building resilience into the processes that support the key biotic components.

Significant gaps in knowledge of many of the components and processes of the Peel-Yalgorup System Ramsar site still exist and this limits the certainty in describing the condition of the system. Most notably is the lack of information of on the benthic, aquatic and littoral vegetation communities, their extent and condition across the entire system. Information on fish assemblages is known from surveys conducted through Murdoch University, but monitoring of fish population is not conducted and largely estimated from catch rates of commercially viable species. For instance the catch of Western King Prawns has diminished, but details are not available on the current population size or whether conditions within the estuarine system have contributed to the decline. Aquatic invertebrate data is almost totally lacking for any of the wetland systems and yet, they are a key part of the food source for most of the waterbirds, particularly those migratory shorebirds. While BirdLife Australia are consistent in collection of annual bird counts in the Shorebird 20-20 program, the data does not allow accurate indications of waterbird populations in the system. There is no consistent water quality monitoring in Black and Goegrup Lakes while the monitoring in the Yalgorup Lakes, though well done, is based on ad-hoc research programs.
1 Introduction

1.1 INTRODUCTION TO THIS REPORT

The purpose of this technical report is to provide a Condition Statement for the Peel-Yalgorup System Ramsar site. It will be used to inform the development of Draft Commonwealth Impact Assessment Report (CIAR) and the Draft Strategic Conservation Plan for the Strategic Assessment of the Perth and Peel Regions (SAPPR).

The report is arranged with an overview of the Peel-Yalgorup in Section 1, followed by a listing and justification of the criteria that have been used in the designation of the site as a Wetland of International Importance under the Ramsar Convention on Wetlands in Section 2. Section 2 also contains a description of the ecosystem components and processes that includes the information on the condition of the components and processes that was included in the Ecological Character Description (ECD) of 2007 (Hale and Butcher 2007). This follows with a description of the past, existing and future threats to the ecosystem’s components and processes and information on the existing management arrangements for the site. The current condition information of the key ecosystem components and processes, using data collected since publication of the 2007 ECD follows in Section 3, together with an assessment of current condition against the criteria used in the designation of the site as a Wetland of International Importance under the Ramsar Convention. Section 4 contains a description of the Limits of Acceptable Change (LACs) that are listed in the ECD for the site and an assessment of the condition of the key ecosystem components and processes against the LACs.

This report has been developed collaboratively by a number of Western Australian State Government Agencies, as the technical experts regarding the Ramsar site. Agency’s authors include:

- Department of Parks and Wildlife.
- Department of Water.
- Department of the Premier and Cabinet.

1.2 PEEL-YALGORUP SYSTEM RAMSAR SITE OVERVIEW

The Peel-Yalgorup System Ramsar site is located in south-western Australia, approximately 80 km south of Perth within the Swan Coastal Plain bioregion (Figure D51). The site covers more than 26,000 hectares and spans four municipal boundaries: City of Mandurah and the Shires of Waroona, Murray and Harvey (Figure D51).

The Peel-Yalgorup System is a large and diverse system of shallow estuaries, coastal saline lakes and freshwater marshes. The site includes the Peel Inlet, Harvey Estuary, Lake McLarty, Lake Mealup and ten elongated coastal saline wetlands inside the Yalgorup National Park (Figure D51).

The Peel Inlet and Harvey Estuary are large shallow estuarine waters fed from the Serpentine, Murray and Harvey Rivers, and are connected to the Indian Ocean through various channels. Lake McLarty and Lake Mealup are seasonal freshwater to brackish wetlands. The Yalgorup National Park wetlands are brackish to hypersaline. The wetlands are shallow and fed mainly from groundwater and rainfall. The site is fringed mainly by samphire, rushes and sedges and paperbark communities.
The Peel-Yalgorup System Ramsar site is the most important area for waterbirds in south-western Australia. It supports a large number of waterbirds and a wide variety of waterbird species. It also supports a wide variety of invertebrates, and estuarine and marine fish.

The Yalgorup Lakes are a group of mostly permanent wetlands which include Lake Clifton, one of the few places in the world where living thrombolites occur in inland water. Thrombolites are underwater rock-like structures that are formed by the activities of microbial communities. They are actively growing and rely on an inflow of fresh groundwater rich in calcium and bicarbonate. In Lake Clifton the thrombolites are considered to be over 2000 years old.

The Peel Inlet and Harvey Estuary are mainly used for recreational and commercial fishing, and other aquatic activities. The estuary system supports the largest professional and amateur estuarine fishery in Western Australia, with a high catch of blue swimmer crabs and formerly of Western King Prawns. However, Western King Prawn have not been caught in commercial catch rates since 2010 (Pers. Comm. Department of Fisheries 2015).

The Peel-Yalgorup Ramsar site lies within Pinjarup country, a dialect group of the Nyoongar. There are hundreds of sites of significance to the indigenous community including sites of artefact scatter, camp sites, ceremonial sites, fish traps, skeletal remains and other sites of significance.
Figure D51: Location of Peel-Yalgurup System Ramsar site
1.3 DAWSVILLE CHANNEL CONSTRUCTION

The Peel-Yalgorup site was first listed under the Ramsar Convention as a Wetland of International Importance in 1990. Since that time there have been a number of changes in the surrounding catchment and to the wetlands. There has been a substantial increase in the population of Mandurah, which has nearly doubled to around 70,000 people since the time of listing. This has put increased pressure on the wetlands in the Ramsar site in terms of recreational use, nutrient and contaminant loads, groundwater extraction and urban development, including the development of canals within the estuary. All of these have the potential to impact on the ecological character of the site. However, the single most influential factor was the construction of the Dawesville Channel, a large artificial connection to the Indian Ocean, designed to decrease the nutrient accumulations and algal problems in the Peel-Harvey Estuary.

As early as the 1970s and continuing through to the early 1990s, the system suffered the effects of eutrophication, predominantly due to inputs of phosphorus from the catchment. This resulted in an increase in algal growth, and of particular concern, blooms of the potentially toxic cyanobacterium, *Nodularia*. The results of investigations in the 1980s concluded that a reduction in nutrient loads from the catchment would be insufficient to alleviate the problem in an acceptable time, and that improved catchment management should be complemented by increasing nutrient loss to the ocean. As a consequence, the Dawesville Channel was commissioned, and this opening to the Indian Ocean was opened in April 1994.

The increased connection to the marine environment has resulted in fundamental and permanent changes to ecological components of the Peel-Harvey Estuary. Attributes such as hydrology and water quality have changed significantly and had effects on the biotic components of the system. Prior to opening of the Dawesville Channel, daily mean tidal range in the Peel Inlet and Harvey Estuary averaged 17% and 15% of the ocean tides respectively. Following the opening of the Dawesville Channel, the tidal ranges in the Peel Inlet and Harvey Estuary are 48% and 55% of the ocean tides respectively. With increased exchange with marine waters, water quality in the estuarine basins has improved, particularly in the Harvey Estuary where periods of stratification and deoxygenation are shorter and less frequent. *Nodularia* blooms have been absent and turbidity during spring has decreased. In contrast to pre-Channel years, water quality in the Harvey Estuary has become very similar to that in the Peel Inlet.

The increased marine influence in the estuaries has affected fauna such as fish and invertebrates as well as fringing samphire and paperbark communities. Studies conducted between 1994 -1998 demonstrated a general decline in canopy condition over the four years following the opening of the Channel, impacting five of the six tree species, but most significant impacts were measured in *Casuarina obesa*, *Eucalyptus rudis* and *Melaleuca rhaphiophylla* (Gibson 2000, Monks and Gibson 2000).
2 Ramsar listing

2.1 LISTING CRITERIA

The designation of the Peel-Yalgorup Ramsar site recognised four of the then six criteria for listing as a Wetland of International Importance which include the site’s size and diversity of estuarine systems and other coastal wetland types in south-western Australia in a near natural condition; the site is one of only two locations in south-western Australia and one of very few in the world where living thrombolites occur in inland waters; the site is the most important area for waterbirds in south-western Australia, supporting in excess of 20,000 waterbirds with numbers as high as 150,000 recorded; the site regularly supports 1% of the global population of Red-necked Avocet, Red-necked Stint, Red-capped Plover, Hooded Plover, Black-winged Stilt, Banded Stilt, Curlew Sandpiper, Sharp-tailed Sandpiper, Fairy Tern, Musk Duck, Grey Teal, Australasian Shoveler, Australian Shelduck and Eurasian Coot.

Additional criteria were adopted by the Ramsar Convention in 1996 and again in 2005 and as a result, two further criteria were recognised as being met at the Peel-Yalgorup System in a revision of the Ramsar Information Sheet in 2007; those being the recognition that the site supports an array of species and communities during critical life stages including large numbers of migratory birds, breeding of waterbirds, fish, crabs and prawns, drought refuge for waterbirds, fish and invertebrates and for Australian Shelduck during moulting and the site is an important as a nursery and/or breeding ground for at least 50 species of fish as well as the Western King Prawn and commercially significant Blue Swimmer Crab and is a migratory route for the Pouched Lamprey.

The listing in December 2009 under the EPBC Act of the Thrombolite (microbialite) Community of a Coastal Brackish Lake (Lake Clifton) as Critically Endangered, the listing in August 2013 of the Subtropical and Temperate Coastal Saltmarsh as vulnerable, and in 2011 of the Fairy Tern (Sternula nereis nereis) as vulnerable, qualifies the Peel-Yalgorup System Ramsar site as meeting a further seventh criteria i.e. Criteria # 2 - A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or Threatened Ecological Communities. The proposed addition of this criteria will be addressed through the next revision of the Ramsar Information Sheet in 2015 and hence is not included in Table d24.
**Table D24: Ramsar listing criteria and justification**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near natural wetland type found within the appropriate biogeographic region.</td>
<td>The site includes the largest and most diverse estuarine complex in south-western Australia and also particularly good examples of coastal saline lakes and freshwater marshes.</td>
</tr>
<tr>
<td>3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.</td>
<td>The site is one of only two locations in south-western Australia and one of very few in the world where living thrombolites occur in inland waters.</td>
</tr>
</tbody>
</table>
| 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions. | The basic description of this criterion implies a number of common functions/roles that wetlands provide and the following apply at the Peel-Yalgorup System Ramsar site, in most if not all cases both at the date of listing and at present:  
  • the critical life stage of migration: annual use by large numbers of many species of migratory animals;  
  • the critical life stage of drought refuge: seasonal influx of large numbers of waterbirds from dried out wetlands in surrounding areas, and periodic massive influx from wider regions during drought;  
  • the critical life stage of breeding: regionally and nationally significant colonies of cormorants occurred in the 1980s in paperbark swamp in “Carraburmup Swamp Nature Reserve” (Jaensch et al. 1988) on the south-east side of Peel Inlet (and part of the Ramsar site) and small breeding colonies of pelicans breed now and then on islets in Peel Inlet; in addition, the Yalgorup Lakes are a significant site bioregionally for breeding of Hooded Plover (Birds Australia 2005);  
  • breeding also applies to fishes, crabs and prawns; and  
  • the critical life stage of moulting: Shelduck and Musk Ducks that congregate on the open waters of the Ramsar site outside the breeding season are engaging in moul (hence, the birds are flightless for a short period). |
| 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds. | The site comprises the most important area for waterbirds in south-western Australia, supporting in excess of 20,000 waterbirds annually, with greater than 150,000 individuals recorded at one time (February 1977). Numbers exceeding 20,000 birds have been recorded in all comprehensive surveys conducted in the 1990s in the Peel-Harvey Estuary. |
A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

According to the 5th edition of Waterbird Population Estimates (http://www.wetlands.org/WatchRead/Currentpublications/tabid/56/mod/1570/articleType/ArticleView/articleId/3376/Waterbird-Populations-Estimates-Fifth-Edition.aspx), the site regularly supports 1% of the population of: Red-necked Avocet (Recurvirostra novaehollandiae), Red-necked Stint (Calidris ruficollis), Red-capped Plover (Charadrius ruficapillus), Hooded Plover (Thinornis rubricollis), Black-winged Stilt (Himantopus himantopus), Banded Stilt (Cladorhynchus leucocephalus), Curlew Sandpiper (Calidris ferruginea), Sharp-tailed Sandpiper (Calidris acuminata), Fairy Tern (Sternula nereis), Musk Duck (Biziura lobata), Grey Teal (Anas gracilis), Australasian Shoveler (Anas rhynchos), Australian Shelduck (Tadorna tadornoides) and, Eurasian Coot (Fulica atra).

A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.

The Peel-Yalgorup System Ramsar site is important as a nursery and/or breeding and/or feeding ground for at least 50 species of fish, the Western King Prawn (Penaeus latisulcatus) as well as the commercially significant Blue Swimmer Crab (Portunus pelagicus). In addition, the Peel-Harvey Estuary is a migratory route for the Pouched Lamprey (Geotria australis).

## 2.2 RAMSAR SITE VALUES

The values of the Peel-Yalgorup System Ramsar site are described in detail in the Ecological Character Description (ECD) of the site (Hale and Butcher 2007). As stated in the ECD p.13, “The Peel-Yalgorup site is large and complex, as a consequence, the wetlands within the site have been grouped according to location and wetland type to describe their ecological character:

- Peel Inlet and Harvey Estuary.
- Yalgorup Lake System.
- McLarty Lake System (Lakes McLarty & Mealup).
- Goegrup and Black Lakes (proposed extensions).

This “sub-system” approach is applied in describing the site’s values from the ECD which are summarised below.

### 2.2.1 Geomorphology

**Peel-Harvey Estuary**

The Peel-Harvey Estuary lies on the western edge of the Swan Coastal Plain and formed approximately 8,000 years ago. Prior to this, the sea level was approximately 150 m lower than today and the Murray and Harvey Rivers joined to flow directly to the Indian Ocean. Rising sea levels led to flooding of the plain and the estuary reached a maximum size approximately 4,000 years ago (when
sea levels were 0.5 to 43 m higher than current). Fossils show that at this time the estuary was more marine in nature and dominated by marine fauna (Brearley 2005).

The estuarine system consists of two interconnected shallow lagoons, the Peel Inlet and the Harvey Estuary, into which the Murray, Serpentine and Harvey Rivers discharge and the estuarine portions of those rivers as defined by saltwater penetration (Figure D52). The Dawesville Channel was opened in 1994 and is a large artificial channel constructed between the Peel-Harvey Estuary and the Indian Ocean. Prior to construction of the Dawesville Channel the only connection between the estuary and the ocean was the Mandurah Channel, a narrow 5 km long channel connecting the northern end of the Peel Inlet to the Indian Ocean.

**Yalgorup Lakes**

Yalgorup Lakes comprise ten wetlands situated between a series of linear coastal dunes within the Yalgorup National Park. They are separated from the Indian Ocean by the recently formed Quindalup Dune System, which is comprised of sand that is subject to movement. The older, more stable Spearwood dune system flanks the eastern shore of Lake Preston and surrounds the other lakes in the system.

The lakes are mostly permanent (except Newnham Lake and parts of Lake Preston), naturally saline to hypersaline, shallow (< 3 m deep) and have no defined inlet or outlet channels. Lake Preston is the largest of the wetlands and is closest to the sea. It is a long, narrow waterbody approximately 30 km long and 0.5–1.5 km wide, running parallel to the coast. An artificial causeway separates the northern section of Lake Preston from the remainder of the waterbody. Lake Clifton is the second largest wetland and the furthest inland. It is approximately 20 km long, and 0.2 to 1.5 km wide. The remaining wetlands are smaller and form a disconnected chain between Lake Preston and Lake Clifton.

**Lakes McLarty and Mealup**

Lakes McLarty and Mealup are shallow, moderate sized wetlands on the plain to the east of the Harvey Estuary.

The lakes are part of the Bibra suite, a linear wetland system that is located near the interface of the Bassendean and Spearwood dune systems. The lakes are approximately 600 m from the Harvey Estuary separated from the estuary by a fossil dune ridge (CALM 2008). They are both on the Spearwood dune system, which is characterised by shallow sandy soils over limestone.

Lake McLarty is approximately 2.1 km long and 1.25 km wide and covers 200 ha. The lake is oval in shape with shallow gradient shorelines and a fine layer of silt across the bottom (CALM 2008). Lake Mealup is situated 500 m to the north, has a similar morphology, but is approximately one-third the size at 70 ha.
Figure D52: Sub-catchments of the Peel and Harvey estuaries

**Lakes Goegrup and Black**

Lakes Goegrup and Black are riverine wetlands on the Serpentine River approximately 5 km upstream of the discharge to the Peel Inlet. Goegrup Lake spans the main channel of the Serpentine River and is connected to the adjacent Black Lake, by a narrow secondary channel. Black Lake is the local name given to a series of lakes comprising of Black Lake (proper), Wolyanup, Bulbiba and Road Lakes. While Lakes Goegrup and Black are not currently within the Ramsar site boundary, they have been identified as an area for potential inclusion within the Ramsar site.
2.2.2 Hydrology

**Peel-Harvey Estuary**

The major sources of water to the Peel-Harvey Estuary are from direct rainfall, surface water flows (rivers and drains), groundwater and tidal exchange via the Dawesville Channel. The river inflows are from three major river systems, the Murray and Serpentine Rivers, which discharge to the Peel Inlet and the Harvey River, which discharges to the Harvey Estuary.

Hydrological aspects such as rainfall, evaporation, river inflows and groundwater influences have not changed as a result of the Dawesville Channel. The Dawesville Channel, however, has had a significant effect on the tidal regime of the Peel Inlet and Harvey Estuary.

The movement of water through the Dawesville Channel now dominates tidal exchange in the estuary. It was predicted that the average residence time would reduce from 30 days to 10 days in the Peel Inlet and from 40–50 days to 17 days in the Harvey Estuary (Ryan 1993). It was also predicted that tidal exchange between the Peel Inlet and the Indian Ocean through the Mandurah Channel and between the Peel Inlet and Harvey Estuary through Grey Channel would increase. Average tidal exchange was expected to remain highest in winter with the influence of river flows, but the magnitude of this seasonal difference would be reduced (DAL 1997). Where summer residence times were approximately five times longer than those in winter prior to the opening of the Channel there is now less than 10% difference between seasons.

The increased tidal exchange through the Dawesville Channel has also affected the tidal levels within the estuary. Model predictions indicated that the maximum water level would increase and the minimum water level decrease, such that the tidal range is much larger. The tidal range has changed from an average of approximately 10 cm for both the Peel Inlet and Harvey Estuary to approximately 32 cm for the Peel Inlet and 45 cm for the Harvey Estuary some 6 cm higher than predictions (DAL 2002). In addition, there has been a phase change such that the Harvey Estuary now experiences high tide approximately 45 minutes before the Peel Inlet.

This increase in tidal range has resulted in changes to the intertidal areas around the estuary. The intertidal zone is now broader than it was and upper intertidal areas are submerged more frequently but for a reduced duration, while lower areas are inundated less frequently for increased periods (DAL 2002).

Prior to the opening of the Channel, extreme water levels were predominantly due to river flows and floods. It was predicted that the Channel would result in decreased flooding from catchment inflows due to the increased drainage to the ocean. However, it was also predicted that storm surges from the ocean would have a more dramatic effect on water levels within the estuary. In 2002, DAL reported that there had been no observed changes in extreme water levels in the estuary following the opening of the Channel.

**Yalgorup Lakes**

The lakes have no inflow or outflow channels and as such water sources comprise of direct precipitation, localised run off and groundwater.

Direct rainfall is the primary water source for the lakes, contributing an estimated 62% (Shams 1999), while groundwater discharge contributes 38% and localised run off is thought to be insignificant.
contributing less than 0.005% of total lake volume (Davies and Lane 1996). The lakes intersect the freshwater surficial unconfined aquifer that flows from the east towards the sea.

Hypersaline water of lake origin lies under the lakes with the fresh groundwater forming a lens above it (Burke and Knott 1989).

Rainfall and evaporation are similar to that of the estuarine system, the majority of precipitation falling in winter and spring, and evaporation exceeding rainfall for six months of the year. Despite this the lakes are near permanent due to the groundwater inflows.

However, groundwater inflow from the unconfined aquifer is also seasonal and water levels fluctuate seasonally.

Lake Clifton is the northeast member of the north-south elongated lakes located in the Yalgorup National Park, between the Peel-Harvey estuary and the Indian Ocean (Fig 1). It is the second largest in the system, measuring approximately 21.5km long by 1.5km wide, with the water body covering approximately 18km$^2$ in maximum extent (Commander 1988). Most of the lake is less than 1.5m deep, with certain areas up to 4.5m deep. Essentially the lake can be divided into three basins; the northern, which is the deepest, the middle and the southern (Knott et al. 2003). Both the northern and middle basins are permanent while the southern basin is ephemeral, typically drying out in summer.

Lakes McLarty and Mealup

Lake McLarty has no natural surface water drainage channels (although there is a drainage channel to the south that has the potential to overbank into the wetland). The dominant water source is groundwater and the lake intersects the shallow, surficial freshwater groundwater aquifer, which flows seasonally in response to rainfall. As a consequence, water levels are highest in spring after winter rains and groundwater seepage reach their maximum. The wetland is seasonally dry, with evaporation and loss of water back into the groundwater as aquifer levels fall. Lake McLarty is typically dry for 1–4 months over late summer and autumn, but not in all years (Craig et al. 2006). This wetland is shallow with maximum water depths typically less than 1.5 m, however, this is greatly variable depending on annual variability in rainfall and temperature.

There is anecdotal evidence that Lake McLarty is now drier more often and for longer periods of time and that the seasonality is shifting. In 1988, the fringing vegetation was inundated in spring; the lake was shallow during summer and dry for approximately one month over autumn. In 2002–2004, the lake dried earlier (January to February) and remained dry for four to five months (Bucktin 2004). It has been suggested that increased extraction of groundwater may be contributing to this changed hydrological regime. Average rainfall in the years 2002–2004 were below average (620 mm, 760 mm and 522 mm, respectively; Bureau of Meteorology), which could have contributed to the increased duration of the dry phase.

The hydrology of Lake Mealup is more complex. It is thought that Lake Mealup not only is connected to the shallow surficial groundwater aquifer, but also to the deeper artesian groundwater (Peter Wilmot, pers. comm. cited in Hale and Butcher 2007). Lake Mealup has water depths of less than 1.5 m and could be classified as seasonal or intermittent with a dry phase in early/late autumn to the first rains in winter.

Lake Mealup is also drier more often and for longer periods of time than at the time of listing. Where once the lake dried on average every two years, it has been dry during late summer to autumn since 1994. There are two major contributing factors to this: the drain connecting the lake to the Harvey...
Estuary was closed in 1994 as it was thought that the increased tides from the opening of the Dawesville Channel may lead to saline water inflows to the lake; and there has been increased development around the lake and corresponding increases in groundwater extraction.

**Lakes Goegrup and Black**

The Serpentine River is the main source of surface water for Lake Goegrup. This river flows through predominantly agricultural catchments before entering the Peel Inlet. The flow is highly seasonal with peaks in winter and spring. With the opening of the Dawesville Channel, the tidal range of the estuary has increased and Goegrup and Black Lakes are under tidal influence. As a consequence the lakes are permanent with tidal fluctuations in water level.

Black Lake also receives water from Nambeelup Brook, which flows into the wetland from the north-east. The narrow channel connecting Black Lake to Goegrup restricts tidal movement and although there is still some tidal exchange, Black Lake water levels fluctuate seasonally.

### 2.2.3 Water quality

**Peel-Harvey Estuary**

**Salinity**

Salinity in the Peel-Harvey Estuary is more stable and more marine than it was at the time of listing due to the construction of the Dawesville Channel. Salinity is generally higher in surface and bottom waters with average salinity approximately 30 ppt. There are still seasonal trends in salinity with freshwater inflows from the rivers during the winter months. However, salinity rarely drops below 10 ppt in surface waters or 20 ppt near the bottom in the centre of the basins. As freshwater inflows decrease after winter, salinity rapidly returns to marine levels of 35 ppt, although hypersaline concentrations of greater than 45 ppt are still regularly recorded in the summer.

During winter months when freshwater inflows are highest, there is a gradient in salinity from the areas of the estuary near the river mouths and the areas near the channel connections to the ocean. There are still instances of salinity stratification, however, they are generally of short duration.

**Dissolved Oxygen**

The Peel-Harvey Estuary is generally well oxygenated and mixed as a result of the shallow water and high winds. Typically dissolved oxygen concentrations are > 8 mg/L and > 90% saturation (PH CD ROM and DoW 2007). The extended periods of oxygen stratification that were characteristic of the system at the time of listing have greatly reduced, particularly during summer (Hale and Paling 1999). The increased flushing and corresponding decrease in eutrophic conditions and phytoplankton growth are likely contributing factors.

While lower river reaches are often very low in dissolved oxygen (< 5 mg/L and < 50% saturation) with incidences of extreme deoxygenation (< 1 mg/L; < 20% saturation), this is not reflected in the water column of the estuarine areas (data from DoW 2007).

Salinity stratification is still common in winter months and this leads to periods of decreased oxygen in bottom waters. Data collected from 1995 to 2001 indicate that this was more common at sites closest
to river inflows. However, this was only recorded on one occasion between January 2005 and December 2006 in the centre of the Peel Inlet (DoW 2007).

**Water Clarity**

Water clarity has improved since the opening of the Dawesville Channel and light penetration is typically to the bottom, especially in areas adjacent to the Channel. In addition, increased flushing and decreased phytoplankton biomass in the Harvey Estuary has resulted in similar conditions in both basins. However, the effects of turbid freshwater inflows are still evident during winter in areas adjacent to river discharge.

Water clarity is difficult to quantify in the Peel-Harvey Estuary as routine measurements have been made for secchi depth and light attenuation. However, the shallow water depth (< 2m) prevents a true indication of water clarity from secchi depth, as the disc can be visible on the sediment surface in conditions of moderate turbidity. In addition, light attenuation measurements over short distances (< 2 m) are also subject to substantial errors (DoW 2007). Monitoring has also included measurements of turbidity, however at reduced frequency (9–15 samples per year). These results indicate clear water (< 5 NTU) during most of the year across both basins. The exception to this was in the Harvey Estuary near to river inflows, where winter measurements were generally 15–20 NTU as a result of turbid water inflows and a summer phytoplankton bloom in January 2005 resulted in extreme turbidity of > 400 NTU (DoW 2007).

**Nutrients**

The strategy to reduce nutrients in the Peel-Harvey Estuary included actions to increase dilution (via the Dawesville Channel) and reduce nutrient inputs (catchment management actions). However, at the time of preparation of the ECD, there was no evidence that there had been significant reductions in nutrient inputs to the system. Phosphorus was identified as the nutrient limiting algal growth and total phosphorus loads from the catchment remained high and were greater than those at the time of listing (Table D25). While load data for nitrogen was not available there is evidence from measurements of water column concentrations that there had been no trend in nitrogen reduction from the catchment (URS 2007). As such total nitrogen loads were expected to remain in the order of 1,200 tonnes per annum.

**Table D25 : Current total phosphorus loads to the Peel-Harvey Estuary (DEH 2006).**

<table>
<thead>
<tr>
<th>Source</th>
<th>Total phosphorus (tonnes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serpentine River</td>
<td>69</td>
</tr>
<tr>
<td>Murray River</td>
<td>15</td>
</tr>
<tr>
<td>Harvey River</td>
<td>61</td>
</tr>
<tr>
<td>Total</td>
<td>145</td>
</tr>
</tbody>
</table>

Peak concentrations in nutrients in the estuary are a result of river inflows during winter and spring months and at the time of the ECD these remained similar to those recorded at the time of listing. Inorganic phosphorus (PO4) concentrations were highest in winter and in areas adjacent to river inflows. Mean (± standard deviation) PO4 concentrations in the Peel Inlet and Harvey Estuary during winter ranged from 55 (± 70) μg/L in areas closest to the rivers to 17 (± 25) μg/L adjacent to the Channel (1995–1999, Hale and Paling 1999). Peak concentrations of > 250 μg/L were recorded
during winter in both basins in the last decade. Summer concentrations of PO4 remained low and were typically less than 10 μg/L.

Concentrations of nitrate-nitrite followed a similar pattern with highest mean concentrations recorded during winter and adjacent to river inflows. Mean (± standard deviation) winter nitrate-nitrite concentrations were approximately 140 (± 150) μg/L in the Harvey Estuary and 230 (± 350) μg/L in the Peel Inlet (1995–1999, Hale and Paling 1999). Peak concentrations greater than 2,000 μg/L have been recorded in the Peel Inlet during winter. Summer concentrations of nitrate-nitrate were typically low and less than 10 μg/L.

Ammonium concentrations were higher in winter than summer and mean winter concentrations were approximately 115 (± 130) μg/L in the Harvey Estuary and 75 (± 80) μg/L in the Peel Inlet (1995–1999, Hale and Paling 1999). Peak winter concentration > 400 μg/L have been recorded in both basins. Summer ammonium concentrations were significantly lower than at the time of listing and were typically less than 10 μg/L. This is due to the reduced incidence of oxygen stratification and a corresponding reduction in sediment nutrient release.

Investigations of sediment water nutrient relations in the Peel-Harvey Estuary indicated that aerobic oxidation processes dominate (Longmore and Nicholson 2007). This results in efficient denitrification and conversion of inorganic, bioavailable forms of nitrogen into nitrogen gas, which is lost from the system. In addition, phosphorus release from the sediment is also low as a result of well oxygenated sediment water interfaces.

The ECD identified concentrations of organic forms of nitrogen and phosphorus as being significantly lower than at the time of listing. This is most likely due to the reduction in phytoplankton biomass in the system. Mean concentrations of organic phosphorus remain similar year round and were between 40 and 50 μg/L. Average concentrations of organic nitrogen were higher in winter (500–600 μg/L) than in summer (300–400 μg/L). Peaks of organic nutrients still occurred, most often during spring and summer algal blooms with concentration of organic phosphorus greater than 300 μg/L and organic nitrogen greater than 2,000 μg/L recorded in the last decade.

**Yalgorup Lakes**

The geomorphology and hydrology of the Yalgorup Lakes are the dominant influencing factors in the water quality. The lack of surface water outflow channels results in particulate and dissolved constituents in groundwater and rainfall being retained in the wetlands and becoming concentrated over time. Although there are no surface water outflows it is likely that groundwater flows through the systems and out towards the sea.

The lakes vary between brackish and hypersaline with strong seasonal patterns. The groundwater is fresh and low in nutrients, however movement through the limestone results in alkaline conditions and high concentrations of calcium and bicarbonate are characteristic of all of the lakes (CALM 1995). There have been few investigations of water quality in this system with the exception of salinity.

There is little long term monitoring information available for the ecological components of the Yalgorup Lakes, with the exception of waterbirds. As such, there are few changes in ecological character from 1990 that can be quantified. There is evidence, however, that the salinity in the lakes and particularly in Lake Clifton is increasing. Knott et al. (2003) reported that the salt load in Lake Clifton was stable throughout the 1980s, but had increased by 40% during the 1990s. Given that average annual rainfall had not significantly changed during this period, the ECD suggested that this may be attributed to changes in the groundwater quality and an increase in salinity. No recent
information exists, however, it would be expected that changes to groundwater quality would have a negative impact on the thrombolites, associated invertebrate communities and to waterbird usage of the system.

Nutrient concentrations in the lakes and the inflowing groundwater may also have increased. Shams (1999) reported concentrations of ammonium, nitrate-nitrite and orthophosphate from 1995/96 in the groundwater source above the then guideline values for West Australian lakes. Concentrations of nitrate-nitrite as high as 10,000 μg/L and ammonium concentrations in excess of 5,000 μg/L were recorded in bores surrounding the lakes. Although phosphorus concentrations were lower, concentrations of orthophosphate as high as 200 μg/L were recorded from bores adjacent to Lake Preston. Shams (1999) concluded that the sources of nutrients were from surrounding horticultural activities and potentially sewage pollution. Shams (1999) estimated that the total nitrogen load from groundwater was 15 tonnes/year for Lake Clifton and 54 tonnes/year for Lake Preston. The total phosphorus load for Lake Clifton was estimated to be 0.4 tonnes/year and Lake Preston, 1.6 tonnes/year. However, with no time series data it is not possible to say if this has or is increasing over time.

In February 2007 there was a large fish kill at Lake Clifton that resulted in the death of a number of Black Bream. Although the exact cause of this event is not known, it has been suggested that increased nutrients lead to deoxygenation of the water column and fish death (John and Paton 2007).

**Lakes McLarty and Mealup**

Water quality in the lakes is a product of groundwater quality and surface water run off from the surrounding local catchment. Lake McLarty is a freshwater system and salinity is less than 1 ppt throughout the year (CALM 2008). However, salinity varies seasonally with water level and with maximum readings in summer/autumn when water levels are lowest and concentration effects are apparent. Salinity typically ranges from 0.1 ppt in winter to 0.9 ppt during summer, although a survey during December 2006 in a few mm of water recorded salinity of 20 ppt (Syrinx 2007).

There is insufficient data to confirm water quality changes in Lake McLarty since the time of listing. However, the increased landuse intensity may contribute to increased nutrients entering the wetlands. At the time of the ECD nutrient data for Lake McLarty existed from monthly samples collected at the centre of the lake from 2001 and 2003 only. Concentrations of nitrate-nitrite and phosphate ranged from 20–3,000 μg/L and 50–3,000 μg/L respectively (Bucktin 2004). However, this may reflect concentration effects as the lake dries down rather than elevated nutrient concentrations due to human induced changes.

Water quality at Lake Mealup has declined since the time of listing. The most dramatic changes have been in the increased acidification, with pH values since 1994 ranging from 3.1 to 4.4 (Lake Mealup Preservation Society unpublished). It is thought that this is related to the acid sulfate sediments within the lake and the increased exposure of these to the air due to declining water levels (Peter Wilmott pers. comm. cited in Hale and Butcher 2007).

The iron pyrite within the sediments oxidises when the lake is dry and exposed to the air and produces sulphuric acid, leading to decreased pH. Nutrient concentrations recorded in Lake Mealup since 1994 may also be elevated, particularly ammonium, for which a maximum concentration of 68,000 μg/L was recorded in November 2006 (Lake Mealup Preservation Society unpublished). It is likely that the increased acidity has affected the denitrification cycle and resulted in the release of
ammonium from the sediments into the water column. In addition, where once Lake Mealup was characterised by high colour (from tannins), the water is now clear.

**Lakes Goegrup and Black**

Water quality in the lakes has not been monitored, however, the water quality monitoring program from the Serpentine River includes a site located at the upstream edge of Lake Goegrup (DoW 2007). Results from this program indicate that salinity varies considerably throughout the year in response to the variability in river flow. During winter when freshwater flows from the river dominate, salinity is fresh (less than 0.5 ppt). However, the influence of the tide and the decreased river flow during summer leads to hypersaline conditions with salinity greater than 50 ppt. The water column is generally neutral during the winter months (minimum pH 6.5) and ranges to alkaline (maximum pH 9.3) during summer and autumn. Monthly median dissolved oxygen concentrations are typically greater than 70% saturation only falling below this in summer (December to February).

Nutrient concentrations also vary seasonally in response to river flows. During summer when tidal influence is the dominating hydrological factor, nutrient concentrations are low; peak concentrations are reached during winter and spring. Results from monitoring in 2005–2006 indicated nitrate-nitrite concentrations ranging from less than 10 μg/L in summer to 300 μg/L in August 2006. Ammonium concentrations ranged from 10 μg/L to 530 μg/L and phosphate from greater than 5 μg/L to 230 μg/L. Concentrations of total nitrogen and phosphorus were linked to both phytoplankton biomass as well as river flow and ranged from 900 μg/L to 2,500 μg/L for total nitrogen and 20 μg/L to 430 μg/L for total phosphorus.

**2.2.4 Acid Sulfate Soils**

**Peel-Harvey Estuary**

Acid sulfate soils (ASS) form in coastal and estuarine environments where waterlogged soil provides ideal conditions for the build-up of mineral iron pyrite (FeS₂). Left undisturbed, ASS are benign, but disturbance exposes sulphidic compounds in the soil to air and results in the formation of sulphuric acid. Further effects are caused by the action of the acid on other elements in the soil, which includes the production of high concentrations of toxic metals (Hicks *et al.* 1999).

Regional mapping by the Department of Environment and Conservation identified more than 11,500 ha in the Peel region that is likely to contain ASS (Sullivan *et al.* 2006), which is predominantly in and around the Peel Inlet. Sampling conducted in canals around the Peel Inlet in 2006 indicated that concentrations of iron pyrite were high in the black organic mud (monosulphidic black ooze, MBO) found around the canal developments (Sullivan 2006). These sediments have a high potential for the production of sulphuric acid if disturbed and potentially for the release of bound contaminants.

Concentrations of most metals and toxicants in the sediments sampled were low. However, sediments with high concentrations of iron pyrite also contained very high levels of selenium. Concentrations as high as 5.4 mg/kg recorded in the sediment and 200 μg/L in pore waters (Sullivan *et al.* 2006). Although selenium is a naturally occurring element and an essential trace mineral for biota, it has the potential to bioaccumulate and in high concentrations can cause reproductive and immune dysfunction in fauna (US Department of the Interior 1998). Concentrations recorded in the Peel Inlet sediments are within the ranges known to cause such effects.
2.2.5 Phytoplankton

**Peel-Harvey Estuary**

The reduction in nutrient concentrations within the water column has had a dramatic effect on phytoplankton in the system. Large prolonged algal blooms are no longer a common feature within the estuary and cyanobacteria comprise a minor part of the phytoplankton community. Data collected in 2005 and 2006 (DoW 2007) indicate that the phytoplankton populations are generally diverse. Diatoms are still a major component, but cryptophytes are more often dominant, particularly species of the marine genus *Plagioselmis*.

In February 2006, the raphidophyte *Heterosigma akashiwo* was the dominant phytoplankton taxa near the river inflows in the Peel Inlet. This is a marine species that is known to be directly toxic to fish, but not to humans. However, at 700 cells/ml it was unlikely to be in sufficient density to cause ecological harm.

Algal blooms still occur on occasion in the estuary, but at the time of the ECD there had been no incidences of *Nodularia* blooms since the opening of the Dawesville Channel in 1994. It is suspected that the increased salinity is sufficient to prevent germination of akinetes. Winter blooms of the non-toxic marine dinoflagellate *Heterocapsa triquetra* occurred in the Harvey Estuary in 1997, 1998, 1999, 2000 and 2001 (DAL 2002) but not in more recent years.

Although no *Nodularia* blooms have occurred in Peel Inlet or Harvey Estuary, they have occurred in the Serpentine River as well as other cyanobacteria such as *Anabaena* and *Microcystis*. There have also been blooms of the potentially toxic dinoflagellate *Alexandrium minutum* recorded in the Murray River (DAL 2002).

Phytoplankton biomass in the Peel-Harvey Estuary is typically less than 10 μg/L year round. Mean chlorophyll a is higher in winter than summer (the reverse of the situation at the time of listing) and generally slightly higher in the Harvey Estuary than the Peel Inlet. Chlorophyll a concentrations of greater than 100 μg/L have been recorded in both the Peel Inlet and the Harvey Estuary in the last decade mostly during winter months. However, they were typically short lived, lasting for less than a week or so.

**Lakes Goegrup and Black**

Phytoplankton blooms are common in the lower Serpentine River and patterns of winter blooms of diatoms followed by summer blooms of *Nodularia* have been recorded (WRC 2004). The monitoring from the site at the upstream end of Lake Goegrup (2005–2006) indicated relatively high cell counts of phytoplankton (greater than 10,000 cells per ml) for much of the year. Blooms (greater than 20,000 cells per ml) are recorded during winter/spring and summer autumn. For example, an autumn bloom (greater than 600,000 cells per ml) dominated by green algae was recorded in April 2005 and a winter bloom of diatoms (170,000 cells per ml) was recorded in June 2006 (DoW 2007). In addition the toxic cyanobacterium *Lyngbya* has been recorded in bloom proportions at both Goegrup and Black Lakes.

In December 2006, *Lyngbya* covered approximately 75% of the surface area of Lake Goegrup. This was present as floating mats in January and February, which then sank to the bottom of the lake and decomposed, resulting in deoxygenation of the water column. At the time of the ECD the triggers for bloom formation were yet to be determined but there were high levels of nutrients within the lake and temperature and salinity changes could have been contributing factors.
2.2.6 Benthic plants

**Peel-Harvey Estuary**

At the time of a 2000 survey, the benthic plant community was dominated by seagrass, which comprised 50% of the total biomass (Wilson *et al.* 2000). *Halophila ovalis* was the most common species although both *Ruppia megacarpa* and *Heterozostera spp* were also recorded. Biomass estimates were 2,568 tonnes (dry weight) in the Peel Inlet and 62 tonnes in the Harvey Inlet.

Prior to the opening of the Channel, seagrass biomass senesced in autumn and was dormant over winter when temperature light and salinity restricted growth. Plants would then germinate from seed or rhizomes in spring and reach a peak biomass in summer. The light and salinity in the estuary may be sufficient for seagrass to sustain vegetative forms during winter, although temperature would still inhibit growth. However, there is insufficient information to determine if this happens. Anecdotal evidence suggests that peak biomass is still achieved in summer and that winter inflows of freshwater and nutrients result in increased epiphytic algae (such as *Hinksia*), which smothers seagrass and leads to a decline in their distribution and biomass.

Macroalgal biomass in the Peel Inlet is significantly lower than at the time of listing. There has been a change in growth and distribution with peak biomass now occurring in spring (as opposed to autumn). In spring 1998 total macroalgal biomass in the Peel Inlet was nearly 6,000 tonnes (dry weight) and by summer this had decreased to 2,560 tonnes. However, mean biomass over the five year period following the opening of the Dawesville Channel (1994–1999) was approximately 8,000 tonnes in spring and summer and 5,000 tonnes in autumn (Wilson *et al.* 1999).

Macroalgal distribution remains similar to 1990 with the highest biomass around the shallow margins of the Peel Inlet. Green algae (Chlorophyta) are the dominant taxonomic group and *Chaetomorpha* dominates the macroalgal community in the Peel Inlet, comprising 50–70% of the total biomass. Other genera recorded include members of the Rhodophyta (red algae) such as *Gracilaria, Spyridia, Ceramium, Polysiphonia, Laurencia; Phaeophyta* (brown alga) *Hinksia, Dictyota* and *Cladosiphon vermicularis* and the Cyanophyta (blue-green algae) *Schizothrix mexicana* and *Microcoleus lyngbyaceus* (Wilson *et al.* 1999). An average of 10–12 species were recorded in each survey.

In November of 2000 a survey conducted by the Aquatic Science Branch, Water and Rivers Commission, found the Cyanophyta *Lyngbya spp.* along the Coodanup foreshore, and in Robert Bay in the Peel Inlet (EPA 2008). However no biomass estimates were made and there is no survey data subsequent to this time.

Although the benthic plant flora is more diverse and lower in biomass than in 1990 and mechanical harvesting of macroalgae by DoW ceased during 2009, City of Mandurah continues to clear navigations channels when required.

Macroalgal biomass is lower in the Harvey Estuary than the Peel Inlet and follows a different seasonal pattern with peak biomass in summer (approximately 1,500 tonnes). Species composition is also different with *Cladophora* comprising the major proportion of macroalgal biomass during spring and summer (47% and 69%), followed by *Caulerpa* and the combined species of Rhodophyta (Wilson *et al.* 1999). The brown algae (Phaeophyta) and blue-green algae (Cyanophyta) are also components of the macroalgal community in the Harvey Estuary.

The macroalgal biomass recorded in the Harvey Estuary in summer of 2000 was higher than mean macroalgal biomass in this basin at the time of listing. It is possible that the increased salinity and
water clarity which has ceased *Nodularia* blooms has provided an ideal habitat for macroalgae, particularly as there has not been a reduction in nutrient loads entering into the system. However, in the absence of more recent data the ECD could not determine if the summer of 2000 was an anomaly or if there is a continuing trend for increased macroalgae in the Harvey Estuary.

**Yalgorup Lakes**

Benthic microalgae are an important ecological component of all of the Yalgorup Lakes. A notable colony has formed within the littoral margins of Lake Clifton, about 15m wide on the eastern side of the lake, occupying a total area of over 4km$^2$ (Moore 1991, Luu et al. 2004). Only a small isolated colony has been observed on the western shoreline at the northern end of the lake (Moore et al. 1984). These microbial communities are the basis of the food chain and support a wide variety of other organisms. In some of the lakes (Hayward, Yalgorup and Newnham) these microbial communities form a thick, mucilaginous layer across the sediment surface (CALM 1995). The thrombolites are arguably the most significant ecological component of this lake system, being the largest in the Southern Hemisphere (CALM 1995). Lakes Pollard, Newnham, Preston and Martins Tank all contain “fossil” stromatolite formations, but Lake Clifton is the only lake that contains living thrombolites (Moore 1991). The thrombolites at Lake Clifton are considered to be 2,000 years old and are one of only two examples of living thrombolites in Western Australia and a handful in the world (Moore 1991). They cover an area of approximately 400 ha and are predominantly located along the eastern shore (Moore 1987).

Thrombolites are rock-like structures that are formed by the activities of benthic microbial communities. These communities are diverse and typically comprise of cyanobacteria, diatoms and “true” bacteria. The thrombolites exhibit a wide range of external morphologies including conical, domical, discoidal and tabular forms (Moore 1991), which vary in width, height and morphology, with the largest up to 1.3m high, and diameters ranging between 20 and 150 cm. The cyanobacterium most commonly associated with the thrombolites at Lake Clifton is the filamentous *Scytonema*. Other genera include *Oscillatoria*, *Dichothrix*, *Chroococcus*, *Gloeocapsa*, *Johannesbaptista*, *Gomphosphaeria* and *Spirulina* (Moore 1991). Thrombolites are similar to stromatolites in outward appearance, but contain a clotted internal structure (compared to the layered strata of stromatolites). This difference in internal structure reflects the difference in formation processes. Stromatolites are formed by the mechanical trapping of sediments while thrombolites are formed by the precipitation of calcium carbonate by the benthic microbial community as they photosynthesise and grow (Moore 1991).

The thrombolites at Lake Clifton are actively growing and rely on the inflow of fresh groundwater rich in calcium and bicarbonate. This water source maintains lake levels that in turn prevents desiccation of the thrombolites, and keeps salinity in the system hyposaline (1–10 ppt) throughout the year. Unlike other cyanobacterial communities (such as phytoplankton) the thrombolites do not require significant nutrient inputs and it has been suggested that increased nutrients could be detrimental (Moore 1991). In 1988, *Cladophora* was noted to be growing over the thrombolites in late spring and summer, but was removed by wave and wind action during winter (CALM 1995). It was hypothesised that if nutrients in the groundwater source increased the growth of this and other macroalgae (or phytoplankton) could affect the thrombolites.

In addition to the thrombolites, there is a benthic plant community that consists of macroalgae (*Cladophora*), seagrass (*Ruppia megacarpa*) and charophytes (*Lamprothamnium papulosum*). The Charophyte (stonewort) *L. papulosum* is also a dominant feature at Lake Pollard where it covers most of the benthos (CALM 1995). This stonewort is adapted to the high alkalinity and calcium carbonate concentrations. It can tolerate a wide range of salinities (up to 70 ppt) but requires fresh to brackish water to reproduce (Burke and Knott 1989).
The Lake Clifton thrombolite potential Threatened Ecological Community (or TEC) and its surrounding habitat is under pressure from numerous environmental threats, including increasing salinity, greater nutrient inputs, climate change and declining water levels, as well as increased human visitation (Moore 1991).

The identification of increasing salinity levels and nutrient concentrations in the lake (Burke and Knott 1989, Moore 1991), led to the thrombolite community of Lake Clifton being assessed as endangered in 1996, and deemed critically endangered in February 2000 due to the increasing salinity and decreasing water levels being observed in lake waters.

2.2.7 Littoral vegetation

**Peel-Harvey Estuary**

Tidal salt marshes are an important component of the fringing vegetation of the Peel-Harvey Estuary. In 2013 these areas were listed under the national *Environment Protection and Biodiversity Conservation Act 1999* as a Threatened Ecological Community ‘Subtropical and Temperate Coastal Saltmarsh’. The community has been listed as vulnerable. Hodgkin et al. (1981) estimated that there was about 13 km² of salt marsh along the shoreline of the Peel-Harvey Estuary, predominantly along the north and eastern margins of the Peel Inlet and the southern fringes of the Harvey Estuary. Salt marshes occur in the intertidal zone where they are inundated by high tide and exposed during low tide. As such, the distribution of salt marshes in the estuary was predominantly determined by shoreline topography and tidal regime (Murray et al. 1995).

A total of 45 plant species were identified from surveys of salt marsh undertaken in 1994 (Murray et al. 1995a) some key aspects of the ecology of dominant species are provided in Text Box 1 below.

Upgradient of the salt marsh there are areas within the estuary that comprise littoral vegetation dominated by trees, including *Casuarina obesa* (Salt Sheoak) and *Melaleuca cuticularis* (saltwater paperbark). Both of these species have a relatively high salt tolerance (10 ppt) and are adapted to periodic inundation. The Ramsar site also retains some areas of riparian vegetation along the inflowing river systems, which comprise a mixture of freshwater and estuarine vegetation including tree species such as *Melaleuca rhaphiophylla* (Swamp Paperbark) and sedges such as *Typha orientalis* (Cumbingi). However, there is no quantitative information on extent and distribution of this vegetation from the time of listing (Monks and Gibson 2000).

<table>
<thead>
<tr>
<th><strong>Sarcocornia quinqueflora</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>This is a small green halophytic shrub with succulent stems and branches, which turn from green to red during autumn. This species occupied the lowest elevations and is tolerant of frequent inundation. Seeds are released in April with the onset of winter rains and it is thought that germination is more successful under low salinity conditions. Seedlings require three days free of tidal inundation to establish.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Suaeda australis</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>This is a small (30 cm) halophytic shrub that was found in association with organic debris. Seeds are released in June and germination is more successful under conditions of low salinity.</td>
</tr>
</tbody>
</table>

| **Bolboschoenus caldwellii** |
This small sedge grows from rhizomes in winter/spring when salinity is low and senesces when salinity increases in summer and autumn. Seeds are produced in spring during high tides and low salinity.

*Halosarcia* species

Several species of halophytic shrub from the genus *Halosarcia* were found in the marshes usually at higher elevation where inundation is less frequent. These species have a high salt tolerance and germination of seed is not thought to be affected by salinity. However, high temperatures are required for successful germination. *Halosarcia* species germinate under intense saline conditions that preclude the germination of seeds of other species.

*Frankenia pauciflora*

This is a small, prostrate shrub found on the drier banks in the marsh. It has an inability to regenerate under conditions of severe disturbance.

*Juncus kraussii*

This is a species of tall (up to 1.5m rush) that was found in the drier, elevated parts of salt marshes or in brackish areas where the salinities were lower. Light is required for germination, which under appropriate conditions takes 12 hours. The fresh seeds are highly salt tolerant but tolerance decreases with age and mature plants possess little salt tolerance.

*Atriplex* species

These are grey coloured herbs or shrubs that occurred in the higher marsh. Germination in *Atriplex* seeds is reduced by saline conditions, and the seeds are very sensitive to aeration, so rarely germinate when inundated.

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**Text Box 1: Ecological characteristics of dominant salt marsh species in the Peel-Harvey Estuary (summarised from Murray et al. 1995b).**

The ECD was not able to determine if there have been significant changes in distribution and composition since the time of listing due to no wide scale mapping of salt marsh extent since 1994. Surveys of samphire in the Peel Inlet and Harvey Estuary undertaken annually from 1994 to 1998 did not indicate any clear patterns of change with the opening of the Dawesville Channel (Monks and Gibson 2000). It was suggested that 5 years might be insufficient to determine changes in perennial vegetation, especially for communities with a high level of natural variability.

Changes to other littoral vegetation in the estuary have been more marked. Over the period 1994 to 1998 there was a significant decline in the canopy condition of *Melaleuca raphiophylla* along the lower Harvey River and a general decline of *Casuarina obesa*, *Eucalyptus rudis* and *Melaleuca raphiophylla* at the river mouth (Gibson 2000 and Monks and Gibson 2000). This was attributed to the increasing intrusion of marine water and the corresponding increased salinity.

In addition, Monks and Gisbon (2000) reported widespread decline in the littoral shrubs and trees along the western shoreline of the Harvey Estuary. This has also been attributed to the increased tidal regime and salinity. However, anecdotal evidence suggests that the large changes in littoral vegetation that occurred after the opening of the Dawesville Channel have settled to a new equilibrium in response with current environmental conditions (B. Pond, pers. comm. cited in Hale and Butcher 2007).
Yalgorup Lakes

Paperbark Swamp vegetation complex dominated by *Melaleuca cicutaris* and *Melaleuca rhaphiophylla*, occurs around the edges of the lakes, with smaller patches of *Melaleuca preissiana* in areas subject to flooding from freshwater sources (CALM 1995). The fringing vegetation is typically narrow, with rural and urban development within 20 metres of the eastern shore of Lake Clifton and western shore of Lake Preston.

The majority of the shorelines are devoid of littoral vegetation due mostly to the hypersaline conditions. Although salt marsh vegetation is adapted to conditions of high salt and alkalinity, most can tolerate salt loads of between 50 ppt and 100 ppt (Datson 2005), which is lower than many of the lakes during summer. The fresher water bodies, such as Lake Clifton, however, can support littoral vegetation and there are areas of the sedges such as *Gahnia trifida*, *Leptocarpus aristatus* and patches of *Typha domingensis*.

Lakes McLarty and Mealup

The ECD identified successional changes in the vegetation at Lake McLarty since 1990. A survey in 2001 indicated that the *Typha orientalis* that once covered the majority of the lakebed and the sedges that dominated the margins were no longer present (Craig *et al.* 2006). A survey in 2004, reported *Typha* in the centre of the lake and in disturbed soils (CALM 2008). This survey reported that *Juncus kraussi* (sea rush) is now dominant on the lake margins.

*J. kraussi* is adapted to saline conditions and is a component of the samphire salt marshes that surround the Peel-Harvey Estuary. Its dominance at a freshwater lake is indicative of increasing salinity within the lake, in the groundwater, the surrounding land, or a combination of these areas. However, salinity measurements collected over the period May 2000 to April 2004 do not support this. In 2000 and 2001 salinity ranged from less than 1 ppt (fresh) during winter and spring to 14 ppt (brackish to saline) when the lake was at its driest in autumn. However, during 2002 to 2004, maximum salinities were lower (less than 5ppt) throughout the year (Bucktin 2004).

Lakes Goegrup and Black

There are three wetland vegetation complexes present at Lakes Goegrup and Black, with zonation in response to water regime (Table D26). The samphire community is similar to that described above for the Peel-Harvey Estuary and occupies the lowest elevation, being regularly inundated by the tidal regime. The saltwater paperbark community sits higher in the landscape and is inundated less frequently. Finally, the freshwater paperbark is located at the highest elevations of the inundation tolerant vegetation. It is likely that this community is inundated only during winter when river flow is high and salinity is low.

Table D26: Wetland vegetation of Goegrup and Black Lakes, September 2006 (Ecoscape 2006).

<table>
<thead>
<tr>
<th>Description</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samphire flats of <em>Sarcocornia quinqueflora</em>, <em>Halosarcia syncarpa</em> and <em>Suaeda australis</em></td>
<td>82.8</td>
</tr>
</tbody>
</table>
Scattered *Eucalyptus rudis* over Low Open Forest of *Melaleuca cuticularis*, *Melaleuca rhaphiophylla*, *Casuarina obesa*, *Acacia saligna* over Sedgeland of *Baumea juncea*, *Juncus krausii* | 144.6
Low Closed Forest of *Melaleuca rhaphiophylla* over Open Herbland of *Conostylis aculeata*, *Dasypogon bromeliifolius* | 47.2

### 2.2.8 Invertebrates

**Peel-Harvey Estuary**

In general, benthic invertebrate species richness was predicted to increase as a result of the Dawesville Channel. Invertebrates are sensitive organisms with many species capable of responding to subtle changes in water quality and habitat types. The changes in salinity regime, the absence of *Nodularia* and the decreased frequency and duration of anoxic periods were all predicted to affect the invertebrate fauna. One of the main expectations was that there would be a shift in species among the polychaete worms and molluscs to longer lived species to those typically found in other less eutrophic estuaries such as Leschenault Inlet and the lower reaches of the Swan-Canning Estuary (DAL 2002). More marine species were expected to dominate the estuarine areas and brackish and freshwater species distribution was expected to contract. Increased tidal range was predicted to create a less extreme environment, particularly in summer, with greater or more frequent inundation of the intertidal zone (DAL 2002).

At the time of the ECD, there had been little investigation of the impacts of the Dawesville Channel on invertebrates within the Peel-Harvey Estuary. The exception is work done on the Blue Swimmer Crab which constitutes a large commercial and recreational fishery. The Peel-Harvey Estuary is the largest fishery for this species in Western Australia with catches in the late 1990s exceeding 200 tonnes in the Peel Inlet and 60 tonnes in the Harvey Estuary (Malseed and Sumner 2001; de Lestang *et al.* 2003a-b). Studies on the Blue Swimmer Crab, *Portunus pelagicus*, pre and post the Channel, show distinct changes have occurred since construction. Density patterns post the Channel being opened were more even from the Mandurah Entrance Channel to the Serpentine River than previously, with densities significantly greater in the Harvey Estuary and Serpentine River than in the 1980s (de Lestang *et al.* 2003a). Increased fishing pressure was also noted in the months February to May post the Dawesville Channel in the late 1990s with overall low densities recorded throughout the estuary. Overall the hydrological changes caused by the opening of the Dawesville Channel led to changes in density, size composition and early growth of the crab as well as stimulating an earlier emigration of ovigerous females (de Lestang *et al.* 2003a).

Annual summer studies indicate that the predictions regarding changes in the polychaete fauna appear to have occurred, with *Capitella capitata* decreasing in abundance, and *Ceratonereis aequisetis*, *Australonereis ehleri* and *Leitoscoloplos normalis* which are longer lived polychaetes occurring in greater numbers. Changes in the abundance of the mollusc *Arthritica semen* were also observed in northern Peel Inlet (Rose, *pers. comm.* cited in DAL 2002). Shifts in spatial and temporal patterns in the benthic invertebrate community were attributed to increased prevalence of marine conditions in the proximity of the Channel and increased diversity and abundance in the Harvey Estuary were also reported (Whisson *et al.* 2004 cited in ECD of Hale and Butcher 2007).
Recruitment of juvenile Western King Prawns and crabs into the Harvey Estuary occurs earlier than it did, due to the decreased duration of freshwater influences on salinity. However, it also seems that these crustaceans are leaving the estuary earlier and at smaller sizes (Whisson et al. 2004 cited in ECD of Hale and Butcher 2007). At the time of the ECD there was no evidence that this has resulted in a change in the population, as indicated by recreational and commercial fishing catches (Fisheries WA 2005).

Changes in tidal regimes are expected to affect the vegetation and also inundation patterns in the marshes, however at the time of the ECD such changes had not been documented. Changes to invertebrate communities are expected to be greater in the estuary than in the salt marsh areas (Keally et al. 1995) but will occur in response to changes in vegetation, inundation pattern, and water quality. This in turn will have implications for the food web structure of the estuary, in particular fish and wading birds, which rely on invertebrates as a major food source. Biotic feedback loops may also come into play, with changes in invertebrate community structure having a feedback on ecological processes such as decomposition, sediment mixing (bioengineering) and nutrient cycles (Keally et al. 1995).

The salt marshes of the Peel-Harvey Estuary are breeding grounds for two species of mosquito of human concern: Aedes camptorhynchus and Aedes vigila. These two species are vectors of Ross River Virus and Barmah Forest Virus in the region. Mosquitos are found in large numbers (greater than 1,000 larvae per m²) and mosquito breeding is strongly linked to climatic and tidal regimes. As such, the change in tidal inundation of salt marshes following the opening of the Dawesville Channel may have impacted on mosquito populations by providing greater areas of inundated land in which to breed.

Yalgorup Lakes

Aquatic invertebrates of the Yalgorup system are poorly studied (National Trust of Australia 1973) with most survey work focusing on vertebrate species or important fishery species. The exception is the fauna associated with the thrombolites. Konishi et al. (2001) published the only study of aquatic invertebrates associated with the fabric of living thrombolites of Lake Clifton. They identified 20 invertebrate taxa associated with the thrombolites: predominantly, by crustaceans (amphipods, isopods) and polychaetes. Other invertebrates collected included species of foraminifera, ostracods, nematodes, midge larvae, water mites, beetles and harpacticoid copepods (Konishi et al. 2001).

Thrombolites in Lake Clifton support a diverse invertebrate community, which includes several grazing species which use the stromatolites as both food and refuge. Invertebrates found associated with the thrombolites include isopods, amphipods, gastropods and bivalves. Other invertebrates recorded associated with the microbialites in Lake Clifton are shrimp, sea anemone and bryozoans (CALM 1995). Two species of snails are reported from the shallow lake edges (CALM 1995).

Lakes McLarty and Mealup

As with other parts of the Peel-Yalgorup Ramsar site the understanding of aquatic invertebrate communities at Lake McLarty and Mealup is limited. Lake McLarty was surveyed in the summer of 2000, the first survey of aquatic invertebrates at the wetland. Forty six species were recorded, with...
species of ostracods, damselflies and diptera being dominant, and considered important food items for waterbirds (CALM 2008).

While the information on the invertebrate fauna is limited for Lake McLarty and lacking for Lake Mealup, these wetlands would support different invertebrate communities to those found in other areas of the Ramsar site. Seasonal freshwater wetlands can be highly productive systems with considerable invertebrate diversity.

**Lakes Goegrup and Black**

Data on aquatic invertebrates at Lake Goegrup samphire is reported in Keally *et al.* (1995) and is the only invertebrate data sourced for Goegrup and Black Lakes. Of the salt marshes surveyed in the study, the site at Lake Goegrup showed very low abundances across all zones of the salt marsh and also relatively low species richness. Species recorded at Lake Goegrup included *Hydracarina*, oligochaetes, *Corixidae* water boatmen and a beetle. Oligochaetes were the most abundant taxa encountered in summer 1993/94 (Keally *et al.* 1995).

**2.2.9 Fish**

**Peel-Harvey Estuary**

It was predicted that the increase in salinity as well as the provision of an additional route for passage of fish between the ocean and the estuary (through the Dawesville Channel) would lead to an increase in recruitment of fish which mature or only occur at marine salinities (DAL 2002). In addition, it was expected that although there should be little effect on estuarine fish, species such as Sea Mullet, which utilise low salinity water in juvenile stages, were expected to be disadvantaged. Finally, the absence of *Nodularia* blooms was expected to be beneficial to all species, but particularly benthic fish, crabs and prawns (Hale and Butcher 2007).

Movement of larvae into and out of the Peel-Harvey Estuary was investigated in 1997 to establish if the Dawesville Channel affected the characteristics of ichthyoplankton. In both the Dawesville and Mandurah channels, flood tides carried significantly more species in higher concentrations than on ebb tides. Peaks in concentration occurred in spring and early autumn. Species that spawned in the ocean such as sandy sprat (*Hyperlophus vittatus*), small toothed flounder (*Pseudorhombus jenynsii*) and goldlined seabream (*Rhabdosargus sarba*) were more abundant on the flood tide, and species which breed in the estuary were more abundant on the ebb tide including elongate hardyhead (*Atherinosoma elongate*), and gobbleguts (*Apogon rueppellii*) (Young and Potter 2003). Species composition of the larvae was not substantially different in each channel and underwent cyclical changes in both tides and both channels (Young and Potter 2003).

Young and Potter (2003b) concluded that the fish fauna in shallow waters of the Peel-Harvey Estuary is now dominated by marine species, with 65% of the species and 70% of the total number of fishes caught representing marine stragglers and marine estuarine-opportunists. Marine species such as the banded blowfish (*Torquigener pleurogramma*) and sandy sprat (*Hyperlophus vittatus*) increased in abundance and penetrated further south into Harvey Estuary, the latter of these comprising 60% of total fish caught (Table D27). Species that showed declines were those that were associated with the increased algal growths of the 1970s and 1980s such as the six-lined trumpeter (*Pelates sexlineatus*) and gobbleguts (*Apogon rueppellii*).
Table D27 : Fish composition and abundance in the Peel-Harvey Estuary 1996-97 for species that comprised >1% of total catch from Young and Potter 2003b.

<table>
<thead>
<tr>
<th>Species</th>
<th>Common Name</th>
<th>Lifecycle</th>
<th>Number</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperlophus vittatus</td>
<td>Sandy sprat</td>
<td>Opportunist</td>
<td>42,275</td>
<td>58</td>
</tr>
<tr>
<td>Atherinosoma elongata</td>
<td>Elongate hardyhead</td>
<td>Estuarine</td>
<td>8,784</td>
<td>12</td>
</tr>
<tr>
<td>Leptatherina presbyteroides</td>
<td></td>
<td>Estuarine &amp; Marine</td>
<td>7,892</td>
<td>11</td>
</tr>
<tr>
<td>Torquigener pleurogramma</td>
<td>Weeping toado/banded</td>
<td>Opportunist</td>
<td>3,931</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>blowfish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aldrichetta forsteri</td>
<td>Yellow-eye mullet</td>
<td>Opportunist</td>
<td>3,210</td>
<td>4.4</td>
</tr>
<tr>
<td>Favonigobius lateralis</td>
<td>Long-headed goby</td>
<td>Estuarine</td>
<td>2,242</td>
<td>3.1</td>
</tr>
<tr>
<td>Apogon rueppellii</td>
<td>Gobbleguts</td>
<td>Estuarine</td>
<td>1,240</td>
<td>1.7</td>
</tr>
<tr>
<td>Atherinomorus ogilbyi</td>
<td>Ogilby’s hardyhead</td>
<td>Opportunist</td>
<td>833</td>
<td>1.2</td>
</tr>
<tr>
<td>Leptatherina wallacei</td>
<td>Western hardyhead</td>
<td>Opportunist</td>
<td>822</td>
<td>1.1</td>
</tr>
</tbody>
</table>

At the time of the ECD, total commercial catch had decreased since the time of listing, however, catch per unit effort had remained relatively stable (Figure D53). There had been a significant change in some commercial species. Cobbler (*Cnidoglanis macrocephalus*) catch had decreased significantly from an average catch of 57 tonnes (1976–1999) to 2.3 tonnes (2000–2005). However, there had also been a corresponding decline in the Swan-Canning Estuary for this species, suggesting that the influencing factors may not be site specific. There was a substantial increase in King George Whiting (*Sillaginodes punctata*) during 1996, possibly due to high rainfall and increased breeding opportunities. However, the recruitment cohort matured after 3–4 years and moved off shore, returning numbers to 1990 levels.
Although there are no data on introduced fish species from within the estuary, there have been investigations into introduced species in the catchment. Within the Peel-Harvey catchment six introduced fishes are known to exist (Morgan et al. 2004). These include the eastern Mosquitofish (*Gambusia holbrooki*), which is widespread throughout, including the upper sections of the estuary; Goldfish (*Carassius auratus*) have been found within the lower Harvey River, Serpentine River and Murray River; Redfin Perch (*Perca fluviatilis*) are common in the Murray and Harvey Rivers; Rainbow Trout (*Oncorhynchus mykiss*) are known from the Harvey, Serpentine and Murray Rivers; Brown Trout (*Salmo trutta*) are found in the Harvey catchment, at least (Morgan et al. 2004). Silver Perch (*Bidyanus bidyanus*) have been reported from the Harvey Dam (M. de Graaf, pers. comm. cited in Hale and Butcher 2007).

**Yalgorup Lakes**

There is little information on the fish communities in the Yalgorup Lakes. Lake Clifton is known to support Black Bream (*Acanthopagrus butcheri*), Western Hardyheads (*Leptatherina wallacei*) and Long-headed Goby (*Favonogobius lateralis*) (Sarre and Potter 2000, Hoddell 2003). While the Hardyhead and Goby may be endemic to the system and remnants from times of greater connectivity between the lakes and other surrounding waterways, the Black Bream have been introduced. Norriss et al. (2002) suggested that they were genetically similar to the population in the Collie River and this may have been the original source. Studies of feeding behaviour suggest that the Black Bream in Lake Clifton are feeding predominantly on polychaete worms (Sarre and Potter 2000), however, Cladophora was a large component of the diet at other sites investigated. The feeding behaviour of Black Bream, which includes grazing from hard surfaces, may pose a threat to the thrombolite communities (D. Morgan, pers. comm. cited in Hale and Butcher 2007).

In February 2007 there was a large fish kill at Lake Clifton that resulted in the death of a number of Black Bream. Although the exact cause of this event is not known, it has been suggested that increased nutrients lead to deoxygenation of the water column and the death of these fish (John and Paton 2007).

While the salinity in many of the lakes (Boundary, Martins Tank, Yalgorup, Newnham and Hayward) would appear to be too high to support the majority of fish species, the brackish to saline waters of Lakes Pollard and Preston would also be suitable for estuarine and marine fish species.

**Lakes McLarty and Mealup**

No information is provided in the ECD on fish in either Lake McLarty or Mealup, however as seasonal wetlands they may not support fish populations.

**Lakes Goegrup and Black**

The fish fauna of Lake Goegrup between 1979 and 1981 is documented in Loneragan et al. (1986). They recorded 17 species of teleosts, including *Pelates sexlineatus*, *Apocon rueppelli*, *Gerres subfasciatus*, *Hyperlophus vittatus*, *Aldrichetta forsteri*, *Favonogobius lateralis*, *Atherinosoma elongate*, *Atherinomorus ogilbyi*, *Sillago schomburgkii*, *Atherinosoma wallacei*, *Nematalosa vlamighi*, *Amniataba caudavittatus*, *Mugil cephalus*, *Pseudogobius olorum*, *Hyporhamphus regularis*, *Allanetta mugiloides*, *Atherinosoma presbyteroides* and *Acanthopagrus butcheri*. Both mean density and
biomass of species was higher in the dry season compared to the wet. They found several other species approximately 4 km downstream of the lake in the Serpentine River. Loneragan *et al.* (1987) recorded a further four species from Lake Goegrup utilising different capture methods, these included *Cnidoglanis macrocephalus, Argyrosomus hololepidotus, Engraulis australis* and *Rhabdosargus sarba*.

Loneragan *et al.* (1986) also reported on the salinities in Lake Goegrup and noted that during the wet season, salinities are significantly lower than sites in the estuaries proper. Loneragan *et al.* (1987) noted that halocline formation in Lake Goegrup tended to be restricted to between May and November and that salinity has a pronounced influence on the diversity of species, with fewer species occurring when salinities become reduced.

### 2.2.10 Marine mammals

Although not well studied, there is anecdotal evidence that the Peel-Harvey Estuary supported a small population of bottlenose dolphins (*Tursiops aduncas*). Animals were observed feeding in the estuary and travelling up the Serpentine River as far as Goegrup Lake. It is possible that the dolphins are resident in the estuary, but this is yet to be confirmed and observations up to 2007, supported an understanding that the dolphins used the estuary for feeding, travelling between the estuary and the ocean via the Mandurah Channel.

### 2.2.11 Birds

**General**

Habitat resources, which are determined largely by climate, geomorphology and hydrological regimes, drive waterbird abundances, with movements of waterbirds in Australia considered to be largely unpredictable and complex. For example, in the drought years of 1969-1970 the Peel-Preston waters showed a marked increase in the annual summer influx of waterfowl that were considered to have immigrated from drier inland areas (National Trust of Western Australia 1973). Shorebirds have the most regular movements, with many species migrating between Australia and the Northern Hemisphere. Within estuarine wetlands, such as the Peel-Yalgorup site, resident shorebird species may be present all year round with migratory species contributing to an influx of species and numbers mainly in spring and summer.

Waterbirds collectively display a number of feeding strategies relating to morphological, behavioural and physiological factors as well as food availability. This affects how waterbirds use wetlands, with different species being able to use the same areas by feeding on different resources (Kingsford and Norman 2002). Bill shape and size is often related to diet, and closely related species can eat different habitats but eat the same or different prey. Diet requirements affect the behaviour and patterns of habitat use, thus it is typical to see herbivorous species feeding for extended periods, as their food is harder to digest.

The 2007 ECD of the Peel-Yalgorup Ramsar site was limited to birds considered wetland dependant and so excluded terrestrial birds recorded in adjacent landscapes. Wetland dependant in this context is defined as birds that are dependent on the habitats and vegetation that are considered to require periods of inundation.
Peel-Harvey Estuary

Diversity and Abundance

The variety of food and habitat resources available within the Peel-Harvey Estuary supports both a diversity of species as well as a great abundance of individuals. A total of 86 species of waterbirds have been recorded in the Peel-Harvey Estuary (Table D28). This includes species such as Black Swans and Pelicans, which are present throughout the year, as well as temporary residents such as migratory shorebirds that use the estuary seasonally. This list includes 29 species that are listed under the international migratory agreements JAMBA and CAMBA as well as an additional 32 Australian migratory species that are listed under the Environmental Biodiversity and Conservation Act 1999 (EPBC).

There are four species that have been observed in the Peel-Harvey Estuary that have not been recorded in any other part of the Peel-Yalgorup Ramsar site; Eastern Reef Egret, Artic Tern, Common Tern and Roseate Tern. However, these are considered rare in the system because they are principally marine species.
Table D28: Number of waterbird species found within the Peel-Harvey Estuary section of the Peel-Yalgorup Ramsar site (1976-2007).

<table>
<thead>
<tr>
<th>Waterbird Group (number within Ramsar site)</th>
<th>Typical feeding and foraging information</th>
<th>Number of species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ducks and allies (12)</td>
<td>Shallow or deeper open water foragers. Vegetarian (Black Swan) or omnivorous with diet including leaves, seeds and invertebrates.</td>
<td>12</td>
</tr>
<tr>
<td>Grebes (3)</td>
<td>Deeper open waters feeding mainly on fish.</td>
<td>3</td>
</tr>
<tr>
<td>Pelicans, Cormorants, Darters (7)</td>
<td>Deeper open waters feeding mainly on fish.</td>
<td>7</td>
</tr>
<tr>
<td>Heron, Ibis, Egrets (13)</td>
<td>Shallow water or mudflats. Feeding mainly on animals (fish and invertebrates).</td>
<td>12</td>
</tr>
<tr>
<td>Hawks, Eagles (3)</td>
<td>Shallow or deeper open water on fish and occasionally waterbirds and carrion.</td>
<td>3</td>
</tr>
<tr>
<td>Crakes, Rails, Water Hens, Coots (8)</td>
<td>Coots in open water; others in shallow water within cover of salt marsh. Omnivores.</td>
<td>7</td>
</tr>
<tr>
<td>Shorebirds (43)</td>
<td>Shallow water mudflats and salt marsh. Feeding mainly on animals (invertebrates and fish).</td>
<td>32</td>
</tr>
<tr>
<td>Gulls, Terns (12)</td>
<td>Terns, over open water feeding on fish; gulls, opportunistic feeders over a wide range of habitats.</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>86</td>
</tr>
</tbody>
</table>

It should be noted that because waterbirds are highly mobile, some with continental or international range of occurrence, and because many are secretive or easily overlooked within dense aggregations, lists of species recorded at a particular site are rarely complete and tend to increase over time. However, given the high level of survey effort within this part of the Ramsar site, it is likely that the relatively few future additions to the list will be vagrants.

One of the reasons that the Peel-Yalgorup site is listed as a Wetland of International Importance is that it regularly supports greater than 20,000 waterbirds. Large total numbers of waterbirds were recorded in the Peel-Harvey Estuary prior to and at the time of listing, the highest being 150,000 in February 1977, which was the highest reported total for wetlands in south-western Australia (Lane and Pearson 2002). This included 63,000 Banded Stilt, 25,000 Grey Teal, 17,000 Eurasian Coot, 13,000 Red-necked Stint, 10,000 Hoary-headed Grebe and 8,000 Black Swans. In addition, Curlew Sandpiper, Little Black Cormorant, Little Pied Cormorant, Pied Cormorant, Black-winged Stilt, Red-necked Avocet, Australian Pelican, Silver Gull, Sharp-tailed Sandpiper, Red Knot and Red-capped Plover all had counts over 1,000 individuals. Of the 67 species recorded in this year only 15 had counts of less than 10 individuals (Lane and Pearson 2002).

During the period 1981-1985 surveys were undertaken in nature reserves, which included portions of the Peel Inlet (Jaensch et al. 1988). For two years of the 1980s study the surveyed portion of the inlet supported in excess of 20,000 waterbirds, with the numbers being just below 20,000 for the remaining years. In each year of the study the Peel Inlet supported more than 10,000 swans and ducks. Species
that occurred in the highest numbers (compared to other reserves assessed) included the Australian Pelican, Pied Cormorant, Grey Teal, Blue-billed Duck, Greenshank, Red Knot, Sharp-tailed Sandpiper, Curlew Sandpiper, Silver Gull, Whiskered Tern, Caspian Tern and Crested Tern. The Eastern Curlew, Osprey, White-bellied Sea Eagle, Little Egret, Royal Spoonbill, Large Sand Plover, Whimbrel, Grey-tailed Tattler and Ruff also had the highest counts at Peel Inlet (although this was less than 10 individuals for these species) (Jaensch et al. 1988). The most abundant species recorded in the 1981-1985 period were the Grey Teal, Red-necked Stint, and the Banded Stilt (Jaensch et al. 1988).

Based on data from the 1970s, the Peel-Yalgorup site has supported > 1% of the known population size of 11 waterbird species (Table D29). This included the resident shorebird, the Banded Stilt, which was regularly recorded in numbers > 20,000, as well as international migratory species such as the Red-necked Stint. In addition, Australian waterbirds such as Shelduck, Musk Duck, Grey Teal and Eurasian Coots were recorded in sufficient numbers to represent 1% of the population. In addition, >10,000 Hoary-headed Grebes have been recorded in the estuary (Lane and Pearson 2002). However, population estimates for these birds, as well as cormorants are not exact and as such an assessment against population levels cannot be made.

Table D29 : Species with maximum 1976-77 Peel-Harvey Estuary counts exceeding 1% population levels (Lane and Pearson 2002).

<table>
<thead>
<tr>
<th>Species</th>
<th>Description</th>
<th>Count</th>
<th>% of population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banded Stilt</td>
<td>Nomad, breeding in the inland, but parts of the population may be sedentary and species has been recorded in the estuary year round. Prefers shallow, saline waters. Feeds mainly on crustaceans and insects by foraging in shallow water.</td>
<td>63,000</td>
<td>30 %</td>
</tr>
<tr>
<td>Red-necked Stint</td>
<td>International migrant, breeds in Siberia; most likely in estuary between late August and early April. Uses intertidal habitat feeding in mudflats and in saltmarsh on invertebrates and plants such as seagrass and seeds.</td>
<td>13,259</td>
<td>4 %</td>
</tr>
<tr>
<td>Red-capped Plover</td>
<td>Australian nomad, but parts of the population may be sedentary and has been recorded in the estuary year round. May breed in coastal wetlands. Prefers shallow, saline waters. Feeds mainly on gastropods and insects by foraging on mudflats and shores.</td>
<td>1,250</td>
<td>1.3 %</td>
</tr>
<tr>
<td>Red-necked Avocet</td>
<td>Australian nomad, breeding in the inland. Occurs in the Peel Inlet predominantly in summer and autumn. Often uses saline to hypersaline shallow waters. Feeds in shallow waters and mudflats on crustaceans and insects.</td>
<td>2,180</td>
<td>2 %</td>
</tr>
<tr>
<td>Fairy Tern</td>
<td>Resident of the Australian coastline. Feeds in shallow waters by plunge diving for small fish.</td>
<td>84</td>
<td>1.4 %</td>
</tr>
<tr>
<td><strong>Curlew Sandpiper</strong></td>
<td>International migratory species that breeds in Siberia. Feeds on invertebrates in mudflats.</td>
<td>6,260</td>
<td>3.5 %</td>
</tr>
<tr>
<td><strong>Sharp-tailed Sandpiper</strong></td>
<td>International migrant that breeds in Siberia. Feeds in shallows and mudflats on small aquatic invertebrates.</td>
<td>1,972</td>
<td>1.2 %</td>
</tr>
<tr>
<td><strong>Musk Duck</strong></td>
<td>Australian nomad, but parts of the population are sedentary. Occurs in permanent waters fresh and saline and prefers open water habitat. Omnivorous.</td>
<td>491</td>
<td>2 %</td>
</tr>
<tr>
<td><strong>Grey Teal</strong></td>
<td>Mainly nomadic wandering large distances across the continent. Occur in most wetland types commonly in intertidal areas in estuaries. Seeds of aquatic plants are an important food source as are invertebrates.</td>
<td>25,077</td>
<td>1.2 %</td>
</tr>
<tr>
<td><strong>Australasian Shoveler</strong></td>
<td>Mainly sedentary occurring on a wide range of wetland types. Feed mainly on aquatic animals.</td>
<td>358</td>
<td>3 %</td>
</tr>
<tr>
<td><strong>Eurasian Coot</strong></td>
<td>Some parts of the population are nomadic. Occurs in many wetland types but favours large areas of deep water and is reliant on littoral vegetation. Feeds mainly on plants and seeds also molluscs and other invertebrates.</td>
<td>17,039</td>
<td>1.7 %</td>
</tr>
</tbody>
</table>

The increased tidal amplitude since opening of the Dawesville Channel has resulted in more frequent inundation of roosting sites across the estuary and a corresponding increase in access to shallow parts of the estuary by boats. This, together with changes through the food chain and possible reduction in fresh drinking water supplies in the Harvey River Delta were predicted to impact on both abundance and distribution of a number of bird species (Lane et al. 1997). In addition, the intertidal mudflats that once occurred around Boundary Island and the estuary near the Creery Marshes may also have been affected by changing tidal amplitude. These relatively small areas were the focus of occurrence by a suite of migratory shorebirds (e.g. plovers, knots, godwits) that were not regularly recorded elsewhere in the estuary.

There is, however little evidence of changed species distribution, composition or abundance. Bamford and Bamford (2003) undertook a statistical comparison of abundance from 1982-1988 and 1998-2003 for five wading species in the Creery Wetlands (Table D30). However, due to the high level of natural variability in the numbers of these birds, no statistical differences were found in mean summer counts. Similarly, Lane et al. (1997) compared pelican numbers from 1975-1977 and 1995-1997. Once again the variability between years in the 1975-1977 counts (< 500 to > 2000) was greater than the differences between the decades. As such, there was insufficient data to determine if there has been a decline in pelican numbers.

However, it must always be remembered that 1974-76 was the wettest period in Australia for more than 100 years, with consequent explosions in waterbird numbers manifest in dispersal from temporary inland wetlands to coastal areas over the following years. Accordingly, 1975-1977 is not a very good benchmark period against which to determine what the characteristic or typical aspects of
Table D30: Waterbird abundance comparison 1982-88 and 2002-03 for the Creery Wetlands (Bamford and Bamford 2003).

<table>
<thead>
<tr>
<th>Species</th>
<th>1982-1988 Mean (Std. Dev.)</th>
<th>2002-2003 Mean (Std. Dev.)</th>
<th>Significance (T-Test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curlew Sandpiper</td>
<td>205 (490)</td>
<td>49 (88)</td>
<td>Not significant</td>
</tr>
<tr>
<td>Sharp-tailed Sandpiper</td>
<td>280 (610)</td>
<td>459 (451)</td>
<td>Not significant</td>
</tr>
<tr>
<td>Grey Plover</td>
<td>95 (149)</td>
<td>7 (9)</td>
<td>Not significant</td>
</tr>
<tr>
<td>Pacific Golden Plover</td>
<td>15 (25)</td>
<td>14 (18)</td>
<td>Not significant</td>
</tr>
<tr>
<td>Banded Stilt</td>
<td>2,488 (3,148)</td>
<td>1,786 (1,331)</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

**Breeding**

The Peel-Harvey Estuary is considered a locally important breeding site for a number of waterbird species. In total, 12 species have been recorded breeding within the estuary using various habitats (Table D31). Breeding was recorded for four species during the 1976-77 waterbird surveys: Black Swan, Australian Shelduck, Grey Teal and Australian Pelican (Lane and Pearson 2002). While there have been relatively few nesting sites recorded for Australian Pelicans in Western Australia (Serventy and Whittell 1976) it would appear that several small colonies have started in the Peel Inlet since 1962 with varying success. Disturbance by humans and also tidal changes have led to abandonment of some nests (D. Rule pers. comm. cited in Hale and Butcher 2007).

During the 1980s, breeding within the Peel Inlet was observed for the Australian Shelduck, Pacific Black Duck, Black Swan and Grey Teal in the Peel Inlet Nature Reserve and Little Pied and Little Black Cormorants from areas of paperbark from Carraburmup Nature Reserve (Jaensch et al. 1988). In addition, breeding of Pied Oystercatcher, Black-winged Stilt, Pacific Black Duck, White-faced Heron and Buff-banded Rail has been recorded at Soldiers Cove in the estuary (Rule 2007). Within the Harvey Estuary only two species had breeding events recorded in the 1981-1985 studies, Pacific Black Duck and Darter. Harvey Estuary was considered an important site for the Darter in terms of number of individuals counted throughout the study.

Table D31: Requirements of waterbirds recorded breeding in the Peel-Harvey Estuary (adapted from Jaensch 2002).

<table>
<thead>
<tr>
<th>Species</th>
<th>Breeding behaviour/nesting sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Shelduck</td>
<td>Typically nests in dead trees in hollows</td>
</tr>
<tr>
<td></td>
<td>Ducklings leave the nest after 2 days by dropping to the ground.</td>
</tr>
<tr>
<td></td>
<td>First flight at approximately 8 weeks.</td>
</tr>
<tr>
<td>Black Swan</td>
<td>Nest mound built in open water, on an island, or in swamp vegetation.</td>
</tr>
<tr>
<td></td>
<td>Requires minimum water depth of 30–50 cm until cygnets are independent.</td>
</tr>
<tr>
<td>Species</td>
<td>Nesting Site</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Grey Teal</td>
<td>Commonly nest in a tree hollow or on the ground or in swamp vegetation.</td>
</tr>
<tr>
<td>Pacific Black Duck</td>
<td>Commonly nest in a tree hollow or on the ground or in swamp vegetation.</td>
</tr>
<tr>
<td>Australian Pelican</td>
<td>Colonial breeder with nests usually on islands with little or no vegetation.</td>
</tr>
<tr>
<td>Darter</td>
<td>Nests in horizontal branches and forks of trees (Eucalyptus or Melaleuca) in or over water. Requires water to remain until nestlings are independent. Hatchlings leave nest after 4 weeks, first flight at approximately 8 weeks.</td>
</tr>
<tr>
<td>Pied Oystercatcher</td>
<td>Nesting takes place on sand, shell grit or shingle just above high water mark on beaches, sandbars. Young remain with parents for 2-3 months.</td>
</tr>
<tr>
<td>Black-winged Stilt</td>
<td>Nest made in a small mound in salt marsh or swamp, or in a scrape in the substrate of an island or spit. Young leave nest within 1 day and self-feed close to parents. White-faced Heron nests in tree forks and horizontal branches, not necessarily in a wetland. Little information on nesting period or fledging.</td>
</tr>
<tr>
<td>Bluff-banded Rail</td>
<td>Nests rarely observed but are built within shallowly inundated vegetation, sometimes within dense cover on dry ground. Hatchlings leave nest within 24 hours but remain with parents for 2 months.</td>
</tr>
<tr>
<td>Little Black Cormorant</td>
<td>Nests in forks and branches of Melaleuca trees in or over water. Colonial breeder with up to tens of nests within a tree. Young remain in nests until mature.</td>
</tr>
<tr>
<td>Little Pied Cormorant</td>
<td>Nests in forks and branches of Melaleuca trees in or over water. Colonial breeder with up to 100 nests in a tree (but typically in the tens). Young remain in nests until mature.</td>
</tr>
</tbody>
</table>

The increased tidal range since the Dawesville Channel has resulted in more frequent inundation of Nirima Cay, which was formerly a nesting site for Australian Pelicans. As a result, Boundary Island is the major nesting site for these birds. This site is subject to frequent disturbance by people (boating, camping, dogs) and this has the potential to disrupt breeding birds. However, Lane et al. (1997) indicated that the breeding success of pelicans has not changed since the 1970s and is sufficient to maintain local populations.

The decline in trees in the Harvey River Delta due to increased salinity also has the potential to affect waterbird breeding for species that nest in trees (Darter, ducks). However at the time of the ECD
there was no information on changes in breeding for these or other species in this area of the Ramsar site.

**Variability**

There is a high variability in the records of waterbirds within the Peel-Harvey Estuary both in terms of numbers and distribution. Spatial and temporal variability in waterbird species is common in wetland environments, and waterbirds in Australia respond to environmental conditions beyond the local or site scale (Chambers and Loyn 2006). Although it is difficult to determine variability based on annual surveys (Underhill and Prys-Jones 1994), Bamford and Bamford (2003) collated summary statistics for waterbirds at Creery wetlands, within the Peel Inlet (but outside the surveyed eastern reserves, Jaensch et al. 1988) from 1982 to 1988. The results illustrate the high degree of variability of numbers recorded between years. The most abundant species often had means less than standard deviations and maximum counts were an order of magnitude higher than counts for some years. In addition, many of the rare species were absent in one or more years and a small number of species were recorded on single occasions only.

**Yalgorup Lakes**

**Diversity and Abundance**

The Yalgorup Lakes are important habitat for a number of waterbird species and are considered a summer sanctuary for waterfowl (CALM 1995). Lake Clifton and Lake Preston, in particular, supported large numbers of waterbirds in the period up to Ramsar listing. The cumulative number of species recorded for the Yalgorup Lakes during 1976-2007 is 73 and represents records spanning three decades (Table D32). This includes 24 species listed under the international Migratory Bird Agreements JAMBA and CAMBA as well as an additional 15 Australian migratory species protected under the EPBC Act. There are two species for which the Lakes represent the only observations within the Ramsar site. These are the Bridled Tern and Pacific Gull, both of which are principally marine species. In addition, the Little Stint and Pacific Golden Plover, which are regularly recorded at the Yalgorup Lakes, have only been rarely seen at other locations within the Ramsar site.
Table D32: Number of waterbirds found within the Yalgorup section of the Peel-Yalgorup Ramsar site 1976-2007.

<table>
<thead>
<tr>
<th>Waterbird Group (number within Ramsar site)</th>
<th>Typical feeding and foraging information</th>
<th>Number of species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ducks and allies (12)</td>
<td>Shallow or deeper open water foragers. Vegetarian (Black Swan) or omnivorous with diet including leaves, seeds and invertebrates.</td>
<td>8</td>
</tr>
<tr>
<td>Grebes (3)</td>
<td>Deeper open waters feeding mainly on fish.</td>
<td>3</td>
</tr>
<tr>
<td>Pelicans, Cormorants, Darters (7)</td>
<td>Deeper open waters feeding mainly on fish.</td>
<td>7</td>
</tr>
<tr>
<td>Heron, Ibis, Egrets (13)</td>
<td>Shallow water or mudflats. Feeding mainly on animals (fish and invertebrates).</td>
<td>7</td>
</tr>
<tr>
<td>Hawks, Eagles (3)</td>
<td>Shallow or deeper open water on fish and occasionally waterbirds, and carrion.</td>
<td>3</td>
</tr>
<tr>
<td>Crakes, Rails, Water Hens, Coots (8)</td>
<td>Coots in open water; others in shallow water within cover of salt marsh. Omnivores.</td>
<td>5</td>
</tr>
<tr>
<td>Shorebirds (43)</td>
<td>Shallow water, mudflats and salt marsh. Feeding mainly on animals (invertebrates).</td>
<td>33</td>
</tr>
<tr>
<td>Gulls, Terns (12)</td>
<td>Terns, over open water feeding on fish; gulls, opportunistic feeders over a wide range of habitats.</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>73</strong></td>
</tr>
</tbody>
</table>

The Yalgorup Lakes regularly support large numbers of waterbirds, and although there have been instances where total waterbird numbers across the lakes exceeded 20,000 (e.g. January 2005; Russell, unpublished), the system would not meet this Ramsar criterion in isolation from the other components of the Peel-Yalgorup site. However, maximum bird counts from the lakes indicate that Lakes Clifton and Preston support > 15,000 birds on occasion.

Large flocks of salt tolerant Musk Ducks and Australian Shelduck have been reported on the lakes as well as Black Swans, with 9,000 Australian Shelduck recorded on Lake Preston in 1988 (National Trust of Western Australian 1973; Halse et al. 1990; Halse et al. 1992; CALM 1995). Counts of up to 3,200 Musk Duck at Lake Clifton (Jaensch et al. 1993) have been the highest for the western population of this species, well above the 1% threshold (250 birds: Wetlands International 2006); these represent aggregations outside the breeding season, and birds presumably dispersing in winter-spring to breed in freshwater wetlands of surrounding catchments. Numbers of Australian Shelduck also exceed the 1% threshold for the western population of that species.

Lake Preston was considered an important site for ducks during their moulting phase, particularly the Australian Shelduck (National Trust of Western Australian 1973, CALM 1995). Large numbers of Black Swans use Lake Pollard and graze on the brackish water charaphyte *Lamprothamnium*
*papulosum* during October to January (CALM 1995). These, together with the Shelducks follow a distinct seasonal pattern arriving in large numbers in spring and departing in late summer.

Relatively large numbers of Great Crested Grebe (up to 190 at Lake Clifton: Jaensch et al. 1993) occur in the Yalgorup Lakes, which are the highest counts from south-western Australia. Though below the 1% threshold (250 birds: Wetlands International 2006), a systematic comprehensive survey across the lakes and estuary may find that the Ramsar site is internationally important for the Australian population of Great Crested Grebe.

The Yalgorup Lakes support at least 1% of the known population size of five waterbird populations; the Banded Stilt, Red-necked Stint, western Hooded Plover, Musk Duck and Australian Shelduck (Table D33). The majority of these birds have been recorded at Lake Preston, although there are significant observations of Banded Stilt from Lake Clifton and Martins Tank (Russell unpublished).

**Table D33 : Species with maximum Yalgorup Lake counts exceeding 1% population levels (Russell unpublished; Jaensch et al. 1993).**

<table>
<thead>
<tr>
<th>Species</th>
<th>Description</th>
<th>Count</th>
<th>% of population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banded Stilt</td>
<td>Australian nomad, breeding in the inland, but parts of the population may be sedentary and species has been recorded at the lakes year round. Prefers shallow, saline waters. Feeds mainly on crustaceans and insects by foraging in shallow water.</td>
<td>5,000</td>
<td>2.5 %</td>
</tr>
<tr>
<td>Red-necked Stint</td>
<td>International migrant, breeds in Siberia; most likely at the lakes between late August and early April. Feeds in shallow lake water and damp mudflats on invertebrates.</td>
<td>15,000</td>
<td>3 %</td>
</tr>
<tr>
<td>Hooded Plover</td>
<td>Resident, breeding locally. Forages at the waterline, feeding on invertebrates.</td>
<td>170</td>
<td>2.3 %</td>
</tr>
<tr>
<td>Musk Duck</td>
<td>Australian nomad, but parts of the population are sedentary. Occurs in permanent waters fresh and saline and prefers open water habitat. Omnivorous.</td>
<td>3,500</td>
<td>14 %</td>
</tr>
<tr>
<td>Australian Shelduck</td>
<td>Generally sedentary, but post breeding migration over short distances for moulting. At Yalgorup Lakes most commonly observed at Lakes Pollard, Clifton and Preston (the less saline wetlands within the system).</td>
<td>5,000</td>
<td>2 %</td>
</tr>
</tbody>
</table>

There is an extensive record of waterbird diversity and abundance at the Yalgorup Lakes (Russell unpublished). However, with high levels of natural variability, it is not possible to determine if there are significant changes to the waterbirds of the system.

**Breeding**

Eight species have been recorded breeding at the lakes (CALM 1995; Birds Australia 2005b; Rule 2007; Russell unpublished) (Table D34). Of particular significance is the Hooded Plover (*Thinornis*...
rubricollis). The Yalgorup Lakes contains the largest known aggregation of documented breeding efforts for Hooded Plovers in Western Australia (Birds Australia 2005). Hooded Plovers use a number of the lakes within the National Park with breeding recorded from Preston Lake, Boundary Lake, Duck Pond and Swan Pond (Birds Australia 2005a; Rule 2007).

**Table D34 :** Requirements of waterbirds recorded breeding at the Yalgorup Lakes (adapted from Jaensch 2002; Birds Australia 2005a).

<table>
<thead>
<tr>
<th>Species</th>
<th>Breeding behaviour/nesting sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Shelduck</td>
<td>Typically nests in dead trees in hollows. Ducklings leave the nest after 2 days by dropping to the ground. First flight at approximately 8 weeks.</td>
</tr>
<tr>
<td>Black Swan</td>
<td>Nest mound built in open water or in aquatic vegetation. Requires minimum water depth of 30-50 cm until cygnets are independent. First flight 20-25 weeks.</td>
</tr>
<tr>
<td>Grey Teal</td>
<td>Commonly nest in a tree hollow or on the ground or in aquatic vegetation. Ducklings leave the nest soon after hatching by dropping to the ground/water. First flight at approximately 8 weeks.</td>
</tr>
<tr>
<td>Pacific Black Duck</td>
<td>Commonly nest in a tree hollow or on the ground or in aquatic vegetation. Ducklings leave the nest soon after hatching by dropping to the ground. First flight at approximately 8 weeks.</td>
</tr>
<tr>
<td>Banded Lapwing</td>
<td>Commonly nest on bare ground not necessarily in a wetland. Observed nesting in samphire at Lake Preston.</td>
</tr>
<tr>
<td>Red-capped Plover</td>
<td>Nests in scrape made in sand or mud. Young leave nest within one day and self-feed, require vegetation for cover.</td>
</tr>
<tr>
<td>Hooded Plover</td>
<td>Nest at Lake Preston between December and February on hard limestone near the waterline. Nesting success is thought to be low (&lt; 30%).</td>
</tr>
<tr>
<td>Great Crested Grebe</td>
<td>Nest on floating mound of aquatic vegetation. Young leave the nest soon after hatching and can dive after approximately 1 week.</td>
</tr>
</tbody>
</table>

**Lakes McLarty and Mealup**

Since the listing of the Peel-Yalgorup Ramsar site, Lake McLarty has undergone significant changes in ecology. The extensive *Typha* beds and *Baumea* sedges have been replaced by mud flats and open water. This has had ramifications for the waterbird populations using the lake, especially for the many species that depend on emergent wetland vegetation for shelter and nest sites. There are records of Australasian Bittern calls from Lake McLarty in the 1980s but none in recent times and this has been attributed to the altered vegetation (Lake McLarty Management Plan 2005). A range of habitats are still utilised by the waterbirds, with the lake still being used as a non-breeding, feeding ground and refuge area for shorebirds (Lake McLarty Management Plan 2005; Craig et al. 2006).

Craig et al. (2006) provide a comparison of data from 1981-1985 and 1996-2000 detailing the changes in waterbird populations. Based on this data, Lake McLarty qualifies as a significant wetland...
in that it supports more than 1% of the population of ten species (Table D35). This includes four international migratory species and five Australian nomads.
Table D35: Species with maximum Lake McLarty counts exceeding 1% population levels (Craig et al. 2001; Craig et al. 2006).

<table>
<thead>
<tr>
<th>Species</th>
<th>Description</th>
<th>Max. Count</th>
<th>% Of Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp-tailed Sandpiper</td>
<td>International migrant that breeds in Siberia. Occurs at Lake McLarty when water levels drop below 370mm, typically January to April. Feeds in shallows and mudflats on small aquatic invertebrates.</td>
<td>5,970</td>
<td>3 %</td>
</tr>
<tr>
<td>Red-necked Stint</td>
<td>International migrant, breeds in Siberia; arrives at Lake McLarty as the water levels drop below 325 mm. Feeds in mudflats on invertebrates.</td>
<td>11,500</td>
<td>2.5 %</td>
</tr>
<tr>
<td>Red-capped Plover</td>
<td>Australian nomad, but parts of the population may be sedentary and has been recorded at Lake McLarty year round. However, peak numbers occur in late summer. Feeds mainly on gastropods and insects by foraging on drier mudflats.</td>
<td>&gt; 1,500</td>
<td>2 %</td>
</tr>
<tr>
<td>Red-necked Avocet</td>
<td>Australian nomad, breeding inland. Occurs at Lake McLarty predominantly in summer and autumn. Feeds in shallow waters and mudflats on crustaceans and insects.</td>
<td>5,468</td>
<td>5 %</td>
</tr>
<tr>
<td>Curlew Sandpiper</td>
<td>International migratory species that breeds in Siberia. Peak numbers occur during February and March as the lake dries out. Feeds on invertebrates in mudflats.</td>
<td>3,000</td>
<td>1.7 %</td>
</tr>
<tr>
<td>Black-winged Stilt</td>
<td>Australian population is mainly nomadic. Occurs in freshwater and saline wetland, using shallow open areas with or without short grass, sedge or saltmarsh. Mainly feeds on invertebrates.</td>
<td>5,400</td>
<td>2 %</td>
</tr>
<tr>
<td>Banded Stilt</td>
<td>Australian nomad, breeding inland, but parts of the population may be sedentary. Prefers shallow, saline waters but may use McLarty Lake when conditions in the nearby estuary are not favourable. Feeds mainly on crustaceans and insects by foraging in shallow waters and mudflats.</td>
<td>5,300</td>
<td>2 %</td>
</tr>
<tr>
<td>Australasian Shoveler</td>
<td>Mainly sedentary occurring on a wide range of wetland types. Feed mainly on aquatic animals.</td>
<td>487</td>
<td>1.9 %</td>
</tr>
<tr>
<td>Australian Shelduck</td>
<td>Generally sedentary, but post breeding migration over short distances for moulting.</td>
<td>4,500</td>
<td>1.9 %</td>
</tr>
<tr>
<td>Eurasian Coot</td>
<td>Occurs in many wetland types but favours large areas of</td>
<td>10,000</td>
<td>1 %</td>
</tr>
</tbody>
</table>
The lake is considered important as it supports a relatively large number of more rare species. The wetting and drying pattern of Lake McLarty is believed to offer habitat to shorebird species at the critical pre-departure times (Craig et al. 2006). The loss of the lake’s emergent vegetation combined with the tidal changes in the Peel-Harvey Estuary as a result of the Dawesville Channel, has been proposed as one explanation for the significant increase in several species of shorebirds such as the Red-necked Stint and Sharp-tailed Sandpiper at Lake McLarty, although adverse environmental conditions at wetlands elsewhere may also be influencing the patterns (Craig et al. 2006).

At the time of the ECD there have been no systematic surveys of the waterbird populations at Lake Mealup in the previous decade.

**Lakes Goegrup and Black**

Goegrup and Black Lakes support moderate numbers of waterbirds, with 52 species recorded from two sampling periods (Bamford and Wilcox 2003) (Table D36). This includes 13 species that are listed under international migratory agreements (JAMBA and CAMBA) and an additional 15 Australian migratory species protected under the EPBC Act.

Anecdotal evidence suggests that the Lakes act as a refuge for waterbirds during high tides in the Peel-Harvey Estuary (Ecoscape 2006). At the time of the ECD, data from 1988/89 and 2000/2001 were the main source of information on waterbirds for the lakes (Bamford and Wilcox 2003). In the 1988/89 sampling period the most abundant species were the Eurasian Coot, Grey Teal, Red-necked Avocet and Australian Shelduck all with counts over 300 individuals (Bamford and Wilcox 2003). Total counts of waterbirds at Black Lake in November 1988 recorded 2,616 birds (Halse et al. 1990).

**Table D36 : Number of waterbirds recorded within Lakes Goegrup and Black**

<table>
<thead>
<tr>
<th>Waterbird Group (number within Ramsar site)</th>
<th>Typical feeding and foraging information</th>
<th>Number of species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ducks and allies (12)</td>
<td>Shallow or deeper open water foragers. Vegetarian (Black Swan) or omnivorous with diet including leaves, seeds and invertebrates.</td>
<td>11</td>
</tr>
<tr>
<td>Grebes (3)</td>
<td>Deeper open waters feeding mainly on fish.</td>
<td>3</td>
</tr>
<tr>
<td>Pelicans, Cormorants, Darters (7)</td>
<td>Deeper open waters feeding mainly on fish.</td>
<td>6</td>
</tr>
<tr>
<td>Heron, Ibis, Egrets (13)</td>
<td>Shallow water or mudflats. Feeding mainly on animals (fish and invertebrates).</td>
<td>7</td>
</tr>
<tr>
<td>Hawks, Eagles (3)</td>
<td>Shallow or deeper open water on fish and occasionally waterbirds, and carrion.</td>
<td>3</td>
</tr>
<tr>
<td>Crakes, Rails, Water Hens, Coots (8)</td>
<td>Coots in open water; others in shallow water within cover of salt marsh. Omnivores.</td>
<td>2</td>
</tr>
</tbody>
</table>
Shorebirds (43)  
Shallow water, mudflats and salt marsh.  
Feeding mainly on animals (invertebrates).

Gulls, Terns (12)  
Terns, over open water feeding on fish; gulls, opportunistic feeders over a wide range of habitats.

Total  
52

Four species were recorded breeding at Goegrup and Black Lakes: Black Swan, Australian Shelduck, Pacific Black Duck, Grey Teal. Bamford and Wilcox (2003) suggested that this is not a complete list as observations were opportunistically collected. It is assumed the site is important for breeding with the fringing vegetation offering sites for nesting and foraging. Black Lake may be the more favoured of the two lakes for waterbird breeding as it is less affected by the tidal influences (Bamford and Wilcox 2003). Black Swan cygnets and juveniles were found at three sites, mainly samphire (mixed species) and marsh club-rush (Bolboschoenus caldwellii) and some patches of sea rush (Juncus kraussii) with fringing vegetation a mixture of sheoak (Allocasuarina obesa) and melaleucas. Australian Shelduck adults with dependent young were observed at one site with dense stands of Sarcocornia quiniqueflora surrounded by Bolboschoenus caldwellii, Juncus kraussii and fringing sheoak and M. cuticularis. Black Duck young were observed at two sites and breeding at a third within similar vegetation associations as the swans and Shelduck. Grey Teal juveniles were observed at one site on Black Lake.

2.2.12 Social and cultural values

Commercial fishing

The Peel-Harvey Estuary is an important commercial and recreational fishery. Commercial species include King George Whiting, Black Bream, Cobbler, blue swimmer crabs and Western King Prawns. It is estimated that the commercial fishing operations in the estuary are worth about $1 million a year in fish (URS 2007).

Recreation and tourism

The Peel-Harvey Estuary and Yalgorup Lakes represent important recreational and tourist sites. Tourism in the Peel Region contributes approximately $150 million annually to the region, with both domestic and international visitors. The most popular recreational and tourism activities associated with the Ramsar site include: bushwalking, birdwatching, camping, fishing, boating, crabbing, water skiing, canoeing, kayaking, kite surfing, sailing, wake boarding and swimming (URS 2007).

Throughout the Ramsar site there is a range of infrastructure that is available for recreation and tourism managed by Department of Parks and Wildlife and Local Government Authorities. This includes camping facilities Martin Tank Lake and Herron Point on the Harvey Estuary and key day use sites including the Thrombolite Boardwalk, Lake Hayward and Island Point. Parks and Wildlife also manage a series of bird hides to watch shore and migratory birds visiting the Ramsar site including at Lake Pollard in Yalgorup Nation Park, Creery Nature Reserve and Samphire Cove Nature Reserve.

The Peel-Harvey Ramsar site also has a range of public and private jetties that facilitate boating on the estuary. This includes commercial tour operators, boat and house boat hire and private recreation vessels.
The opening of the Dawesville Channel has increased access to the estuary for both a greater number and larger vessels. This has the potential to increase the problem of shoreline erosion and the effect on fringing vegetation will have habitat effects on reliant fauna. The *Economic Development and Recreation Management Plan for the Peel Waterways* (PIMA 2002) identified erosion of foreshores in the estuary from boat wash as a major threat to the fringing vegetation.

There has also been an increased in usage and access to the reserves on the eastern side of the Peel-Harvey Estuary following the opening of the Forrest Highway and the popularity of land based recreational pursuits that utilise the Ramsar site including crabbing and net fishing has seen decline in condition of littoral vegetation from physical disturbance. This includes unlawful 4wd access through nature reserves to access popular and new fishing and crabbing spots.

There are a range of other unlawful recreational activities that occur within the Ramsar site. These include four-wheel driving, trail bike riding, quad bike riding, horse riding and pig hunting. Bird hides referenced above are also subject to vandalism.

**Indigenous values**

The Peel-Yalgorup System Ramsar site lies within Pinjarup country, a dialect group of the Nyoongar Native Title claimants. As with other Indigenous Australians, Pinjarup people were strongly connected to each other, their culture and their country through the Dreaming. In southwest Australia, water is of special significance and the ‘Waugal’ is the creative and life-giving being associated with all freshwater sources, surface and ground. Although dormant most of the time, the Waugal may cause immense harm if disturbed. Hence all fresh water bodies may be considered to be highly significant mythological sites, with certain areas having particular significance as a place where the Waugal enters or exits the ground, or where it rests. (Dortch *et al.* 2006).

There are over 356 sites of Aboriginal significance in the Peel-Harvey catchment and 27 specific sites on the Peel-Harvey Estuary have been identified for the proposed heritage trail (Dortch *et al.* 2006). This includes sites of artefact scatter, camp sites, ceremonial sites, fish traps, skeletal remains and sites of mythological significance.

### 2.3 PAST, EXISTING AND FUTURE THREATS

The major threatening activities, which have and could continue to impact on the ecological character of the Peel-Yalgorup Ramsar site, are:

- agricultural activities in the catchment;
- water use and groundwater extraction;
- urban, industrial and rural residential development;
- commercial and recreational fishing;
- recreation; and
- climate change.
2.3.1 Agriculture

The Peel-Harvey Estuary has suffered the effects of eutrophication for a number of decades. The construction of the Dawesville Channel was a component of a three part strategy to address the excessive nutrients entering the system. Although the nutrient concentrations within the estuary basins have decreased significantly since the opening of the Channel in 1994 due to increased tidal flushing, there is no evidence that there has been a corresponding reduction in nutrient loads entering the system from the catchment.

Nutrient concentrations in the water column and the sediment of the river mouths and Lakes Goegrup and Black remain high and this has resulted in excessive algal growth in the form of both phytoplankton and macroalgae. Although flushing of the system to the Indian Ocean through the Dawesville Channel is keeping concentrations of inorganic nutrients within the estuary basins low, this is not a panacea and if nutrient loads from the catchment continue at current levels, or increase, it is likely that the system could turn eutrophic once more.

To address the problem of eutrophication in the estuary, targets have been set for phosphorus and dissolved oxygen in the Water Quality Improvement Plan (EPA 2008). These set a target for the load of total phosphorus entering the system of 75 tonnes per annum, with a target concentration of total phosphorus of 30 μg/L. Dissolved oxygen concentration targets of 70-80% saturation are also proposed.

These targets have been established in order to manage the nutrient run off from the catchment and the total load entering the Peel-Harvey Estuary. However, measures of total phosphorus (and nitrogen) are not indicative of the amounts of nutrients available for uptake by phytoplankton and other plants. As such, when assessing the condition of a wetland system, inorganic nutrients should also be considered (Harris 1999).

Increased nutrient concentrations as a result of surrounding landuse also have the potential to affect the Yalgorup Lakes and the freshwater wetlands Lakes McLarty and Mealup. These nutrients may enter the system through overland flow, and in the case of the Yalgorup Lakes there is little vegetated buffer to intercept any nutrients entering the system in this manner. However, it is more likely that nutrients will enter these systems through groundwater. The aquifer that provides the majority of the water for both the saline and freshwater wetland systems is unconfined and as such vulnerable to inputs from activities on the land under which it flows. The agricultural and rural residential catchment surrounding the lakes is a source of nutrients from animals and fertiliser applications.

2.3.2 Water use and groundwater extraction

Hydrology is a key driver of wetland ecology and has an effect on both abiotic and biotic components. Of particular concern in the Peel-Yalgorup Ramsar site is the alteration of river flows into the Peel-Harvey Estuary and the reduction in groundwater flow into the Yalgorup Lakes and Lakes McLarty and Mealup.

The Peel-Harvey Estuary is reliant on river flows from the Serpentine, Murray and Harvey Rivers both as a source of carbon and nutrients and also to maintain the salinity regime of the system. The effects of increased salinity due to the opening of the Dawesville Channel are permanent and cannot be managed. However, the system is an estuary and relies on freshwater inflows into the system to maintain ecosystem function and processes such as reproduction. The Water Quality Improvement Plan (EPA 2008) sets a river flow objective for the tidal reaches of the Serpentine, Murray and Harvey...
Rivers to ‘maintain current flow variability’. However, this is not explicitly quantified in terms of discharge volumes.

The shallow, unconfined groundwater aquifer has been estimated to contribute 38% of water volume main for the Yalgorup Lakes is Shams (1999). This study suggested that groundwater discharge rates was being affected in some parts of the discharge path by extraction for horticultural, agricultural and rural residential purposes. However, the changes in volume have not been quantified. Similarly, there is indirect evidence of a reduction in groundwater entering Lakes McLarty and Mealup, however, no quantitative data on groundwater levels could be found.

2.3.3 Urban, Industrial and Rural Residential development

A large proportion of the Peel-Yalgorup Ramsar site is located within the City of Mandurah, which is experiencing rapid population growth, especially since 2007 (Ruibal-Conti et al. 2013). In addition, there are current and proposed urban, industrial and rural residential developments, under the Peel Regional Scheme and draft sub-regional framework footprints that are within close proximity to the Ramsar site. This is particularly the case within the Shire of Murray e.g. Nambeelup Industrial area and Austin Cove Estate. There are a number of potential induced threats associated with increased development around the wetlands that could impact on the primary determinants of ecological character of the site. These include:

- Clearing of native vegetation (including saltmarsh and paperbark communities).
- Increased nutrient and contaminant run off.
- Disturbance of acid sulfate soils.
- Increased recreational pressure and related direct disturbance on the wetland sites.

2.3.4 Clearing

There are no specific statistics available for clearing of native vegetation for residential development in the Peel region. However, it is thought that there has been significant removal of deep-rooted perennial vegetation both historically and in the recent past (URS 2007). This includes vegetation buffer zones from around wetland areas as well as the saltmarsh and paperbark communities that provide habitat for the fauna of the Ramsar site. There are also unreported cases of unlawful clearing of riparian vegetation within nature reserves surrounding the estuary by adjacent private landowners to improve the view from their property. Clearing by stealth also occurs through domestic stock being illegally grazed within nature reserves containing riparian vegetation and in the long term by invasive weeds which inhibit recruitment of native vegetation (such as watsonia along the lower portion of the Harvey River).

2.3.5 Increased nutrient and contaminant run off

Development can result in large loads of nutrients in surface and groundwater. Zammit et al. (2005) estimated that the phosphorus load from residential landuse was 2.275 kg/ha/year, which is more than twice that for agricultural landuses. Recently there has been some evidence of rapid change in population growth being accompanied by an increase in dissolved (biologically available) nutrients (Ruibal-Conti et al. 2013. Any increase in nutrient loads to the wetlands in the system will potentially contribute to eutrophication.
There is little information on the contaminant loads entering the system or the loads that could be expected from urban run off. The overall threat of contaminants on the waterways in the area is not understood and is an area where monitoring and/or research are required (URS 2007).

2.3.6 Acid sulfate soils

ASS are common in coastal areas of Australia (Sammut and Lines-Kelly 2000) and are benign unless disturbed. Dredging in the Peel Inlet has disturbed the ASS and exposure of these disturbed soils to the air, either from disposal of dredge spoil or intertidal water level variation, can result in the formation and release of sulphuric acid into the water column. The carbonate concentrations in seawater should be sufficient to buffer this effect (Sullivan et al. 2006) and in effect neutralise any pH changes. However, if this occurs during times when freshwater inflows are dominant and carbonate concentrations are low, there is potential for the pH to decrease. This decrease in pH affects the immune system of fish and has been shown to cause skin lesions and increased infection (Sammut and Lines-Kelly 2000).

In addition, the acidic conditions within the sediment can result in the release of toxicants into the water column. Recent work has revealed that the concentrations of most heavy metals and toxicants are low within the sediments of the Peel Inlet (Kilminster 2010). So this is unlikely to be a significant threat for this area, but similar work needs to be conducted in other parts of the estuary.

2.3.7 Commercial and recreational fishing

Commercial fishing

There are 11 commercial licences for finfish in the Peel-Harvey Estuary (Fletcher and Santoro 2013). This fishery and the commercial and recreational crab fisheries are currently undergoing third-party environmental certification by the Marine Stewardship Council (Pers. Comm. Department of Fisheries 2015). A target catch is set annually (based on control charting techniques) to allow catch levels to fluctuate in response to natural variation in fish stocks. The target for 2012/13 was 75-220 tonnes (Fletcher and Santoro 2013). The major species caught are Sea Mullet, Yellow-eye Mullet and Western Sand Whiting. Although Cobbler, Black Bream and King George Whiting were previously significant proportions of the catch, the numbers of these taxa have declined.

There is a commercial fishery in the Peel-Harvey Estuary for blue swimmer crabs with 11 commercial authorisations (interim managed fishery permits) (Johnston et al. 2014). Since the conversion from gill nets to traps in the mid to late 1990s, annual commercial catches have fluctuated between 45 tonnes per annum in 2002/03, to a peak of 104 tonnes in 2006/07 (Johnston et al. 2014). The catch for 2012/13 was 104 tonnes (Fletcher and Santoro 2013). The effect of the crab fishery on the ecosystem is considered minimal due to:

- The legal size at first capture (127-135 mm carapace width) is above the size at maturity (86-97 mm carapace width depending on the fishery) and as such breeding stock levels are expected to be adequate to maintain stocks under normal environmental conditions.
- The shift from using gill nets to traps which resulted in a significant decrease in by-catch with few non-target species collected and minimal benthic habitat disturbance.
- Commercial fishing is prohibited on weekends from 0900 h (1 Nov-31 Mar) or 1000 h (1 Apr-31 Aug) on Saturday to 0330 h on Monday.
• In 2010 an agreement was made between the recreational and commercial sectors for a voluntary no-take of legal-sized females between November 1st and March 1st by commercial fishers.

• The commercial collection of crabs represents a small proportion of the total biomass and so trophic level effects are negligible (Fisheries Western Australia 2006; Fletcher and Santoro 2013; Johnston et al. 2014).

Recreational fishing

The Peel-Harvey Estuary and the Peel Inlet in particular, are popular recreational fishing locations, both from boat and shore based anglers. Two recreational surveys undertaken a decade apart estimated that the total recreational catch of Blue Swimmer Crabs in the Peel-Harvey Estuary had decreased from 251-337 tonnes in 1998/99 to 107-193 tonnes in 2007/08 (Johnston et al. 2014). A comparison of the recreational catch to the commercial catch shows that the recreational proportion of the total catch has decreased from 79-85% in 1998/99 to 54-68% in 2007/08 (Johnston et al. 2014). The recreational quotas for crabs are 20 per powered boat (when two or more licensed fishers are on board) and the limit is 10 crabs if there is only one licensed fisher on board (Fletcher and Santoro 2013).

Recreational fishers also took Australian Herring, whiting other than King George (Sillago spp.), Tailor, Skipjack Trevally, trumpeters, King George Whiting, Silver Bream (Tarwhine) and Black Bream. Malseed and Sumner (2001) found high levels of compliance with the size regulations with only ~6% of boat anglers retaining undersized fish and ~9% retaining undersized crabs, compared to 13% of shore based crabbers keeping undersize crabs.

Wise management of the fishery is important to ensure continued qualification of the site against Ramsar criteria 4 and 8.

2.3.8 Recreation

Tourism and recreation are a strong focus in the Peel Region, and it is estimated that tourism brings in $147 million dollars per annum (URS 2007). The increase in residential development following the construction of the Perth Bunbury Highway is likely to increase recreational pressure on the Peel-Yalgorup site. Recreational activities within the wetlands include bushwalking, camping, horse riding, motorbikes, four-wheel drives, boating, jet skiing, water skiing and swimming. While recreational enjoyment of the Peel-Yalgorup site is a service/benefit of the wetlands, it also has the ability to impact negatively on the ecological character. The two major impacts are erosion of the shoreline due to boating and recreational vehicle use, and disturbance of waterbirds at vulnerable stages in their lifecycle.

Disturbance of birds

Migratory shorebirds travel over 10,000 km from breeding grounds in the northern hemisphere to non-breeding sites in the Southern Hemisphere, and return north each year. It has been found that disturbance of birds when feeding or roosting may result in a significant loss of energy. This may even compromise their ability to build up enough reserves to complete the return journey to breeding grounds (DEH 2006). Disturbance of migratory shorebirds may occur as a result of recreational
fishing (in some instances), four-wheel vehicles and motor cycles driving on beaches, use of jet skis and unleashed dogs and cats.

In addition to disturbance of migratory shorebirds, there is evidence that increased recreational pressure is leading to the disturbance of breeding birds within the Peel-Yalgorup site. Pelicans on Boundary Island have been observed to be disturbed by boats, campers and dogs during nesting (Lane et al. 1997).

Increased lighting at night, either from vessels or onshore activities can also impact on migratory birds and seabirds, particularly those that are nocturnal. Artificial lighting can affect birds by:

- disorientating breeding birds returning to colonies at night;
- decreasing the time birds attend to nests (and impacting on breeding success); and
- displacing birds from breeding or feeding grounds.

Degradation of claypan and shoreline vegetation

Claypans surrounding the estuary are favoured locations for illegal four-wheel driving, motor cycles and quad bikes. With more people living around the estuary there has been an increase in this type of activity.

Foreshore Erosion

The Economic Development and Recreation Management Plan for the Peel Waterways (PIMA 2002) identified erosion of foreshores in the estuary from boat wash as a major threat to the fringing vegetation. The opening of the Dawesville Channel has increased access to the estuary for both a greater number and larger vessels. This has the potential to increase the problem of shoreline erosion and the effect on fringing vegetation will have habitat effects for reliant fauna.

2.3.9 Climate change

Climate observations for south-west Western Australia indicate the region has become hotter and drier over the last 50 years (Text Box 2). There is already evidence that climate may be affecting components of biodiversity within the region. The most recent climate projections suggest a further decrease in winter and spring rainfall, increases in mean temperature and frequency of extreme temperatures, increases in evaporation and increases in mean sea level (Hope et al. 2015). This has the potential to impact significantly on the hydrology and hence ecological character of the Ramsar site.

In south-west WA reduced rainfall, runoff and declining groundwater levels, combined with increasing evapotranspiration, will continue to result in reduced river flow, and drying wetlands. Reduced river flow coupled with sea level rise has the potential to irreversibly impact coastal freshwater wetlands (Kauhanen et al. 2011).

By 2030, Fremantle sea levels are projected to be between 0.07 to 0.17 metres higher than 1986-2005 levels, with only minor differences between emission scenarios. As the century progresses, the projections suggest an increase of between 0.22 and 0.84 metres by 2090. The frequency and height of storm surges will also increase. These changes will increase the risk of coastal erosion and flooding of coastal reserves and estuarine peripheral zones, including fringing vegetation which is
often very important habitat for wetland fauna. Other implications are likely to include an increasing demand for freshwater resources and increased risk that groundwater and surface water recharge to wetlands is not adequate to maintain water quality, aquatic and fringing vegetation requirements.

Increased knowledge of the potential impacts of climate change to the Peel-Yalgorup Ramsar site can assist in the identification of management activities to build the resilience of the wetland systems, reduce the impacts and assist in adaptation to observed changes in the climate. The increasing demand for freshwater related to the drying climate will mean water allocation plans will be an essential mechanism for ensuring environmental requirements are considered in the planning process.

In any future modelling undertaken for the Peel-Yalgorup System it is vital to consider the “marine embayment” nature of the Peel Inlet and Harvey Estuary and the critical role of freshwater inputs (from either or both surface water and groundwater inflows) in moderating habitat suitability within the estuary and lakes of the System.

As climate and biogeographical patterns in biodiversity, hydrology of wetlands, and the health of aquatic ecosystems are linked, decision making for the Peel-Yalgorup System will need to consider the future impacts of climate change on the Ramsar site. Climate change risks should be considered in the context of other threats and pressures such as urban encroachment, water use and extraction and other human activities, as these may exacerbate climate risks or alter the potential for the system to adapt to changes in climate.

Observed changes to the climate of the southwest of Western Australia:

- Prolonged period of extensive drying from the 1970s to 2013, with a decrease in both winter and autumn rainfall (Hope et al. 2015).
- Increase in mean temperature of around 1.1 °C between 1910 and 2013 (Hope et al. 2015).
- Autumn and winter rainfall in the south-west Western Australia has declined by 20% over the past 60 years (IOCI, 2012). The decline in rainfall has resulted in even larger decreases in annual average runoff since 1975 of over 50% compared to the long term pre-1975 average (CSIRO, 2009).
- Sea levels recorded at Fremantle indicate a long term average rise of 1.5mm/year 1897-2004 (Pattriartchi and Eliot, 2005).
- Relative sea level rose around Australia at an average rate of 1.4 mm/year between 1966 and 2009 and 1.6mm/year after the influence of the El Nino Southern Oscillation (ENSO) on sea level is removed.

Text box 2: Changes to the climate in the south-west of Western Australia.
2.3.10 Cattle grazing

Controlled cattle grazing is permitted within parts of Lake McLarty under the Lake McLarty Nature Reserve, 2008, Management Plan No 60, Dept. Environment & Conservation, Conservation Commission WA. Although the management plan indicates that this is limited in both numbers and season, there is no indication of what seasonal patterns of grazing are permitted. Grazing was used to control the spread of emergent plants such as Typha and provide more extensive mud flat habitat for wading species of waterbird. However, Typha has been controlled in recent years by mechanical slashing and no grazing by cattle has taken place at the Lake since the final stage of the rural residential “Birchmont” subdivision to the west was commenced in approximately 2008. While cattle grazing may have some benefits, the consequences of this must also be considered. These include, increased nutrient loads, and corresponding increases in phytoplankton and other opportunistic plant species; decline in palatable species of vegetation and an increase in less palatable vegetation types; an increase in weed species, and trampling of waterbird eggs/nests and compaction of wetland soils. In addition, cattle have been found to preferentially graze on new and emerging shoots (Lovett and Price 2007) and as such may not only consume the target species, but seedlings of native plants as they emerge. Finally, Typha has been shown to be competitively advantaged under conditions of high nutrient loads and disturbed soil surfaces (Drohan et al. 2006) and as such may be both controlled and promoted by grazing.

2.4 EXISTING MANAGEMENT ARRANGEMENTS

2.4.1 Legislative protection and/or management requirements

Australia is a participant of, and signatory to, a number of important international conservation agreements that influence the management of the Peel-Yalgorup System Ramsar site, by promoting consistent standards of management for wetlands. These are:

- Convention on Wetlands of International Importance (Ramsar Convention).
- CAMBA, JAMBA and ROKAMBA bilateral agreements relating to conservation of migratory birds.
- Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention).

At a national level the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) is the primary piece of legislation relating to Ramsar sites. This Act establishes a legislative framework for environmental protection and biodiversity conservation, including assessment and approvals of proposed actions, species and Ramsar site listing, recovery plans and management plans. The ecological character of Ramsar wetlands is one of the nine matters of national environmental significance under this Act. Any action that has had, will have, or is likely to have a significant impact on a matter of national environmental significance is required to undergo an environmental assessment and approvals process. The EPBC Act also establishes standards for managing Ramsar wetlands through the Australian Ramsar Management Principles, which are stated as Regulations under the Act and which describe the principles and guidelines for the management of Ramsar wetlands (Environment Australia 2015). The Native Title Act 1993 and Wetlands Policy of the Commonwealth Government of Australia 1997 are also relevant.
There is a suite of Western Australian legislation that is relevant to Ramsar sites, both in terms of protecting and managing the sites, but also for regulating potential impacts. The most relevant legislation is listed below:

- *Environmental Protection Act 1986.*
- *Aboriginal Heritage Act 1972.*
- *Rights in Water and Irrigation Act 1914.*
- *Metropolitan Water Supply Sewerage and Drainage Act 190.*
- *Metropolitan Arterial Drainage Act 1982.*
- *Planning and Development Act 2005.*
- *Bushfires Act 1954.*
- *Fish Resources Management Act 1994.*
- *Western Australian Marine Act 1982.*

There are also a number of state, regional and local policies and planning schemes that are relevant to Ramsar sites. These include *inter alia*:

*Wetlands Conservation Policy for Western Australia 1997.* This policy outlines the WA Government's commitment to identifying, maintaining and managing the State's wetland resources, including the full range of wetland values, for the long term. It provides broad objectives for wetlands, waterways, estuaries and shallow marine areas, and provides an implementation strategy specifically for the management of wetlands in Western Australia. It also identifies the agencies involved and their responsibilities.

*State Planning Policy. 2.1 The Peel-Harvey Coastal Plain Catchment.* This policy includes specific provisions addressing land use changes within the Peel-Harvey estuarine system likely to cause environmental damage to the estuary. The objectives of the policy are to:

- Improve the social, economic, ecological, aesthetic, and recreational potential of the Peel-Harvey coastal plain catchment.
- Ensure that changes to land use within the catchment to the Peel-Harvey estuarine system are controlled so as to avoid and minimise environmental damage.
- Balance environmental protection with the economic viability of the primary sector.
- Increase high water-using vegetation cover within the Peel-Harvey coastal plain catchment.
- Reflect the environmental objectives in the *draft Environmental Protection Policy (Peel-Harvey Estuarine System) 1992.*
- Prevent land uses likely to result in excessive nutrient export into the drainage system.
Metropolitan Region Scheme. The Peel-Yalgorup Ramsar site is within the Peel Region Scheme and Bunbury Region Scheme and is reserved Regional Open Space or Waterways.

Coastal and Lakelands Planning Policy 1999

Local Government Planning Schemes. Local government authorities are responsible for planning for local communities by ensuring appropriate planning controls exist for land use and development. The Peel-Yalgorup System Ramsar site is located in the Shires of Murray, Waroona and Harvey, and the City of Mandurah. The Strategic Assessment area does not include the southern portion of the Ramsar site that is located within the Shire of Harvey (see Figure D51).

EPA Guidance Statement 28 for the Protection of the Lake Clifton Catchment

Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986 Report 1359 May 2010.

Despite the listed suite of legislation, agreements and policies, the overlaps and gaps reduce the efficacy of these “documents” to protect and/or manage the values of the Ramsar site. Many of the documents, including the Peel Region Scheme, make no reference to the Ramsar site or its ecological values. For instance, the Department of Transport produces the “Peel region Recreational Boating Facilities Study 2010 (Technical Report 449, April 2011) in response to the “supply and demand” for boating facilities and states, “As the Peel Region is an area of exceptionally high growth with a very high ratio of recreational boat ownership per head of population (101.7 per 1,000 for 2009, forecast to rise to 120.9 per 1,000 for 2013) the strategies proposed in this report should be reviewed regularly against growth and development of the Peel Region”. The ecological carrying capacity of the waterways and disturbance to the Ramsar site’s values caused by increased boating use is not considered. Similarly, the Department of Transport control the use of the waterways and can legislate a “no-go” zone due to human safety but not for environmental protection (PHCC pers. Comm.).

2.4.2 Current management of the Ramsar site

The current management arrangements within the Peel-Yalgorup System Ramsar site are complex, consisting of a number of government agencies (State and Local) who hold land within the site, a number of government agencies with responsibilities in relation to waterways, land owned privately (Lake Mealup Preservation Society) and an extensive network of community groups with varying role and responsibilities, undertaking conservation, monitoring and research and education activities within the Ramsar site.

Land management

The Department of Parks and Wildlife manages lands within the Ramsar site that are vested within the Conservation Commission of Western Australia under the CALM Act, including the Yalgorup National Park that contains all of the Yalgorup Lakes and multiple nature reserves and conservation parks that fringe the Peel-Harvey Estuary, including Lake McLarty and a portion of Lake Mealup.

Parks and Wildlife develops and implements annual works programs for CALM Act lands in accordance with management plans, which include the following:

- weed control;
ongoing management of unauthorised vehicles, through installation and maintenance of barriers and patrols; and

managing recreation usage within the National Park including camping, walk trails and interpretive signage to facilitate visitor use while limiting disturbance to the reserves.

Regular and ongoing operational monitoring is undertaken with fencing patrols and maintenance patrols including review of signage, firebreaks and rubbish dumping.

Predation by foxes has been identified as a threatening process for the breeding and foraging waterbirds and other native fauna within Yalgorup National Park. Fox baiting as part of Parks and Wildlife Western Shield program is being implemented every second month throughout the majority of the National Park.

The Department of Water also manages a few foreshore reserves in and around the Ramsar site. Generally these are managed to a minimum level on a risk management basis (e.g. firebreaks, essential weed control and public safety) as land management is not seen as a priority function of the Department. The Wilgie Creek reserve in North Yunderup is managed to improve water quality in Wilgie Creek through a pumping program to keep the water in the creek oxygenated and at a minimum level.

The Ramsar site is located within the City of Mandurah and Shires of Murray, Waroona and Harvey. The Strategic Assessment area does not include the southern portion of the Peel-Yalgorup Ramsar site that is located within the Shire of Harvey. The four local government authorities have land management responsibilities for conservation and recreation reserves inside or adjacent to the Ramsar site.

The City of Mandurah has 10 Bushcare Groups and six Coastcare Groups, consisting of volunteers from the community involved in a variety of activities within the City’s reserves, with the aim of protecting and restoring biodiversity and conservation values.

The Mealup Preservation Society Inc. owns three freehold lots within and adjacent to the Peel-Yalgorup Ramsar site. The properties are subject to conservation covenants through the National Trust of Australia (WA) and are managed by the Society in accordance with a management plan for the covenanted bushland (Lake Mealup Preservation Society and National Trust of Australia, 2003).

The Lake Clifton thrombolite community occurs within the Yalgorup National Park and is managed by the Department of Parks and Wildlife. The Lake Clifton thrombolite community was assessed by the Western Australian Threatened Ecological Communities Scientific Committee, and endorsed by the Western Australian Minister for the Environment as a critically endangered ecological community in 2000. There is an Interim Recovery Plan for the ecological community, called Interim Recovery Plan No. 153 Thrombolite (Stromatolite-like microbialite) Community of a Coastal Brackish Lake (Lake Clifton) 2004-2009, which sets out priority actions for its ongoing management and recovery (Luu et al., 2004).

The Lake Clifton thrombolite community is subject to numerous threats, most of which originate outside the ecological community itself. There has been significant deterioration of water quality, with increasing salinity and nutrient levels, at Lake Clifton since at least the early 1990s (Moore, 1990; WA CALM, 2004a). This is despite the Peel-Yalgorup System being recognised as a Wetland of International Importance, and Lake Clifton being situated within the Yalgorup National Park (Moore, 1990).
The greatest current threat to the ongoing growth and survival of the Lake Clifton thrombolite community is the sharply increasing salinity. This is thought to be principally the result of reduced rainfall recharge (which supplies around 68% of lake water), from the drying climate. However, groundwater abstraction has been shown to reduce groundwater levels in the Lake Preston catchment (Shamms 1999), and indicates that abstraction is also likely to be reducing groundwater levels in the Lake Clifton catchment and hence recharge into Lake Clifton (Whitehead, unpublished data 2015). Pine plantations in the south east corner of the Lake Clifton catchment may also reduce recharge and suppress groundwater levels. If Lake Clifton becomes permanently hypersaline, it is likely that the patterns of thrombolite growth, faunal diversity and waterbird usage will also be affected.

Increasing nutrient loads originating from adjacent agricultural, horticultural/viticultural industries and rural residential properties also threatened the health of the Lake Clifton thrombolite. Increasing nutrient levels in the lake have been well documented and have been the cause of increasing incidence of algal growth in Lake Clifton. This is largely attributed to nutrients in groundwater discharging to the lake. While the volume of surface water entering the lake is very low, large areas where vegetation buffer zones are inadequate have been found to contribute significantly more nutrients than for the other buffer zones (Davies and Lane, 1996).

Pollution, changes to surrounding vegetation, sedimentation and the introduction of fauna not native to the area also negatively impact on the ecological community (WA CALM, 2004a). Public visitation to Lake Clifton has also led to crushing or trampling of some sections of the thrombolite structures. Finally, possible impacts of climate change in addition to rainfall decline, such as changing wetting patterns, increased temperature and evaporation must also be considered.

Recovery Actions of the Interim Recovery Plan are coordinated by the Recovery Group which is chaired by the Department of Parks and Wildlife and includes membership from the Department of Water, Peel-Harvey Catchment Council, City of Mandurah, Lake Clifton Landcare Group and research scientists from Murdoch University and the University of Western Australia and two independent research scientists. Recovery actions and their progress in being implemented include:

- **Map critical habitat** – a component of research that is currently being undertaken by the University of Western Australia.
- **Clarify the extent and condition of the community** – ongoing research contributed by Murdoch University and the University of Western Australia in collaboration with an independent researcher, Mike Whitehead. In preparation for publication;
- **Seek creation and protection of a suitable native vegetation buffer for the lake**. A buffer guide is yet to be formalised.
- **Conduct biological research to clarify threats to the thrombolites and help design recovery actions**- Collaborative research programs continue at Lake Clifton that include a number of PhD projects. Projects include hydrological studies of microbialite communities, study of the biogeochemistry and evolution of microbial deposits; investigation of the microbial populations present in modern thrombolites, composition of the mat community and isotope analysis. Results of research findings are reported back to the Recovery Group via quarterly meetings.
- **Manage access to site** - access is managed by Parks and Wildlife by gating non-formal access roads.
- **Ensure areas containing the microbial community are protected from physical damage** – Parks and Wildlife have constructed and maintain a boardwalk that extends out into the microbial community.
• Manage physical impacts to thrombolites through provision of information – Parks and Wildlife have constructed interpretive signage at main carpark and at intervals along the boardwalk.

• Undertake ongoing monitoring of physical condition and microbial assemblage of thrombolites - ongoing surveys contributed by Murdoch University and the University of Western Australia in collaboration with an independent researcher, Mike Whitehead. In preparation for publication.

• Monitor water quality and hydrology - ongoing surveys contributed by Murdoch University and the University of Western Australia in collaboration with an independent researcher, Mike Whitehead. In preparation for publication. Groundwater monitoring collected by the Department of Water and data accessed publically via the Water Information Reporting platform http://wir.water.wa.gov.au/SitePages/SiteExplorer.aspx.

• Determine the range of normal fluctuations for hydrological regimes and attempt to maintain them within that range – Yet to be determined.

• Provide information to surrounding landholders to ensure actions on their lands do not impact the thrombolites - A recent project was undertaken by Peel-Harvey Catchment Council with the Lake Clifton Landcare Group that targeted local landholders in projects involving the rehabilitation of private property adjoining Lake Clifton with the second phase of developing community awareness.

• Cooperate with appropriate agencies to manage land uses to ensure appropriate water quality within the lake – being collaboratively introduced through land use planning policy managed by the City of Mandurah with advice provided by Parks and Wildlife and the Peel-Harvey Catchment Council and Groundwater Allocation Planning managed by the Department of Water.

• Liaise with the EPA to encourage the updating of Bulletin 864 and the formulation of an Environmental Protections Policy – Yet to be undertaken. However the Strategic Environmental Advice on the Dawesville to Binningup Area Advice of the Environmental Protection Authority to the Minister for Environment under Section 16(e) of the Environmental Protection Act 1986 Report 1359 lists a recommendations for the protection of Lake Clifton and Yalgorup Lakes.

• Collect relevant baseline information and ongoing monitoring data for the vegetation that provides a buffer for the thrombolite community - Yet to be undertaken.

• Control weeds and rehabilitate plant communities on eastern side of lake – Ongoing weed control activities by Parks and Wildlife. Yet to achieve control over many weeds, including Cotton Bush, Gomphocarpus fruticosus.

• Develop and implement an approved fire management strategy – Fire management plan exists for the Yalgorup National Park.

• Ensure maintenance of strategic firebreaks on occurrences or construction of new strategic fire breaks on surrounding lands to help prevent fire spreading to community – Fire breaks are constructed and maintained by Parks and Wildlife within the Yalgorup National Park.

Groundwater management

The two main tools used by the Department of Water to manage groundwater use are allocation limits and groundwater licences – which are the regulatory instrument under the Rights in Water and Irrigation Act 1914.

All licence applications are individually assessed to consider potential impacts to groundwater dependent ecosystems (DoW 2009).
Conditions and restriction have been placed on some licenses under Clause 15 of Schedule 1 of the Act. This includes operating strategies (DoW 2010) which describe the licensee’s responsibilities in complying with the conditions of their licence.

Current management of the area’s groundwater is guided by the Peel Coastal groundwater allocation plan (2015) The South West groundwater areas allocation plan (2009) and evaluation statement (2009-2019) guide allocation areas south of the Peel Coastal groundwater allocation plan area.

Allocation limits/policies are guided by Peel Coastal Groundwater Allocation Plan 2015. Allocation limits have been reduced from 20.7 GL/year (set in 1989) to 11.2 GL/year. This reduction is based on observed increases in salinity and future risks to groundwater from any increased abstraction, and reduced recharge through changes to climate and land use.

In accordance with the Peel Coastal groundwater allocation plan, allocation limits are set at current use for all subareas.

**Estuarine, urban water and drainage management**

The Department of Water (DoW) is responsible for developing strategies and management plans to protect the quantity and quality of water resources, protect infrastructure from flooding, and enhance the living environment for the community.

DoW manages the legislative requirements of the Waterways Conservation Act 1976, created for the purpose of conservation and management of certain lands, as well as the Waterways Conservation Regulations 1981. While the Act is still current, the current Government’s water legislation review process aims to review and ensure new and more contemporary legislation that more accurately provides for management of priority water resource areas.

The Act allowed the creation of the Peel Inlet Management Area within which the Act applies. The Peel Inlet Management Area includes the open waters of the Peel Inlet and Harvey Estuary, the Murray River to the Darling Scarp, and the Serpentine Rivers to the furthest extent of its lake system. It also includes some surrounding lands.

The Act also requires DoW to prepare and continually review a management program for any declared management area. The current program was last updated in 1992.

The Act gives DoW the general duties of conserving the rivers, inlets and estuaries to which it applies, and specifically to preserve and enhance the quality of the environment and amenities, control or prevent pollution, provide advice, generate and disseminate knowledge, act in concert with stakeholders, and to generally provide a coordination function. It requires DoW to have consideration for navigation, fisheries, agriculture, water supply, recreation and leisure-time occupation for the benefit of the public, natural beauty, amenity of the area, and preservation of public rights of access. The Act gives the ability to ‘call in’ certain development applications for consideration and the provision of advice to relevant authorities.

The Regulation prohibits certain activities include dredging, reclamation, drainage into the waters, disposal of wastes, launching of vessels except at designated ramps, destabilising the bed and banks, and the construction of groynes and retaining walls.

DoW actively licences dredging and reclamation activities, as well as the construction of retaining walls and groynes.
DoW also conducts regular monitoring of estuarine waters and catchment inflows, though this work has been rationalised and prioritised in recent years due to staff resourcing constraints and a reduction in available external funds.

DoW in the past has run a number of coordinating committees, though there is no committee active at present.

In recent years DoW has re-prioritised resources allocated to its duties as outlined in the WC Act. This has partly been offset by the establishment of regional NRM bodies such as South-West Catchments Council and the Peel-Harvey Catchment Council and the subsequent development of regional water quality improvement strategies.

DoW has been an active member and participant in both of these bodies since their inception.

DoW has played a key role in developing and reviewing the Water Quality Improvement Plan, as well as seeking funding for and actively managing a number of WQIP implementation projects. These projects were completed by June 2014.

DoW through the Better Urban Water Management framework works closely with the Department for Planning, local governments, and stakeholders to improve water management; drainage and flood management in particular, through landuse planning (strategic and statutory) and urban development processes.

DoW also has a formal responsibility for Regional and Arterial Drainage Planning and exercises this role through the development of Drainage Water Management Plans (DWMPs) which in turn are developed from rigorous surface water-groundwater interaction models and flood modelling.

In the Peel-Harvey catchment the operation and maintenance of various drainage infrastructure is undertaken by either the Water Corporation, local government or private landholders.

The Water Corporation manages drainage responsibility via operation funding from the State government as per operating licences. The licence specifies that the Water Corporation manage the drains for flooding, safety and waterlogging. There is no licensing or regulatory requirement for the Water Corporation to manage their drains for water quality (e.g. nutrients).

Local governments are exempt from licensing as a drainage service provider. There is no licensing or regulatory requirement for local governments to manage their drains for water quality.

There is no licensing or regulatory requirement for private land holders to manage their drains for water quality, except that in gazetted parts of the Peel-Harvey catchment the Soil Conservation Act could be used if it was shown that their drains were causing environmental harm.

The Department of Fisheries is responsible for conserving, developing and managing fish and aquatic resources. The Department utilises an Ecosystem Based Fisheries Management approach to manage the ecological resources of WA's six bioregions according to cumulative risk. It manages and licenses commercial and recreational fishing activities within the Ramsar site, through compliance and community education. Popular activities within the Ramsar site include recreational fishing, prawning and crabbing. The Department of Fisheries is also responsible for providing scientific knowledge and advice to support the conservation and sustainable use of the State’s aquatic resources. It is also the lead agency for aquatic biosecurity.
The Department of Transport is responsible for marine safety and the provision of coastal facilities such as jetties and moorings. This includes managing designated water ski areas, launching ramps and jetties, moorings, boating prohibited areas, boating speed restrictions, navigation aids and dredging within the Ramsar site. However, while this occurs within the Ramsar site, their imprimatur is not the protection of the ecological character of the site. The Department of Transport’s dredging role is as a proponent for navigational channels in natural waterways. DoW regulates dredging through the WC Act.

**Community group management**

There is an extensive network of community groups with varying roles and responsibilities, undertaking conservation, monitoring and research and education activities within the Ramsar site.

The Peel-Harvey Catchment Council (PHCC) is an incorporated, not-for-profit, community based Natural Resource Management organisation that promotes an integrated approach to catchment management and protection and restoration of the environment within the Peel-Harvey catchment.

The PHCC works with landholders, community groups, industry, the Australian Government, Government of Western Australia and local governments.

Sustainable Natural Resource Management (NRM) activities include climate change, river and wetland restoration, biodiversity protection, stormwater and drainage management, sustainable agriculture and building community and local government capacity.

The PHCC board membership is comprised of 10 community members, 2 local government representatives and representatives of the Departments of Agriculture and Food, Parks and Wildlife, Water and the Peel Development Commission. The PHCC board is skills based, with members selected by an independent panel based on their experience and understanding of Natural Resource Management.

The PHCC since 2004 has led the Ramsar initiative, raising awareness of the Peel-Yalgorup System’s status as a Ramsar site, and working with the then Department of Environment and Conservation to in 2007 establish the Ecological Character Description for the site. Following this the PHCC, with input from numerous government and community stakeholders, developed the *Peel-Yalgorup Ramsar site Management Plan*, (PHCC 2009) which has been endorsed by both the Western Australian and Australian Governments.

The primary source of funding for the PHCC projects is via the Australian Government. Other sources of funds are also sort from other grant schemes such as the Coastwest and State NRM (WA Government) and directly from local government and industry partners such as Alcoa.

Examples of projects being undertaken in the Ramsar site by PHCC include:

- Peel-Harvey Rivers 2 Ramsar: Connecting River Corridors for Landscape Resilience The retention and restoration of corridors from the head water of major rivers to the receiving waters of the Peel-Yalgorup Ramsar site.

There are a number of Landcare Centres, supported by local government authorities, across the Peel-Harvey catchment that provides a focal point for community based projects. Staff employed at the Centres work closely with the community and provides technical support, raise awareness and build community capacity in regard to a range of NRM activities and issues. They also provide administrative support for community groups to engage in the regional, and other funding processes
such as NHT, NAP, Envirofunds, non-Government organisation grants, and State government grants programs.

The Centres support the planning and implementation of on-ground activities conducted by local government, private landholders and community groups on public land. Examples of these activities include revegetation, streamlining (fencing and revegetation of riparian areas), protection of bushland, weed control, litter removal and wetland enhancement.

Other community groups undertaking activities in the Ramsar site include the Peel Preservation Group, Lake Mealup Preservation Society, Men of Trees and the Mandurah Bird Observers Group and BirdLife Australia (Peel).

3 Current condition DATA AVAILABLE TO INFORM CONDITION ASSESSMENT

3.1.1 Hydrology data

The hydrology data in the last Ecological Character Description by Hale and Butcher (2007) was predominantly from gauged information in Hodgkin et al. (1981). Therefore much of the data was out of date by at least 25 years at that time. The following condition assessment uses current data from the Bureau of Meteorology website (http://www.bom.gov.au/) and modelled data produced by Kelsey et al. (2011). The sources of data are noted on each table.

Depth to Groundwater data was collected from DoW bores, stored within the Water Information System (WIN) and accessed via the Water Information Reporting (WIR) platform http://wir.water.wa.gov.au/SitePages/SiteExplorer.aspx. Biannual surface water levels for Lakes Clifton and McLarty were gathered over a 35 year period as part of the South-West Wetlands Monitoring Program, conducted by the Department of Parks and Wildlife (Lane et al 2013). Monthly to bimonthly surface water levels were collected by the Department of Parks and Wildlife from 2005 until present (unpublished reports-Department of Parks and Wildlife).

3.1.2 Water quality and phytoplankton data

Caution must always be taken when interpreting trends in water quality data as error can result from many sources, including faulty equipment, varying data collectors and particularly from ad-hoc measurements or measurements taken at extended intervals which may not allow interpretation of natural variability of water quality parameters. The 35 year Southwest Wetlands Monitoring Program conducted by Lane et al. involved biannual measurements of depth, pH and Salinity in wetland. It is quite possible that the biannual monitoring of pH and salinity will not provide an accurate estimation of the variation in theses parameters, but the length of the monitoring program provides a very accurate indication of the trend in these parameters.

With respect to the Peel-Harvey Estuary, the Peel-Harvey Estuarine Reaches water quality monitoring program was initiated as part of the Ministerial conditions for the Dawesville Channel (EPA, 1994). The Department of Water has conducted all of the sampling since 2000. The program currently has 12 fixed sampling sites, three in each of the four major water bodies i.e. the estuarine reaches of the Serpentine and Murray Rivers, the Peel Inlet and the Harvey Estuary (Figure D55). All sites are routinely sampled for phytoplankton abundance and identification, chlorophyll a, and nutrient parameters (TN, NOx, NH3/NH4+, TP, filterable reactive phosphorus) with the exception of sites near the Dawesville Channel (PHE02 and PHE58) where no nutrient samples are collected. Phytoplankton
and chlorophyll $a$ are sampled through the water column, while nutrients are sampled at the surface and bottom at each site. Measurements of physical/chemical parameters (temperature, salinity, pH, dissolved oxygen) at ~50 cm intervals through the water column are also taken at all sites. Secchi depth is also recorded. The frequency with which all sites are monitored has varied at times over the last seven years. However, they are generally collected fortnightly for phytoplankton, chlorophyll $a$, physical/chemical parameters, secchi depth and monthly for nutrients.


The samples were collected under a chain of custody, submitted to NATA accredited laboratories that are quality assured by independent auditors every five years. Nutrients are analysed with methods appropriate to low nutrient detection. Staff are trained in water quality sampling and periodically audited by an environmental chemist at the Department. All data are stored in the State Water Information Database (WIN) and managed by trained data custodians.

Biannual salinity and pH data for Lakes Clifton and McLarty were gathered over a 35 year period as part of the South-West Wetlands Monitoring Program, conducted by the Department of Parks and Wildlife (Lane et al 2013). Monthly to bimonthly salinity and pH data were collected by the Department of Parks and Wildlife for Lakes Mealup (Figure D54) and McLarty from 2005 until present (unpublished reports-Department of Parks and Wildlife) which has facilitated an evaluation of the effectiveness of the management of the hydrological regime as a result of the construction of the weir on the Mealup Main Drain in 2011/12.

Salinity and water quality data have been collected through ad-hoc research programs, mainly in Lake Clifton in response to concerns over the health of the Thrombolite community and other microbial assemblages, these include (Moore 1987, Knott et al. 2003, John et al. 2009, Smith et. al. 2010 and Whitehead - unpublished 2015).

### 3.1.3 Phytoplankton data

Phytoplankton cell numbers and chlorophyll $a$ for The Peel-Harvey Estuary were plotted spatially and temporally using the Contour Plot feature in Sigma Plot 12 (Systat Software, USA, 2011-2012). The distance of each of the 12 sampling sites from the inner mouth of the Dawesville Channel was determined for plotting purposes such that in the Peel Inlet site PHE02 = 2.5 km, PHE07 = 6.6 km and PHE04 = 10.9 km. Continuing upstream to the Serpentine site PHRS4 = 16.7 km, PHRS6 = 21.9 km and PHRS7 = 28.7 km. In the Murray, distances from the inner mouth of the Dawesville channel were PHRM2 = 14.4 km, PHRM 4 = 19.2 km and PHRM 9 = 22.1. For the Harvey Estuary, distance from the mouth were PHE58 = 2.8 km, PHE01 = 8.6 km and PHE31 = 14.1 km.

Monthly to bimonthly chlorophyll $a$ were collected by the Department of Parks and Wildlife for Lakes Mealup and McLarty from 2005 until present (unpublished reports-Department of Parks and Wildlife) which has facilitated an evaluation of the effectiveness of the management of the hydrological regime as a result of the construction of the weir on the Mealup Main Drain in 2011/12.
3.1.4 **Benthic plants**

Information on macroalgae and seagrass in the Peel Inlet and Harvey Estuary was synthesized from a survey conducted in Nov/Dec 2009, 10 years after the previous survey and 15 years since the Dawesville Channel was opened (Pedretti *et al.* 2011). The purpose of the survey was to detect significant long term changes in abundance, distribution and diversity since the opening in 1994.

Data on the condition on the Thrombolite community in Lake Clifton Salinity has been collected through ad-hoc research programs, these include (Moore 1987, Knott *et al.* 2003, John *et al.* 2009, Smith *et. al.* 2010 and Whitehead - unpublished 2015).

3.1.5 **Littoral vegetation**

Data on the condition of tree health in the lower reaches of the Harvey River and in fringing areas of the Peel Inlet since the publication of the ECD in 2007 has been limited to *empirical* observations of staff from DoW.

Data on cover of *Typha* at Lakes Mealup and McLarty have been collected by the Department of Parks and Wildlife 2010-2015 as part monitoring the success of management of this weed.

3.1.6 **Invertebrates**

Information on catch rates of Blue Swimmer Crab are collected by the Department of Fisheries as part of their monitoring sustainability of the industry. Universities have conducted ad-hoc monitoring of other invertebrates over the years. Information on Western King Prawns in the basins and estuarine portions of the rivers is lacking.

3.1.7 **Fish**

Information on catch rates of commercial fish species are collected by the Department of Fisheries as part of their monitoring sustainability of the industry. Universities have conducted ad-hoc monitoring of fish communities over the years. Information on fish kill events is reported by members of the public and the data collated by the Department of Water and Department of Fisheries.

3.1.8 **Waterbirds**

Waterbird species composition and abundance data has been obtained from BirdLife Australia’s annual Shorebird 20-20 survey. The Shorebird 20-20 survey is a one day snapshot of species composition and abundance collected in February each year and relies on a large community involvement to cover all major waterbird habitats across the Peel-Yalgorup System.
Figure D54: Location of sampling sites at Lake Mealup (Parks & Wildlife 2010)
Figure D55: Location of sampling sites in the Peel-Harvey Estuary including the estuarine portion of Serpentine and Murray Rivers. Details of parameters and frequency of sampling in legend.
3.2 CURRENT CONDITION

For the purposes of this Condition Statement the current condition is interpreted as meaning the period from the publication of the Ecological Character Description in 2007 (Hale and Butcher 2007) until present or whatever is the most current data for each system component and process.

The site is large, (26,500 hectares), complex (contains four sub-systems), meets multiple Ramsar criteria, for multiple reasons, and has been suffering the effects of the identified threats to the System since well before its listing in 1990.

This Condition Statement analyses the data, where available, to determine the current condition of each of the four sub-systems of the Peel-Yalgorup Ramsar site. In turn this Condition Statement will provide guidance to assist with the identification of further future impacts from proposed developments within the Perth Peel region. The impacts to the site from proposals, such as increasing Preston Beach townsite from 400 to potentially 10,000 residents (with the townsite abutting Lake Preston, plus indirect impacts of the increased population recreating within the broader Yalgorup National Park; note the “Lands and Lakes of Yalgorup National Park” are Ramsar listed) must be considered.

3.2.1 Geomorphology

No data exists to determine if there have been changes in shorelines, bathymetry etc. since 2007. Due to this lack of data, current condition is assessed as per description provided in 2.2.1.

3.2.2 Hydrology

Peel-Harvey Estuary

Hydrological components such as rainfall, evaporation and river inflows have changed since that reported in Hale and Butcher (2007). The updated data is presented below with reference to that shown in the 2007 report.

Annual rainfall and flow have declined in the region since 1984 (plotted since 2000 to match water quality data described in the next section) (Figure D56). Of the three rivers contributing flow to the Peel-Harvey Estuary, the Murray River has the greatest annual contribution compared to the Serpentine and Harvey Rivers. This is true even when the Serpentine and Harvey Rivers have greater annual rainfall because the Murray catchment is so large. Dry years are noted in 2001, 2006 and 2010 characterised by a drop in rainfall and flow.

One of the key differences in hydrology since the last condition report is greater evidence of the drying climate in the south-west of Western Australia. There have been significant changes in rainfall regime, where there has been a sharp decline – one in 1975, referred to earlier in Section 2.4.9 and another in 1996 (CSIRO 2009). During the last decade (2003-2013), this has resulted in total rainfall inflows into the Peel Inlet declining by 22% compared with the historical period at the time of listing (1900-1990) (Table D37). Similarly, the inflows into the Harvey Estuary have declined by 18%. This is mostly due to declines in rainfall from February through to October.
Another key difference in hydrology since the last condition report is the change in timing of rainfall inflows. In the last decade (2003-2013), rainfall is higher in the late spring/early summer months of November, December and January than it was during the period at the time of listing (1900-1990).

Although groundwater has not been measured directly, an analysis of low summer flows over the period 1999-2010 suggests a decline in groundwater storage and base flow contribution (Ruibal-Conti et al. 2013).

Like rainfall inflows, river flows have declined in the more recent period (1997-2007) compared with the previously reported period (1977-1988), except in the case of the Murray (Table D38). The Murray continues to contribute the majority of the surface water flows to the Peel-Harvey Estuary, but the proportion has increased to more than three times that of the Serpentine compared to the last reported period when it was double (1977-1988). The Harvey still contributes about a third of the total surface water flows.
Table D37: Average monthly inflows (ML) to the Peel Inlet and Harvey Estuary from direct rainfall (calculated from Bureau of Meteorology website data Mandurah station 9977 (2003–2013) compared with that previously reported* (1900–1990) in Table 8 from Hale and B

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>720</td>
<td>1,425</td>
<td>540</td>
<td>1,159</td>
</tr>
<tr>
<td>Feb</td>
<td>1,000</td>
<td>753</td>
<td>750</td>
<td>612</td>
</tr>
<tr>
<td>Mar</td>
<td>1,500</td>
<td>1,276</td>
<td>1,100</td>
<td>1,038</td>
</tr>
<tr>
<td>Apr</td>
<td>3,300</td>
<td>3,102</td>
<td>2,500</td>
<td>2,523</td>
</tr>
<tr>
<td>May</td>
<td>9,500</td>
<td>7,414</td>
<td>7,100</td>
<td>6,030</td>
</tr>
<tr>
<td>Jun</td>
<td>14,000</td>
<td>9,147</td>
<td>11,000</td>
<td>7,440</td>
</tr>
<tr>
<td>Jul</td>
<td>13,000</td>
<td>8,853</td>
<td>9,800</td>
<td>7,200</td>
</tr>
<tr>
<td>Aug</td>
<td>9,500</td>
<td>7,009</td>
<td>7,100</td>
<td>5,701</td>
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<tr>
<td>Sep</td>
<td>6,400</td>
<td>5,644</td>
<td>4,700</td>
<td>4,591</td>
</tr>
<tr>
<td>Oct</td>
<td>3,900</td>
<td>2,640</td>
<td>2,900</td>
<td>2,147</td>
</tr>
<tr>
<td>Nov</td>
<td>1,700</td>
<td>1,972</td>
<td>1,300</td>
<td>1,604</td>
</tr>
<tr>
<td>Dec</td>
<td>870</td>
<td>1,583</td>
<td>650</td>
<td>1,288</td>
</tr>
<tr>
<td>Total</td>
<td>65,000</td>
<td>51,000</td>
<td>50,000</td>
<td>41,000</td>
</tr>
</tbody>
</table>

Table D38: Average annual river flows (GL) entering the Peel-Harvey Estuary (modelled 1997–2007) compared to that previously reported (gauged 1977–1988) in Table 9 Hale and Butcher (2007).

<table>
<thead>
<tr>
<th>Source</th>
<th>Gauged flows (McComb and Humphries, 1992)*</th>
<th>Modelled flows (Kelsey et al, 2011)#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serpentine River</td>
<td>129 21%</td>
<td>112 16%</td>
</tr>
<tr>
<td>Murray River</td>
<td>264 43%</td>
<td>383 56%</td>
</tr>
<tr>
<td>Harvey River</td>
<td>225 36%</td>
<td>188 28%</td>
</tr>
</tbody>
</table>

*For comparative purposes modelled flows generated for the Mandurah sub-catchment (3.0 GL) has been added to those draining to the Serpentine River. Flows generated for the Coolup (Peel) sub-catchment (23 GL) have been added to the Murray River, and flows generated for the Coolup (Harvey) sub-catchment (16 GL) have been added to the Harvey River.

Another change that has been noted, for all three rivers, is the peak of the monthly mean rate of discharge (m³/s) has shifted from July to August over the period 2004–2011.(Ruibal-Conti 2014). This is believed to be because of a change in catchment storage potential where the rate of moisture accumulation in autumn has declined before the winter rains.
Monthly and total evaporation from the Peel-Harvey Estuary was calculated using Bureau of Meteorology data obtained through the Australian Government enhanced climate database (SILO) (Table D39). Two periods are compared, the historical period at the time of listing (1900-1989) and the period since then (1990-2013). In terms of outflows, evaporation remains high and has increased by 6% in the more recent period.

Table D39: Estimated monthly and total evaporation (mm) and corresponding volume lost through evaporation (ML) for the Peel-Harvey Estuary.

<table>
<thead>
<tr>
<th>Month</th>
<th>1900–1989</th>
<th>1990–2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>152</td>
<td>156</td>
</tr>
<tr>
<td>February</td>
<td>129</td>
<td>132</td>
</tr>
<tr>
<td>March</td>
<td>127</td>
<td>132</td>
</tr>
<tr>
<td>April</td>
<td>87</td>
<td>92</td>
</tr>
<tr>
<td>May</td>
<td>66</td>
<td>68</td>
</tr>
<tr>
<td>June</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>July</td>
<td>60</td>
<td>59</td>
</tr>
<tr>
<td>August</td>
<td>73</td>
<td>71</td>
</tr>
<tr>
<td>September</td>
<td>73</td>
<td>74</td>
</tr>
<tr>
<td>October</td>
<td>107</td>
<td>111</td>
</tr>
<tr>
<td>November</td>
<td>124</td>
<td>130</td>
</tr>
<tr>
<td>December</td>
<td>159</td>
<td>168</td>
</tr>
<tr>
<td>Total (mm)</td>
<td>1,214</td>
<td>1,250</td>
</tr>
<tr>
<td>Volume (ML)</td>
<td>159,000</td>
<td>169,000</td>
</tr>
</tbody>
</table>

Lakes Goegrup and Black

Data has not been collected to determine trends in hydrological parameters for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, the Serpentine River is the main source of surface water for Lake Goegrup and recent data (Figure D55) suggests that the trend is variable, but reduced flow from the Serpentine River, as noted by Hale and Butcher (2007), has continued and that together with decreases in rainfall and increased evaporation rates (Table D39) and the noted increase in tidal range that followed the opening of the Dawesville Channel, means that hydrological and chemical conditions are going to be more influenced by conditions within the Peel Inlet/Serpentine River interchange zone.
Black Lake also receives water from Nambeelup Brook, which flows into the wetland from the north-east and pressures on river flows from the catchment are likely to lead to greater tidal exchange for this lake system as well.

**Yalgorup Lakes**

Depth to groundwater measurements taken from a number of bores around the Yalgorup Lakes suggests that there has been a slight reduction in groundwater flows into the lake system (Figure D57). The causes of reduced groundwater flows include reduced rainfall and increased evaporation across the catchment, altered groundwater hydrology as a result of engineering works and increased groundwater abstraction for private and commercial purposes. The lakes intersect the freshwater surficial unconfined aquifer that flows from the east towards the sea and contributes an estimated 38% of lake volume. The combined impacts from reduced rainfall, (direct rainfall contributes 62% of lake volume) and reduction in freshwater flows into the system would be expected to lead to significant increases in the salinity of the surface water as the deeper, hypersaline groundwater exerts a greater influence and evaporation later in the season leads to concentration of the salt content. Reduced groundwater level is also expected to lead to increased release of salt ions from clay sediments as a result of acid sulfate chemical processes (pers. comm. M. Whitehead 2015).

The critically endangered Thrombolite (microbial) Community at Lake Clifton, as well as other microbial assemblages at Lake Preston, rely on fresh water seepages. As outlined in 3.2.3 appropriate pH and salinity ranges are also vital to the health of the Thrombolites.

Water levels are highest in spring after winter rains and groundwater seepage reach their maximum. The majority of the Yalgorup Lakes are permanently inundated with the exception of the southern portion of Lake Preston and South and North Neunham Lakes which dry out in mid-late summer.

The depth of inundation varies throughout the year depending on rainfall and evaporation rates.

The reduction in groundwater depth is reflected in the reduction in lake depth in Lake Clifton as measured in early and late spring (September and November). The trend towards a lower lake depth of around 0.5 metres is shown in Figure D57 from data collected over a 27 year period from 1985 through 2012 by Lane et al. (2013).
Figure D57: Depth to groundwater from a single bore on the east side of Lake Clifton, close to Thrombolite viewing area (1995-2014)

Figure D58: Depth of Lake Clifton 1985-2014 (Lane et. al. 2014)
**Lakes McLarty and Mealup**

Since 2007, Lake McLarty has maintained a seasonal pattern of wetting and drying. It has previously been noted that Lake McLarty is generally dry for 1-4 months of the year, but that a drying trend had been observed anecdotally (Hale and Butcher 2007). Data collected over a 21 year period (1993-2014) from biannual monitoring in early and late spring (September and November), when maximum lake depths are expected, supports the observations of a drying trend (Figure D59). While water depth varies considerably, there is a significant downwards trend from the start of data collection in November 1993. Lake levels are responding to declining rainfall over the last 20 years and very low lake levels correspond to the dry rainfall years of 2001, 2006 and 2010. An historic low occurred in 2010 which also corresponded to one of the driest rainfall years on record.

Further data collected monthly from January 2005 through August 2014 (Figure D59 - unpublished data Department of Parks and Wildlife), confirms to a drying trend and while the period of drying is still highly variable, there is decrease in lake maximum depth, more frequent drying out events, earlier drying out of the lake and out an increase in the length of time the lake is dry. For example, during the summer/autumn of 2007, 2010, 2011 and 2012 the lake was dry for 6 months or longer. Water levels have remained variable since 2007 and peaked over 1 metre in 2005, 2008 and again in 2013.

If the drying trend continues, the lake will experience lower maximum depths and have more extended periods of being completely dry, which would reduce the suitability of Lake McLarty for waterbird habitat, encourage terrestrial vegetation and weeds to encroach and increase the risk of damage from fire events.
Up until the construction of the weir on the Mealup Main Drain in 2012, Lake Mealup had been experiencing a trend of decreasing lake levels and had been empty more often and for longer periods of time than at the time of listing under the Ramsar Convention in 1992 (Figure D61). Where once the lake dried on average every two years, it had been dry during late summer to autumn since 1994. Dropping lake levels and extended periods of being totally dry had exposed lake sediments containing acid sulfate soils and led to increasing salinity (Figure D72), acidity (Figure D84) and nutrients (Figure D96) and the spread of Typha orientalis across the lake. The construction of the weir on the Mealup Main Drain was completed in November 2011 and facilitated drainage water being directed into Lake Mealup starting in June 2012 to mimic more closely, the natural hydrological regime before the blockage of a creek that historically flowed into the lake.

The hydrological modelling for Lake Mealup has established a goal of a maximum lake depth of 1.3-1.5 metres AHD, but this figure is being adapted as more data on the response of vegetation and water quality is gathered (Lake Mealup Technical Advisory Group unpublished report February 2013).
3.2.3 Water quality

Monitoring in the lower reaches of the rivers indicates deterioration in water quality since construction of the Dawesville Channel, particularly in the Serpentine. The changes in water quality are probably due to the influence of the Dawesville Channel driving salinity stratification further upstream, the concurrent decline in rainfall reducing flushing and the result of continued nutrient loads from the catchment.

SALINITY

Peel-Harvey Estuary

Salinity in the Peel Inlet and Harvey Estuary continues to be stable and marine with annual surface medians between 34 to 39 ppt (Figure D62). Bottom medians follow a similar pattern over the 10 year period. However surface salinity in the estuarine portions of the Serpentine and Murray Rivers appears to be increasing over time with major fluctuations associated with heavy rainfall. Bottom salinities in the Serpentine, but not the Murray, also follow this pattern. In the Murray, the bottom salinities are consistently over 30 ppt and have reached marine levels in four of the 10 years.
As noted in Hale and Butcher (2007), there are still seasonal trends in the basins with freshwater inflows from rivers during winter months. At this time in the centre sites, salinity rarely drops below 10 ppt in surface waters or below 20 ppt in bottom waters.

However, hypersalinity (>35 ppt) extends beyond the summer months into autumn in all systems now. Values over 60 ppt are regularly recorded in the basins during summer and over 70 ppt in the upper sites of the estuarine portion of the Serpentine River during autumn.

The estuarine portion of the Murray River, unlike the other well mixed systems, is stratified for the majority of the year with saltier water on the bottom (blue fill bars) and fresher water on the surface (open bars) (Figure D63).
A winter gradient in salinity from river mouths to channel of the basins continues to be evident as reported previously (Hale and Butcher 2007).

However, stratification in the basins is now common in winter at all sites, not just near the river mouths.

The limit of acceptable change (LAC) for wet season salinity in the centre of the Peel Inlet is exceeded in three of the last ten years (2004, 2006 one sample taken only, 2010). In these years surface salinities did not remain below 30 ppt for three months of the year (Figure D64). These years were also characterised by low rainfall. Note that the original LAC referred to winter months (Jun, Jul, Aug) which, if applied here, would mean that there were exceedances in six of the ten years.
The limit of acceptable change (LAC) for wet season salinity in the centre of the Harvey Estuary is exceeded in four of the last 10 years (2003, 2004, 2006 one sample taken only, 2010). In these years surface salinities did not remain below 30 ppt for three months of the year (Figure D64). These years were also characterised by low rainfall except for 2003. Note that the original LAC referred to winter months (Jun, Jul, Aug) which would mean that there were exceedances in seven of the ten years.
Figure D65: Surface and bottom salinity measurements (raw data) in the wet season (Jun-Oct) in the middle of the Harvey Estuary (site PHE01) (2002-2011). Red dotted line shows limit of acceptable change of 30 ppt where salinities should remain for 3 months of the year.

**Lakes Goegrup and Black**

Data has not been collected to determine trends in water quality for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, there is a DoW site directly upstream of Goegrup Lake on the Serpentine River (PHRS6) (Figure D55), which provides the best available information. As this data has not been taken from within the lakes, caution should be applied when drawing conclusions on trends.

Salinity at the site varies seasonally and ranges from fresh in the high rainfall months (July to October) to hypersaline in the drier months, with peaks of salinity generally in March. Data from 2002 to 2011 does not indicate any significant trends or changes in salinity at the monitoring site (Figure D66).
Figure D66: Surface salinity measurements from PHRS6 on the Serpentine River north of Goegrup Lake 2002-2011.

Yalgorup Lakes

Significant increases in the salinity of Lake Clifton have been reported for the period between 1984 through to 2006 (Figure D67 – Smith et. al. 2010). The salt load during this period has been reported to have increased by 40% which is likely to be caused by a combination of factors, including the reduction of direct rainfall which accounts for an estimated 68% of lake volume, reduced freshwater recharge from the groundwater, increased abstraction of freshwater from the Superficial Aquifer and upwelling of more dense saltier groundwater from deeper aquifer systems as the hydrostatic pressure is reduced and the release of salt ions from the clay sediments of drained inland wetland areas as a result of sulphide oxidation processes (pers. comm. Whitehead 2015). Further analysis is being conducted to assess the possible influence of the increased marine tidal forces as a result of the Dawsville Channel opening on the hydrology of Lake Clifton (pers. comm. Whitehead 2015).
The maximum salinities measured in 2004 and 2005 were above 35 ppt (seawater) and were above the established LAC of 35 ppt. Biannual monitoring of water quality in Lake Clifton in early and late spring over the 27 year period from 1985 until 2014 (Figure D68) indicates that the upwards trend in salinity reported by Smith et al. 2009 has continued and the salinity in the open water has been above sea water (35 ppt) and therefore the LAC since 2003 and has been regularly hypersaline (>50 ppt) since 2010 (Lane et al. 2013). Monitoring from fringing sedge communities on the east side of Lake Clifton has been picking up freshwater seepages which allow these plant communities to continue growing in the hypersaline conditions (data not shown).

The most recent water sampling from Lake Clifton (Figure D69 unpublished data Whitehead 2015) indicates seasonal variation in the salinity of Lake Clifton from a minimum around 40 ppt in late winter up to almost 140 ppt at the end of summer (Figure D67). This is a significant concern as the minimum recorded salinity is now well above the LAC. The implications of these hypersaline conditions for the thrombolite community in the lake are still not determined, but with the continuing trend of increasing salinity, there is concern that the conditions will be a limiting factor in the function of the micobialite formation process (pers. comm. Mike Whitehead 2015) and fringing vegetation may start to also be impacted, particularly if freshwater seepages stop recharging fringing zones.

The seasonal patterns in salinity exist for all of the Yalgorup Lakes (Figure D70) with individual parts having salinities that reflect the source of groundwater being expressed. For instance Site C at Lake Preston has the highest salinity recorded in the Yalgorup Lakes of 300 ppt while Site B has the lowest salinity of 7.5 ppt and is the only site that is consistently below the salinity of seawater. Site B has the highest density of waterbird usage which is likely a result of the fresher conditions favouring higher densities of macroinvertebrates (Whitehead unpublished data 2015).
Figure D69: Salinity in Lake Clifton (TDS ppt) August 2013-April 2014 (Whitehead unpublished data, 2015).

Figure D70: Salinity of Yalgorup Lakes compared with ocean salinity (TDS ppt) (Whitehead unpublished data, 2015).
**Lakes McLarty and Mealup**

Both Lakes McLarty (Figure D71) and Mealup (Figure D72) remain freshwater systems with minimum salinities below 1 ppt at maximum depth in mid-spring and maximum salinities approaching 7-11 ppt when water levels are at their lowest in late summer. There is no apparent trend in salinity for Lake McLarty, although the maximum in the summer of 2012/13 was the highest since recordings began in 2008 and is likely to become higher if lake levels continue to fall. Salinity levels for both Lakes McLarty and Mealup remain above the LAC of 1 ppt during a significant period of inundation and the impacts to fringing vegetation should be monitored to determine condition trends.

![Figure D71: Salinity of Lake McLarty 2008-2013](image)

Similar to Lake McLarty, there was no significant trend in salinity in Lake Mealup, although the highest annual maximums occurred in low rainfall years and until the construction of the weir on the Mealup Drain, the lake levels were falling and this was associated with sharp spikes in salinity. The construction of the weir has allowed for water regimes that more closely mimic the natural regime and water levels are now much higher and this together with the control of *Typha orientalis* has facilitated better water quality, including salinity that is generally below 2 ppt (Figure D72).
Figure D72: Salinity of Lake Mealup 1987-2014 (Department of Parks and Wildlife unpublished 2015).

**Dissolved Oxygen**

**Peel-Harvey Estuary**

Prior to opening of the Dawesville Channel, daily mean tidal range in the Peel Inlet and Harvey Estuary averaged 17% and 15% of the ocean tides respectively. Following the opening of the Dawesville Channel, the tidal ranges in the Peel Inlet and Harvey Estuary are 48% and 55% of the ocean tides respectively. With increased exchange with marine waters, water quality in the estuarine basins has improved, particularly in the Harvey Estuary where periods of stratification and deoxygenation are shorter and less frequent. *Nodularia* blooms have been absent and turbidity during spring has decreased. In contrast to pre-Channel years, water quality in the Harvey Estuary has become very similar to that in the Peel Inlet.
The rivers experience more stratification than the basins and like salinity, oxygen stratification in the Murray is persistent (Figure D73). Median dissolved oxygen concentrations remain outside the Limits of Acceptable Change in all systems except for the bottom waters of the Serpentine. The shallow nature of the upper two Serpentine sites (~0.5 m) means that they are well mixed by wind, hence more consistently well oxygenated.

![Dissolved oxygen in each system (2002–11)](image)

Figure D73: Dissolved oxygen in the surface and bottom waters of the Peel-Harvey Estuary and the estuarine portions of the rivers (2002-2011) showing medians (squares symbols), 25th -75th percentile (box) and 5th -95th percentiles (whisker).

Red dotted lines show the limit of acceptable change for dissolved oxygen is 70-80% saturation (Figure D73). It is frequently not met in all systems with most median values being higher than 90% saturation, except for the estuarine portions of the Serpentine which largely lie within the range.

The marked salinity stratification of the Murray River leads to anoxic conditions (< 4 mg/L dissolved oxygen) in the bottom waters while the surface waters remain oxygenated. This is illustrated with a contour plot over a depth profile of the whole system in April 2008 (% saturation) (Figure D74), as well as with a monthly box and whisker plot over the ten year period (mg/L) (Figure D75).
Figure D74: Two dimensional spatial distribution of dissolved oxygen (% saturation) in the Peel-Harvey Estuary and the estuarine portions of the rivers on 8th and 9th April 2008. Distances are measured from the Dawesville Channel (DC).

Figure D75: Monthly dissolved oxygen concentration in the Murray River (2002–11) showing medians (squares symbols), 25th-75th percentile (box) and 5th-95th percentiles (whisker) Red dotted line shows point below which water is described as anoxic.
There is a significant downwards trend in annual median dissolved oxygen (DO) concentrations in surface waters of the Peel-Harvey Estuary and the estuarine portions of the Serpentine and Murray Rivers (Figure D76). Although the DO is taken from monthly readings and affected by temperature and varies diurnally, the DO appears to be declining consistently over the ten year period 2002-2011 and is noted in bottom waters as well. It is also consistent with an increase in surface temperatures described below and with an increase in salinity for the surface and bottom waters of the Serpentine and the surface waters of the Murray. It will be critical to continue evaluation of dissolved oxygen concentrations and consider alternative management if dissolved oxygen levels approach that not tolerated by fish i.e. < 4 mg/L.

![Surface median dissolved oxygen](image)

Figure D76: Annual median dissolved oxygen concentrations in surface waters of the Peel-Harvey Estuary and the estuarine portions of the rivers (2002-2011).

**Lakes Goegrup and Black**

Data has not been collected to determine trends in water quality for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, there is a DoW site directly upstream of Goegrup Lake on the Serpentine River (PHRS6) (Figure D55), which provides the best available information. As this data has not been taken from within the lakes, caution should be applied when drawing conclusions on trends.

Monthly median measurements from 2002-2011 of dissolved oxygen indicate that the monitoring site is generally well oxygenated, only falling below 70% saturation in summer (December to February). The raw data shows some periods of low dissolved oxygen (less than 30%) during summer, however, the seasonal patterns do not appear to illustrate any trends (Figure D77).
Figure D77: Lake Goegrup surface dissolved oxygen measurements 2002-2011.

**Yalgorup Lakes**

Data not available.

**Lakes McLarty and Mealup**

Data not available.

**Temperature**

**Peel-Harvey Estuary**

Annual surface temperatures range from about 17 C to 20 C in the Peel Inlet, Harvey Estuary and estuarine portion of the Serpentine River. However the temperature is consistently warmer in the Murray River ranging from about 18.5 C to 21.5 C over the 10 year period. The temperatures appear to increase over the 10 year period in the estuarine portions of the rivers (Figure D78), as was observed for salinity (Figure D62). This increase in temperature is expected to reduce the solubility of oxygen and is indeed reflected in surface oxygen concentrations (FigureD72). Peaks in temperature in 2006, one of the driest years on record, coincide with those for salinity in all systems (FigureD62). Bottom temperatures follow a similar pattern in all respects.
Figure D78: Annual median temperature for surface waters of the Peel-Harvey Estuary including estuarine portions of the rivers (2002-2011).

**Lakes Goegrup and Black**

Data has not been collected to determine trends in water quality for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, there is a DoW site directly upstream of Goegrup Lake on the Serpentine River (PHRS6) (**Figure D55**), which provides the best available information. As this data has not been taken from within the lakes, caution should be applied when drawing conclusions on trends.

Monthly median surface temperatures for 2002-2011 range from 12.8°C in July to 24.3°C in February. Raw data from the monitoring site demonstrates the seasonal variation and there is no indication of trends or changes in surface temperature from 2002 to 2011 (**Figure D79**).
Figure D79: Surface temperature (degrees Celsius) of Goegrup Lake.

_Yalgorup Lakes_

Data not available.

_Lakes McLarty and Mealup_

Data not available.

**pH**

_Peel-Harvey Estuary_

The median pH in the Peel-Harvey Estuary and the estuarine portions of the rivers is between 7.8 to 8.2 over the ten year period 2002-2011 (Figure D80).

The limit of acceptable change for pH > 7 at all times, was exceeded less than 10% of the time in the Serpentine River and less than 2% of the time in the Harvey Estuary over the period 2002-2011. The Peel and the Murray do not exceed the limit during this time (Table D40).
Figure D80: pH in the surface and bottom waters of the Peel-Harvey Estuary and the estuarine portions of the rivers (2002-2011) showing medians (squares symbols), 25th-75th percentile (box) and 5th-95th percentiles (whisker). Red dotted line show limit of acceptable change where pH must not fall below 7.0.

Table D40: Percent of times that pH is < 7 in surface and bottom waters of the Peel-Harvey Estuary and estuarine portions of the rivers (2002-2011).

<table>
<thead>
<tr>
<th>pH &lt; 7</th>
<th>Peel Inlet</th>
<th>Harvey Estuary</th>
<th>Murray River</th>
<th>Serpentine River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>0.0%</td>
<td>1.5%</td>
<td>0.0%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Bottom</td>
<td>0.0%</td>
<td>1.3%</td>
<td>0.0%</td>
<td>7.5%</td>
</tr>
</tbody>
</table>
Lakes Goegrup and Black

Data has not been collected to determine trends in water quality for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, there is a DoW site directly upstream of Goegrup Lake on the Serpentine River (PHRS6) (Figure D55), which provides the best available information. As this data has not been taken from within the lakes, caution should be applied when drawing conclusions on trends.

Monthly median pH from 2002-2011 indicates that the monitoring site ranges from neutral in the winter months (pH 7) to alkaline (pH 8.5) in autumn and summer. The seasonal variation appears to be maintained with no evidence of significant trends, however, between 2009 and 2011, it does appear that pH remained between 8 and 9 for a longer period during summer than previously recorded (Figure D81).

![Goegrup Lake surface pH 2002-2011](image)

**Figure D81**: Surface pH from Goegrup Lake 2002-2011.

Yalgorup Lakes

The pH of surface water for Lake Clifton remains above the LAC of pH 7 and there is no significant trend (Figure D82). It is possible that greater variation exists in the pH as these readings are from biannual monitoring. However, given the length of the data set, the confidence that it is reflecting the actual variation is greater. The water contains a significant level of alkalinity as a result of dissolved carbonates from groundwater (Whitehead unpublished data 2015), which will effectively buffer acidification that may result from exposure of acid sulfate soils in the system.
Lakes McLarty and Mealup

The pH of surface water of Lake McLarty remains above the LAC of pH 7 and there is no significant trend (Figure D83).

Figure D83 : pH of Lake McLarty 1980-2013 (Department of Parks and Wildlife unpublished 2015).
The pH of surface water of Lake Mealup was of significant concern up until the weir on the Mealup Drain was constructed in November 2011 and water was redirected into the lake in June 2012. At this point, the pH was regularly between 2.8 and 4 and was related to a drying out of the lake sediments and exposure of acid sulfate soils. Initial re-flooding of the lake sediments led to further decreases in pH as sulphuric acid from exposed sediments became mixed with lake water. However with slashing and flooding death of the *Typha orientalis*, the organic matter provided the chemical buffering of the sulphuric acids and the pH rose sharply to over pH 6 and has steadily climbed to between generally 7-8 and meets a LAC of > pH 7 (Figure D84).

![Lake Mealup pH](image)

**Figure D84**: pH of Lake Mealup - 1987-2014 (Department of Parks and Wildlife unpublished 2015).

**Water Clarity**

**Peel-Harvey Estuary**

Water clarity, in terms of secchi depth, in the Peel-Harvey Estuary and the estuarine portions of the rivers has been measured from 2002 to 2011. As the systems have different bathymetry, a direct comparison of secchi depths between them is not appropriate. However it is possible to compare the proportion of times that light penetrated to the bottom of the river and estuary bed by examining the number of times that the secchi depth was equivalent to bottom depth (Figure D85). Water clarity was greatest in the Peel Inlet and Harvey Estuary as expected with increased flushing from the Dawesville Channel. The rivers showed lower clarity, with the secchi disk rarely visible on the Murray River bed.
Figure D85: Annual changes in light penetration to the bottom as measured by secchi depth relative to bottom depth in the Peel-Harvey Estuary including estuarine portions of the rivers (2002-2011).

Water clarity is affected by rainfall as shown by the greater visibility in all systems in the driest years on record 2006 and 2010 (Figure D85). There is also evidence of increasing clarity over time, again this could be due to the drying climate.

Seasonal influences on water clarity are also evident (Figure D86). The river/estuary bed visibility declines in heavier rainfall periods in winter. Summer and autumn declines in visibility in the rivers are most likely due to algal blooms.

Figure D86: Seasonal changes in light penetration to the bottom as measured by secchi depth relative to bottom depth in the Peel-Harvey Estuary including estuarine portions of the rivers (2002-2011).

Nutrients
**Yalgogrup Lakes**

Data not available.

**Lakes McLarty and Mealup**

Data not available.

**Nutrients**

**Peel-Harvey Estuary**

The Serpentine River has highest median concentrations (ranging from ~0.025 up to 0.37 mg/L) of total phosphorus compared to the other systems in both surface (open bars) and bottom waters (blue fill bars) (Figure D87). However all systems except the Peel Inlet have median phosphorus concentrations that exceed the ANZECC guidelines of 0.03 mg/L (ANZECC, 2000) which is also the same as the limit of acceptable change.

![Total phosphorus concentrations in each system (2000–11)](image)

Figure D87: Total phosphorus concentrations in surface and bottom waters of the Peel-Harvey Estuary including estuarine portions of the rivers (2000-2011). Note that bottom samples were taken from the Serpentine River at site PHRS4 only as PHRS 6 and 7 are too shallow. Red dotted line shows ANZECC (2000) guideline of 0.03 mg/L which is also the limit of acceptable change.
The percent of samples that exceed the LAC (0.03 mg/L TP) is greatest in both the surface (96%) and bottom waters (89%) of the Serpentine, followed closely by the bottom (80%) of the Murray (Table D41). The surface waters of the Harvey and Murray show the same exceedance (61%). The Peel shows the least exceedance for surface (24%) and bottom (20%).

Table D 41 : Percent of surface and bottom samples that exceed the limit of acceptable change of 0.03 mg/L total phosphorus (TP) (2000-2011). Note that the bottom samples were taken from for the Serpentine River site PHRS4 only, as PHRS 6 and 7 were too shallow.

<table>
<thead>
<tr>
<th>TP &gt; 0.03 mg/L</th>
<th>Peel Inlet</th>
<th>Harvey Estuary</th>
<th>Murray River</th>
<th>Serpentine River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>24%</td>
<td>61%</td>
<td>61%</td>
<td>96%</td>
</tr>
<tr>
<td>Bottom</td>
<td>20%</td>
<td>56%</td>
<td>80%</td>
<td>89%</td>
</tr>
</tbody>
</table>

Seasonal concentrations of bioavailable (soluble) phosphorus are highest for the Serpentine, Peel and Harvey in winter (Figure D88). However they are also high in summer for the Murray, but only in bottom waters when dissolved oxygen is also at its lowest (Figure D74).

In contrast to that recorded for phosphorus, only the Serpentine River has median total nitrogen concentrations that exceed the guidelines of 0.75 mg/L (ranging from ~ 0.05 to 3.2 mg/L), although the Murray River comes close (Figure D89) (ANZECC 2000).
Figure D89: Total nitrogen concentrations in surface and bottom waters of the Peel-Harvey Estuary including estuarine portions of the rivers (2000-2011). Red dotted line shows ANZECC (2000) guideline value of 0.75 mg/L. Note that the bottom samples were taken fro

Seasonal concentrations of bioavailable N in the form of ammonia/ammonium are greatest in winter in all systems in both surface (S) and bottom waters (B) (Figure D90). As for total nitrogen, the estuarine portion of the Serpentine River has the greatest concentrations of all the systems except in spring when the bottom waters of the Murray take over. All systems exceed the LAC of 0.01 mg/L in both surface and bottom waters.

Like ammonia/ammonium, seasonal median concentrations of bioavailable N in the form of oxidised nitrogen (nitrate and nitrite) are greatest in winter in all systems in both surface (S) and bottom waters (B) (Figure D90). However, the Murray has the greatest or equal concentrations of all systems except in spring when the Serpentine takes over. In contrast to that seen for ammonia/ammonium, only in winter do all systems exceed the LAC of 0.01 mg/L in both surface and bottom waters.
Figure D90: Seasonal ammonia/ammonium concentrations in the Peel-Harvey Estuary and the estuarine portions of the rivers in surface (S) and bottom (B) samples (2000-2011). Red dotted line shows limit of acceptable change of 0.01 mg/L. Note that the bottom samples.

Figure D91: Seasonal oxidised nitrogen concentrations in the Peel-Harvey Estuary and the estuarine portions of the rivers in surface (S) and bottom (B) samples (2000-2011). Red dotted line shows limit of acceptable change of 0.01 mg/L. Note that the bottom sample.

Annual nutrient loads to the estuary from the catchments of the Serpentine, Murray and Harvey Rivers were calculated between 1997 to 2007 (Table D42) (Kelsey et al. 2011). They remain high with median annual loads of 1,060 tonnes of nitrogen and 135 tonnes of phosphorus. The annual phosphorous loads over this period exceed the target set by the Environmental Protection (Peel Inlet-
Harvey Estuary) Policy (EPA 1992) by over 50%. Not surprisingly, phosphorus loads quoted in the last condition report from 1990 to 2004 (Hale and Butcher 2007) are similar to that studied most recently from 1997 to 2007 (Kelsey et al. 2011) (Table D42). The Murray contributes the greatest loads of nitrogen followed closely by the Harvey, with the Serpentine the least (Table D42). In contrast, the Harvey contributes the most phosphorus, followed by the Serpentine with about half as much, with the Murray contributing only an eighth.

Table D42: Nitrogen and phosphorous average and median annual loads to the Peel-Harvey Estuary (1997-2007) compared with previous condition report period (1990-2004) and Environmental Protection Policy targets (EPA, 1992) (phosphorous only).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nitrogen (tonnes)</td>
<td>Phosphorus (tonnes)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>Median</td>
<td>Median</td>
</tr>
<tr>
<td>Serpentine</td>
<td>245</td>
<td>245</td>
<td>69</td>
</tr>
<tr>
<td>Murray</td>
<td>402</td>
<td>411</td>
<td>15</td>
</tr>
<tr>
<td>Harvey</td>
<td>376</td>
<td>373</td>
<td>61</td>
</tr>
<tr>
<td>Total</td>
<td>1022</td>
<td>1060</td>
<td>145</td>
</tr>
</tbody>
</table>

Lakes Goegrup and Black

Data has not been collected to determine trends in water quality for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, there is a DoW site directly upstream of Goegrup Lake on the Serpentine River (PHRS6) (Figure D55), which provides the best available information. As this data has not been taken from within the lakes, caution should be applied when drawing conclusions on trends.

Monthly median total nitrogen measurements between 2000 and 2011 indicate that the monitoring site ranges from 2.1 mg/L in winter to 1.5 mg/L in summer. There is an increasing trend in TN, however, the data are not conclusive and as the monitoring site is just north of Goegrup Lake itself, may not be indicative of conditions within the lake (Figure D92).
Figure D92: Goegrup Lake total nitrogen (mg/L) recorded between 2000 and 2011.

Nutrient data (Figure D92, Figure D93) indicates that Goegrup Lake has been moderately eutrophic since at least 2000 with a Total-N concentration generally between 1.0-3.0 mg/L and a Total-P concentration between 0.02-0.5 mg/L. The Australian and New Zealand Guidelines for Estuary Water Quality establish a trigger level of 0.75 mg/L for Total-N and 0.03 for Total-P (ANZECC and ARMCANZ 2000). The latest readings from 2011 (DoW) are between a minimum of 1.5 mg/L Total-N and a maximum of 2.6 mg/L Total-N and a minimum of 0.08 mg/L for Total-P and a maximum of 0.24 for Total-P.
**Figure D93**: Goegrup Lake total phosphorus (mg/L) recorded between 2000 and 2011.

**Yalgorup Lakes**

Nutrient concentrations have not been regularly monitored in the Yalgorup Lakes and the most recent available data was collected from Lake Clifton between 2005-2006 (John et al. 2009). Aggregated nutrient data (Figure D94) indicates that the lake has been mildly eutrophic since at least the 1970’s with a total nitrogen concentration generally between 1.5-3 mg/L and a total phosphorus concentration between 0.01-0.23 mg/L. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality establish a trigger level of 1.5 mg/L for TN and 0.06 for TP (ANZECC and ARMCANZ 2000). The latest readings from 2006 (John et al. 2009, Smith et al. 2010) are between 2-4 mg/L for TN and 0.13 mg/L for TP, suggesting there is a trend towards increasing nutrient concentrations. However, there are few reported incidences of algal blooms (pers. comm. Whitehead 2015).

The lack of surface water outflow channels results in particulate and dissolved constituents in groundwater and rainfall being retained in the wetlands and becoming concentrated over time. The only source of flushing would be through loss of groundwater to the ocean. The nutrient concentration is not considered the significant threat that salinity currently is. However, a dedicated water monitoring program is necessary in order to manage the threat.

![TP Concentration for Lake Clifton (mg/L) 1979-2006](image)

![TN Concentration for Lake Clifton (mg/L) 1979-2006](image)

**Figure D94**: (a,b): Total nitrogen (a) Total phosphorus (b) concentrations in Lake Clifton (1979-2006) compared to ANZECC guidelines from various sources: 1979 – Moore et al.1987; 1991-92 – Rosen et al.; 2006 – John et al. 2009, Smith et al. 2010).
Lakes McLarty and Mealup

There is insufficient data to confirm water quality changes in Lake McLarty since the time of listing. However, the increased landuse intensity may contribute to increased nutrients entering the wetlands and the lack of surface outflow or flushing leads to nutrients, particularly phosphorus building up in lake sediments, causing the highly eutrophic conditions that have been measured. Concentrations of nitrate-N and phosphate-P ranged from 0.1–5 mg/L and 0.1–2 mg/L respectively (Figure D95 Department of Parks and Wildlife 2015). The maximum concentrations of NO$_3$-N are greater than one magnitude above the ANZECC guidelines for moderately disturbed wetlands, while the maximum PO$_4$-P concentration is almost twice the magnitude of the ANZECC guidelines. These concentrations coincide with low lake levels and indicate the significant concentration of nutrients that can occur as lake levels drop.

![Nitrate-N (NO3-N) and Orthophosphate (PO4-P) for Lake McLarty 2008-2013](image)

**Figure D95**: Nitrate-N and Orthophosphate-P concentrations in Lake McLarty (2008-2014-Department of Parks and Wildlife unpublished 2015).

Nutrient concentrations in Lake Mealup have been significantly elevated since listing under the Ramsar Convention and in 2009, the total nitrogen concentration was 27 times above the ANZECC guidelines for moderately disturbed wetlands, while the total phosphorus was seven times the ANZECC guidelines (Figure D96).

Construction of the weir on the Mealup Drain in 2011 and diversion of drainage water into Lake Mealup in June 2012, led to a rapid improvement in the concentration of nitrogen in the water column (Figure D97). The improvement was largely the result of the immediate increase in water volume in the lake and a dilution of the nitrogen load. The total nitrogen concentration in Lake Mealup is now between 3.5-6 mg/L TN, still eutrophic and above the ANZECC guidelines, but it has potential to drop further as denitrification processes occur. However, the Mealup Main Drain comes from a catchment that includes agricultural and horticultural industries and will continue to introduce water that contains variable water quality (Figure D96). Further management of nutrients is likely to be required for the Lake Mealup system. This is particularly the case for phosphorus, which has actually increased in...
concentration in Lake Mealup since the construction of the weir and diversion of water from the Mealup Drain into the lake (Figure D96). The elevated concentration of total phosphorus in Lake Mealup is now regularly between 0.15-0.25 mg/L or between two to four times the ANZECC guidelines for moderately disturbed wetlands. This level is still generally lower than the concentrations recorded in Mealup Main Drain (Figure D97), indicating that the lake loads may still increase in the future, unless management intervention removes the P loading from the drain.

Figure D96: (a, b): Total nitrogen Total phosphorus concentrations in Lake Mealup (2009-2014) compared to ANZECC guidelines (Parks and Wildlife unpublished 2015).
3.2.4 Acid Sulfate Soils

**Peel-Harvey Estuary**

Following on from work in the Peel Inlet on issues of acid sulfate soil development (Sullivan *et al.* 2006), Morgan *et al.* (2012a) and Kraal *et al.* (2013a) showed that the sediments were highly reducing, organic- and sulphide-rich (Figure D98). Surprisingly, the less stable iron monosulfide (FeS) was present in high concentrations (>300 μmol/g) (Kraal *et al.* 2013a). This form of iron compound is usually rapidly replaced by the more stable pyrite (FeS₂), especially below the surficial sediment layer and as described previously, both of these compounds are important as sinks for trace metals including those that are toxic to biota. Therefore accumulation of these forms of iron compounds is of great significance in shallow coastal systems because these sediments are easily disturbed. Disturbance can lead to oxidation of FeS which can result in deoxygenation of adjacent waters, acidification and release of these metals (Morgan *et al.* 2012b).

Figure D97: (a, b): Total nitrogen (2009-2013) and total phosphorus (2003-2013) concentrations in Mealup Main Drain (2003-2013) compared to ANZECC guidelines (Parks and Wildlife unpublished 2015).
However, contrary to previous work on iron sulphide sediments, recent work in the Peel-Harvey suggests that rare earth elements are bound to organic compounds in the sediments rather than directly to the FeS (Morgan et al. 2012a). This complements suggestions that the source of these iron sulphide sediments is not from acidic drainage from disturbed acid sulfate soils but from organic matter present in the estuary (Sullivan et al. 2006).

In the previous Ecological Character Description, work by Sullivan et al. (2006) had raised concerns about high concentrations of selenium (up to 5.4 mg/kg) in the sediments of the Peel-Harvey which, at these levels, could adversely affect biota. However the method used for this analysis was not standardised for salt water analysis as is appropriate in the Peel-Harvey Estuary but for freshwater where most acid sulfate soil work occurs in eastern Australia. When selenium, among other metals was surveyed again in 2007/08 using the appropriate method, concentrations of the total metal in sediments (0.4-1.4 mg/kg) were well below the previous values and more importantly the biologically available component was below detection limits (Kilminster 2010).

### 3.2.5 Phytoplankton

**Peel-Harvey Estuary**

The abundance of phytoplankton and their distribution through the estuary has been interpolated over the period October 1999 to April 2012 (Figure D99). In general, the estuarine portions of the rivers have more frequent and greater concentrations of phytoplankton cells than the basins of the Peel Inlet.
and Harvey Estuary. Of the two rivers, the Serpentine shows more frequent blooms of phytoplankton (cyanophytes, diatoms and dinoflagellates) with extreme algal growth (> $1 \times 10^6$ cells/mL, i.e. one million cells per mL, mostly cyanophytes) in most years since 2007. In contrast the Murray, which had extreme numbers from 2000 to late 2004 (mostly dinoflagellates and diatoms) in the upper most sites of the river, appears to have mostly stabilised at lower numbers since 2005 (< $1 \times 10^5$ cells/mL).

Of the basins, the Harvey has more frequent blooms of phytoplankton than the Peel, with both consistently growing less than < $1 \times 10^5$ cells/mL like the Murray in more recent years.

Figure D99 : Spatial and temporal distribution of phytoplankton cell numbers from the inner mouth of the Dawesville Channel through the Peel Inlet, Harvey Estuary and the estuarine portions of the Serpentine and Murray Rivers (2000-2012).

*Note the interpolation method used in these figures has not yet been optimised for this data, but still provides a reasonable fit.*

The concentration of chlorophyll $a$ (collected since 2007) follows the same trends as total phytoplankton cell numbers across the systems. The Serpentine River has the highest chlorophyll $a$ concentrations, sampled through the water column, followed by the Murray River, Harvey Estuary and the Peel Inlet (Figure D100). The estuarine portions of the Serpentine and Murray exceed the
guideline of 0.003 mg/L chlorophyll $a$ for estuaries in south-west Australia (ANZECC 2000) except in winter/early spring. The Peel and Harvey show chlorophyll $a$ levels below the guideline all year long.

Large peaks in median chlorophyll $a$ occur in summer and autumn in the rivers compared with much smaller ones in the Peel and Harvey (Figure D100). In fact chlorophyll $a$ levels in the Peel and Harvey are as high or higher in winter than is summer and autumn.

![Monthly median chlorophyll $a$](image)

**Figure D100**: Monthly variation in median chlorophyll $a$ (mg/L) sampled through the water column of the Peel Inlet, Harvey Estuary and the estuarine portions of the Serpentine and Murray Rivers (2007-2011).

**Lakes McLarty and Mealup**

Chlorophyll $a$ concentrations, sampled through the water columns of Lake Mealup over the period February 1993-June 2014 (Figure D101), indicate that in general, the wetland has not been supporting dense algal blooms. This may have been the result of the tannin content reducing available light through the water column, although this was reported as being reduced as the acidity rose during low lake levels prior to the construction of the weir on Mealup Main Drain (Department of Parks and Wildlife unpublished 2015). The three sampling occasions which indicated that the ANZECC guideline value of 0.03 mg/L for chlorophyll $a$ had been exceeded for moderately disturbed wetlands in south-west Australia (ANZECC, 2000) occurred in late spring and summer, reflecting optimum periods of concentration of nutrients and warm water temperatures. Conditions that support rapid algal proliferation will continue to be dually determined by the water quality within the main source of water for Lake Mealup, the Mealup Main Drain (Figure D97), particularly the phosphorus content, but also the acidity of the water within Lake Mealup itself and the release of tannins from the sediment. The significant peak in chlorophyll $a$ in March 2013 of 0.1 mg/L (Figure D101), reflects the need to consider future management of phosphorus loads being introduced through the Mealup Main Drain. However, no further elevations in chlorophyll $a$ were detected within the lake over the following year and levels remained near undetectable which may also reflect the observation that tannin levels have returned to near normal.
The single measurement of chlorophyll $a$ in October 2014 from Lake McLarty (Figure D101), indicates that algal growth was within acceptable limits at that time and that monitoring of water quality should continue on a similar schedule as Lake Mealup to manage lake conditions in the future, particularly as climate change has the potential to continue to reduce freshwater recharge to the system.

Figure D101 : Chlorophyll $a$ (mg/L) sampled through the water column of Lake Mealup (1993-2014) and a single reading from Lake McLarty in October 2014 (Department of Parks & Wildlife unpublished data 2015).

3.2.6 Benthic plants

**Peel-Harvey Estuary**

The last macroalgae and seagrass survey was conducted in Nov/Dec 2009, 10 years after the previous survey and 15 years since the Dawesville Channel was opened (Pedretti et al. 2011). The purpose of the survey was to detect significant long term changes in abundance, distribution and diversity since the opening in 1994.

Pedretti et al. (2011) wrote “Sampling was carried out in November/December of 2009 at 45 sites in the Peel-Harvey Estuary. Cores of seagrass and macroalgae were collected by snorkel divers in the field and then sorted into species categories in the laboratory. Biomass estimates were calculated and results were entered into the computer program (ArcMap), to produce contour maps of seagrass and macroalgae abundance and distribution. Additionally, where biomass was collected in sufficient quantities, the tissue was analysed for nitrogen and phosphorus concentrations.”

“Comparisons made in this document between the historical and current data need to be viewed with caution as different methods were applied to determine GIS interpolated information.”

“The total macroalgal biomass in the Peel-Harvey Estuary was 8,442 tonnes with the Peel Inlet comprising 59% and the Harvey Estuary 41%. The highest concentrations of macroalgal biomass (230 g/m$^2$) for the Peel Inlet were located in the south-eastern regions above Austin Bay. Lower biomass extended from the east into the central basin and along the western region. In the Harvey Estuary the highest macroalgal biomass (230 g/m2) was recorded at sites in the southern area, with
smaller amounts extending north as far as Mealup Point. The dominant macroalgal group for the Peel-Harvey Estuary was Chlorophyta with 7,046 tonnes of biomass, being an order of magnitude higher than the next major macroalgal group, Rhodophyta, with 1,098 tonnes. Biomass distribution in the Peel Inlet was slightly higher than the Harvey Estuary for Chlorophyta, while Rhodophyta biomass was divided relatively evenly between the two systems. The total biomass for Phaeophyta (252 tonnes) was almost exclusively contained within the Peel Inlet (211 tonnes), whereas Charophyte was entirely restricted to the Peel Inlet.”

“Chaetomorpha linum was the dominant macroalgae and seagrass species within the Peel-Harvey Estuary resulting in 3,535 tonnes of biomass for the Peel Inlet and 1,366 tonnes in the Harvey Estuary. The species with the next highest biomass for the Peel-Harvey Estuary was Ulva spp., where the Harvey Estuary (718 tonnes) biomass was much greater in comparison to that of the Peel Inlet (460 tonnes). The other main species with high biomass in the Peel Inlet were Spirodicta filamentosa (195 tonnes) and Caulerpa spp. (185 tonnes). The Harvey Estuary also had comparably high biomass of Ulva spp., Cladophora montagneana (608 tonnes) and S. filamentosa (501 tonnes). The majority of other species recorded less than 50 tonnes of biomass for either the Peel Inlet or the Harvey Estuary.”

“The total seagrass biomass in the Peel-Harvey Estuary was 3718 tonnes, comprising 68% in the Peel Inlet and 32% in the Harvey Estuary. When considering seagrass biomass as part of the total macroalgae and seagrass biomass for the Peel-Harvey Estuary, the seagrass in Peel Inlet constituted 21% and in the Harvey Estuary 10%. The highest seagrass biomass was located on the eastern shoreline of the Harvey Estuary north of Mealup Point and in the Peel Inlet near Ward Point. The dominant species for the Peel-Harvey Estuary was Zostera spp. (1772 tonnes), followed by Ruppia sp. (1295 tonnes), with Halophila spp. having the lowest biomass (644 tonnes). Ruppia sp. provided the greatest biomass (1295 tonnes) in the Peel Inlet and was mainly located in the eastern and southern regions with dense concentrations around Stony Point, Ward Point and Robert Bay. Zostera spp. biomass was greatest in the Harvey Estuary (910 tonnes) and was only marginally lower for the Peel Inlet (862 tonnes). The majority of Zostera spp. biomass was located around site 27 just north of Mealup Point in the Harvey Estuary. The area covered by Halophila spp. was much more extensive than the other two species of seagrass even though the volume of biomass was significantly lower. The majority of Halophila spp. biomass was located in the central basin, eastern and south-western regions in the Peel Inlet and at a site near Point Mortiff in the north-west of Harvey Estuary.”

“The greatest changes in biomass and distribution were observed in the Harvey Estuary, where a 90% increase occurred for both macroalgae and seagrasses compared to post Channel years. This has elevated the quantity of biomass in the Harvey Estuary to within the same range as that of the Peel Inlet. Seagrass beds are now present mainly in the areas closest to the Dawesville Channel, where flushing of ocean water reduces nutrients, increases light, and salinity remains constantly marine. The greatest quantities of macroalgal biomass continue to be located near river flows and appear to be highly influenced by increased nutrients, reduced light availability and fluctuating salinities.
The predicted long term increase in diversity for macroalgae taxa was validated, although one species of macroalgae, *Chaetomorpha linum*, continues to dominate biomass in both the Peel Inlet and Harvey Estuary (Figure D102). Further surveys that incorporate seasonal, physical and chemical data are required in order to confirm long term changes in system dynamics.

*Figure D102: Photograph left: Zostera sp. near the Dawesville channel with Chaetomorpha linum surrounding. Photograph right: Chaetomorpha linum in Austin Bay, south-eastern Peel Inlet. Images Pedretti et al. (2011).*

The increase in biomass of macroalgae in the Harvey River may indicate that it is replacing *Nodularia* as a symptom of eutrophication.

**Yalgorup Lakes**

Within the littoral margins of Lake Clifton is a community of thrombolites, that formed by biologically influenced precipitation of a particular form of calcium carbonate, termed aragonite in a Coastal Brackish Lake (Moore and Burne 1994). The thrombolite community, which is the largest in the Southern Hemisphere (CALM 1995) is situated in a zone about 15m wide on the eastern side of the lake, occupying a total area of over 4km² (Moore 1991, Luu et al. 2004). Only a small isolated colony has been observed on the western shoreline at the northern end of the lake (Moore et al. 1984). The thrombolites exhibit a wide range of external morphologies including conical, domical, discoidal and tabular forms (Moore 1991), which vary in width, height and morphology, with the largest up to 1.3m high, and diameters ranging between 20 and 150 cm (Figure D103).
The salinity in Lake Clifton seldom exceeded that of seawater in the early 1980s when the microbialites were discovered, described and investigated for the first time (Moore 1987). John et al (2009) hypothesized that salinity less than that of seawater and interaction between fresh groundwater and microbial communities were essential for the continued growth and conservation of microbialites. John et al (2009) considered salinity readings from Lake Clifton over a 25 year period, noting a change in that period from 19 to 80 ppt. John et al (2009) also noted that there has been massive break-up of the benthic microbial mats in 2002 and 2007 from the bottom of the lake, discolouring and adding nutrients into the lake. Massive fish death was also associated with the break-up of the algal mats in 2007. Similar salinity data is shown from Lake Clifton in Figure D68 (Lane et al. 2013). John et al (2009) concluded that prolonged declines in rainfall, and increased nutrient enrichment from a rapidly developing catchment area and a lack of outlet and flushing of the system seemed to be responsible for the degradation of the ecosystem, posing serious threats to the conservation of the thrombolites.

However, Knott et al. (2003) compared salt loads and rainfall, and noted that if rainfall was the only driving factor in determining the lakes salinity, then increased rainfall in the late 1990s and the subsequent water level rise should have returned the salinity to lower levels that were observed in the 1980s. As a result, Knott et al. (2003), attributed rising salinity to an increase in the amount of brackish water inflowing to the lake system in comparison to fresh ground water, rather than rainfall. This is an important potentially threatening process as catchment activities (irrigated horticulture etc.) are likely to be increasing groundwater salinity. This will obviously be increasing the salt load via groundwater inflow and when combined with declining rainfall levels could result in the observed salinity increase in Lake Clifton.
Forbes and Vogwill (2008) suggest that decreased freshwater recharge into Lake Clifton has decreased hydrostatic pressure over the lake, facilitating a larger recharge from deeper hypersaline aquifer water (Figure D104). The most recent water quality monitoring by Whitehead (unpublished 2015), confirmed that salinity in the system is still increasing and it is this trend that is considered the critical threat to the thrombolite formation process of Lake Clifton (Figure D69).

Recent research has shown that the thrombolytic community at Lake Clifton remain actively growing, although growth is only seasonal and subject to the collective action of a number of biogeochemical processes occurring simultaneously (unpublished work Whitehead and Vogwill, 2015). The inflow of fresh groundwater which brings calcium and bicarbonate is still inflowing, however, data on depth to groundwater indicates that the recharge of freshwater may be decreasing. It is thought that if freshwater seepages around the periphery of the lakes can be maintained it is possible that the microbial communities will continue to thrive despite lake water conditions (Forbes and Vogwill 2008).

Moore (1991) noted that the eutrophication of the system may also be detrimental to the thrombolites, as they do not require significant nutrient inputs. However it is now understood that the microbial communities adapt composition to suit the conditions that exist in the system and are quite resilient to nutrient fluctuation it should be noted however that high nutrient inputs could result in a change to the species composition of the microbial mats favouring species that contribute less to the microbialite formation process (unpublished data Whitehead and Vogwill, 2015).

Blooms of the green alga Cladophora have been noted around the Thrombolites and growing on them as a result of nutrient enrichment of waters entering the Lake Clifton (Moore 1991). This threat was recognised in early 1991 when the EPA provided guidance on the proposed irrigated horticulture industry on the east side of Lake Clifton (EPA 1991), but little reporting is available on the ongoing contribution of this landuse to the nutrient loads entering the system. The Cladophora effectively competes for light with the microbes forming the thrombolites. It can lead to decreased light penetration that reduces or prevents photosynthesis of the thrombolite forming benthic microbial community, and has the potential to prevent thrombolite formation and growth. Bream in the lake have been observed to graze on the Cladophora (pers. Comm. PHCC), but the interaction it is not fully understood.
understood, or exactly what impact the Cladophora or bream are having on the health of the Thrombolites.

3.2.7 Littoral vegetation

*Peel-Harvey Estuary*

A noticeable change in the fringing and peripheral wetlands of the Peel-Harvey since construction of the Dawesville Channel has been the establishment of waterside urban development. Along with establishment of this development have been subsequent changes to fringing wetlands traditionally found bordering the estuarine system. The wetlands fringing the Peel-Harvey are an important component to the ecological functioning of the estuarine system. Fringing wetlands act as filters to the estuary, as often both groundwater and surface runoff pass through these water bodies prior to entering the estuary. Much of the sediment and nutrient load that could potentially enter the estuarine system is assimilated during residence time in the fringing wetlands, thus improving the quality of waters entering the estuary. In turn, nutrients added to fringing wetlands are utilised within these systems and passed on as increased productivity to the estuarine system rather than as nutrients, and provide a resource for waterbirds that are an important feature of the Peel-Harvey region. Despite the critical part fringing wetlands play in the ecological functioning of the Peel-Harvey, a clear understanding of the qualitative or quantitative impacts of urban development around the periphery of the system on fringing wetland habitats and their function is not known.

Since the opening of the Dawesville Channel in 1994, a deterioration in tree health in the lower reaches of the Harvey River has been observed, most markedly in the paperbark *Melaleuca*, and a decrease in the number of fringing trees and shrubs on the western side of the Harvey Estuary has been recorded (*Figure D105*). It is suggested that the decline in tree health in the lower reaches of the Harvey River is the result of increased salinities in these waters. Vegetation losses on the western side of the Harvey Estuary are considered to be the result of changes to tidal regimes in this part of the waterway; these findings are consistent with results of shore erosion studies.
Figure D105: Fringing vegetation deaths Island Point, Harvey Estuary. Image F. D’Souza, DoW (February 2014).

**Yalgorup Lakes**

There is no information to assess the condition of littoral vegetation within the Yalgorup Lakes.

**Lakes McLarty and Mealup**

The large infestations of *Typha orientalis* which threatened the ecological function of Lake Mealup and McLarty Nature Reserves have been successfully managed by slashing and chemical control and in the case of Lake Mealup, by construction of a weir on the Mealup Main Drain in 2011 (Lake Mealup Recovery Team report – unpublished). The use of the weir to restore a near natural water regime for the lake is a key management tool to control the infestation of Typha and the serious acidification and eutrophication of the lake.

**Lakes Goegrup and Black**

There is no information to assess the condition of vegetation since the vegetation condition survey of Ecoscapes 2006 shown in Table D43.
### Table D43: Extent of bushland by condition (Goegrup and Black Lakes Action Plan – Ecoscape 2006).

<table>
<thead>
<tr>
<th>Condition Rating</th>
<th>Criteria</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good -</td>
<td>• 80-100% native flora composition</td>
<td>296.9</td>
</tr>
<tr>
<td>Excellent</td>
<td>• Vegetation structure intact or nearly so</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cover/abundance of weeds less than 5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Minor signs of disturbance</td>
<td></td>
</tr>
<tr>
<td>Fair - Good</td>
<td>• 50-80% native flora composition</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>• Vegetation structure modified or nearly so</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cover/abundance of weeds 5-20%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Disturbance influence moderate</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>• 20-50% Native Flora composition</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>• Vegetation structure completely modified</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cover/abundance of weeds 20-60%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Disturbance incidence moderate</td>
<td></td>
</tr>
<tr>
<td>Very Poor</td>
<td>• 0 – 20% Native Flora composition</td>
<td>24.2</td>
</tr>
<tr>
<td></td>
<td>• Vegetation structure disappeared</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Cover/abundance of weeds 60-100%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Disturbance incidence very high</td>
<td></td>
</tr>
<tr>
<td>Not assessed</td>
<td>Recent fire</td>
<td>24.9</td>
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<tr>
<td></td>
<td>Waterbody</td>
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<td></td>
<td>Freehold land not accessed</td>
<td>40.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>774</strong></td>
</tr>
</tbody>
</table>

### 3.2.8 Invertebrates

**Peel-Harvey Estuary**

Sixty-three species of macroinvertebrates were recorded in 2003/04. This was more than twice the 28 recorded by Rose (1994) in 1986/87. While *Capitella* spp and *Corophium minor* were the most abundant species in both periods, contributing 60% and 55% to the total number of individuals in those periods (Wildsmith *et al.* 2009).

Nine phyla were represented in the samples from 2003/04 (Cnidaria, Sipuncula, Annelida, Platyhelminthes, Nemertea, Nematoda, Arthropoda, Mollusca and Echinodermata). The Sipuncula, Nematoda and Echinodermata were not recorded in 1986/87. The Polychaeta and Crustacea contributed 28% and 43% respectively in 1986/87, and 46% and 28% of species respectively in 2003/2004 (Wildsmith *et al.* 2009).

There has been an overall reduction in the density of benthic macroinvertebrates between 1986/87 and 2003/04 reflecting a decline in the amount of cover and/or productivity and thus food that would have resulted from the very substantial reductions in macroalgae (Wildsmith *et al.* 2009). The new species in 2003/04 were typically marine.
Data presented in Wildsmith et al. (2009) indicate that the benthic environment of the Peel-Harvey Estuary has deteriorated since the construction of the Dawesville Channel. This is illustrated by the presence of Polychaeta which is the least sensitive taxa to environmental stress (Reise 1982, Warwick and Clarke 1993), whereas the Mollusca and more particularly the Crustacea are more sensitive to such stress. The change in proportions of these taxa, strongly indicates that the quality of the benthic environment has declined. (Wildsmith et al. 2009)

Of the invertebrates present in the Peel-Harvey, Blue Swimmer Crabs continue to be caught commercially and recreationally in the Peel-Harvey Estuary.

**Commercial crab fishery**

The commercial crab fishery in the Peel-Harvey Estuary is worth approximately $1 million (Fletcher and Santoro, 2014). Over the last decade stock abundance has remained relatively constant as determined by comparing current and historical commercial and fishery-independent datasets (Johnston et al., 2014). This is in part due to the spawning stock being naturally protected when they exit the estuary over winter to spawn in oceanic waters. Consequently the current levels of fishing in the Peel-Harvey Estuary appear to be sustainable (Johnston et al. 2014). The trap catch between 2002/03 and 2010/11 has fluctuated between 45 and 104 t and catch rates (catch per unit effort) have fluctuated between 0.8 and 1.5 kg/trap lift, but since 2003/04 have generally remained above the Limit of Acceptable Change of a median of 1.0 kg/trap (Figure D106).

![Annual nominal catch rates for blue swimmer crab](image)

*Figure D106 : Annual nominal catch rate for Blue Swimmer Crab commercial fishery in the Peel-Harvey Estuary from 1995 to 2013 (adapted from Fletcher and Santoro 2014).*

**Recreational crab fishery**

The Peel-Harvey Estuary is a popular location for recreational fishing, and within the estuary, the Blue Swimmer Crab (*Portunus pelagicus*) is the most common species targeted by recreational fishing.
From November 2007, the recreational bag limits in the West Coast bioregion were reduced to 10 crabs per person, and 20 crabs per boat (Johnston et al. 2014).

The total recreational catch and effort in the Peel-Harvey Estuary, which covered fishing from boats, shore, canals, and houseboats was estimated from November 2007 to October 2008 to be between 107-193t (Johnston et al. 2014). This was lower than a similar catch estimated of 251-377t for the same region undertaken in 1998/99 (Malseed and Sumner 2001).

A survey during 2007/08 estimated that the recreational take accounted for approximately 60% of the total catch. Thus trends in the recreational fishery can affect the stock status. (Fletcher and Santoro, 2013, Johnston et al. 2014).

**Commercial and recreational prawn fishery**

The biggest change in the estuarine fishery since the cut has been the decline in the catches of the Western King Prawn (*Penaeus latisulcatus*). It was caught commercially up until July 2014 in Comet Bay just outside of the Mandurah Channel where the prawns would migrate out of the estuary. The Department of Fisheries bought back the last three licenses mid-2014 for several reasons. These included a drop in numbers of prawns exiting the estuary from the Mandurah Channel once the Dawesville Cut was created and therefore the fishery no longer being economically viable; and public concern about trawlers and crab traps in the same area (Errol Sporer, Department of Fisheries, pers. comm.). Catches varied from 4 to 14 t between 04/05 and 2013/14, with an average of 9.2 t. There have not been any reports on recreational catches of prawns between 04/05 and 2013/14.

**Mosquitos**

As described earlier, the vectors of Ross River Virus are *Aedes camptorhynchus* and *Aedes vigilax*. A recent study (Jardine et al, 2015) has shown that residents living within 1 km of a mosquito breeding habitat had a significantly higher rate of the disease compared to the background rate across the Peel Region in all individual years investigated. In addition the researchers examined cumulative data over the 10-year study period which showed that residents in the 1- and 2-km buffers had a significantly higher rate, whereas those living between 3 and 6 km away did not. This study demonstrates an increased mosquito-borne disease risk associated with living in close proximity to a mosquito breeding habitat in a rapidly expanding region of WA and highlights the importance of considering mosquito-borne disease risks when planning authorities assess new residential development applications.

**Introduced pest invertebrates**

There has been a sighting of the Asian paddle crab (*Charybdis japonica*) in Mandurah in 2010 and other sightings in the Swan River (Department of Fisheries, 2015). The crab is an aggressive non-native crab that could spread disease to prawns, crabs and lobsters. It can also carry a disease that causes poisoning in humans, and could out-compete native crabs like the blue swimmer. The freshwater yabbie *Cherax destructor* has also been discovered in Logue Brook, a tributary of the Harvey River (Beatty and Morgan, 2008) and the Serpentine River catchment (Klunzinger et al, 2011). In the same report by Klunzinger et al (2011) an introduced species of crustacean which is an ecto-parasite, the anchor worm *Lernaea cyprinacea* (Marina et al, 2008), is also described in the Serpentine River. It has been found attached to the marine/estuarine cobbler as well as other freshwater native species.
3.2.9 Fish

**Peel-Harvey Estuary**

The last Ecological Character Description of Hale and Butcher (2007) compared the fish fauna of the nearshore shallow waters of the Peel-Harvey Estuary from studies before the Dawesville Cut in 1980-81 (Loneragan et al, 1986) and after the cut in 1996-97 (Young and Potter, 2003). Further studies of these shallows were conducted in 2008-10 by Veale (2013) and the following provides a comparison of all three periods as analysed and interpreted by Veale (2013). Methods such as size and type of net and location of sampling sites were the same in each of the three studies making the comparison robust.

Of note, is that eight of the ten most abundant species of fish caught in 1980-81 were also in the top ten for 1996-97 and 2008-10 (Veale, 2013). However the relative contributions of these species to the total catch varied between periods as did their density. The number of species of fish recorded in 2008-10 was 56 (155 samples); in 1996-97 was 47 (120 samples) and in 1980-81 was 39 (62 samples).

Veale (2013) concluded that two key factors influence the observed changes in fish fauna over the three periods 1) salinity as described in Water quality above and 2) habitat as described in benthic plants above. The salinity has changed from being more estuarine (1980-81) to more marine (1996-97) as the cut has allowed greater tidal exchange across the basins and upstream into the rivers. The salinity has then further increased (2008-10) because of the declining rainfall and flow that continues to occur. The biomass of benthic plants has changed from extremely high macroalgae and little seagrass (1980-81) to low of both (1996-1997) and more recently (2008-10).back to high macroalgae but also increasing seagrass.

Although salinity would appear to be the most obvious change in the Peel-Harvey Estuary, habitat and/or food in the form of macroalgae/seagrass seems to have had the most influence on the fish fauna. In 1980-81 the fish catches were dominated by the macroalgae and seagrass-associated species Western Striped Grunter *Pelates octolineatus* (36.6% of the total catch) and the Western Gobbleguts *Ostorhinchus rueppellii* (14.3%). This dominance continued into 2008-10 and both periods exceeded the density and catch contribution of these two species that occurred in 1996-97 when biomass of macroalgae and seagrass was low. Further evidence of the importance of habitat/food is shown by the trend in the densities of three species (*Gymnaplastes marmorus, Haletta semifasciata* and *Sillaginodes punctatus*) also associated with seagrass, being greater in 2008-10 than in either of the earlier periods. The increase in these seagrass-associated species is probably partly due to the higher biomass of seagrass in this most recent period.

Salinity changes were reflected in the composition and abundance of fish fauna over the three periods as illustrated by three marine species *Hyperlophus vittatus, Torquigener pleurogramma* and *Leptatherina presbyteroides*. These three species are typically found in salinities approximating full strength seawater and thus were in greater abundance in 1996-97 and 2008-10 after the Dawesville Cut. The cut would have provided a large new route for immigration of these fish as well as maintained more marine salinities for longer periods of time.

The lamprey *Geotria australis* continues to be sighted both in the Peel Inlet (David Morgan, pers. comm.) where it migrates out to the sea for its adult life and in the Serpentine River (Klunzinger et al, 2011) where it travels upstream to breed.
**Commercial finfish fishery**

Sea mullet, yellow-eye mullet, yellow-fin whiting, Australian Herring, tailor, cobbler, King George Whiting, and Perth herring are eight of the 28 species reported in commercial fishery landings from 1999-2013 in the Peel-Harvey Estuary. There are 11 licensed fishers in the estuary, with all of them active in 2013. Total catch value (wholesale) is currently between $2 and $3 million per year.

The long term stability of the trend in the standardised catch per unit effort of two key species in the Peel-Harvey estuarine fin fishery — cobbler and Sea Mullet, suggests stock abundance is stable (Figure D107). There are no concerns about stock status for either species (Fletcher and Santoro 2014). Cobbler catch rates have improved since the last Ecological Character Description (Hale and Butcher, 2007), while Sea Mullet has continued to fluctuate at similar levels over the last ten years.

![Annual standardised catch rates for cobbler and sea mullet](chart)

**Figure D107 : Annual standardised catch rates for commercial fisheries of cobbler and Sea Mullet in the Peel-Harvey Estuary from 1995 to 2013.**

**Introduced species of fish**

As described in the previous Ecological Character Description (Hale and Butcher, 2007), there is no data on introduced species within the Peel-Harvey Estuary. However work on pest species has continued in the catchment. Species discovered, other than those described in Section 2.2.9 Fish, are the One-spot livebearer *Phalloceros caudimaculatus* (Morgan and Beatty, 2008).

**Fish kill events**

As described previously, water quality has deteriorated in the estuarine reaches of the Murray and Serpentine Rivers since construction of the Dawesville Channel. Consequently fish kill events are a feature of these systems. Fish kill events are most likely caused by low dissolved oxygen due to...
stratification and/or algal blooms, but they can also result from gills clogged by suspended matter (phytoplankton or sediment), toxic phytoplankton species or toxic gases from anoxic sediments.

The most number of fish kill events in the period 1999-2012 occurred in the Murray River (16), followed by the Serpentine (11) and then Peel Inlet (2) (Figure D108). No fish kill events have been noted in the Harvey Estuary during this period.

![Total number of fish kill events in each system (1999–2012)](image)

*Figure D108 : Number of fish kills events in the Peel Inlet, Harvey Estuary and the estuarine portions of the Serpentine and Murray Rivers (1999-2012).*

The annual frequency of fish kill events reported in the system has reduced since the mid-2000, however there is still at least one event per year (Figure D109).

The total number of fish killed in each event have declined from peaks recorded between 2002-2005 (Figure D110).
Figure D109: Annual frequency of fish kill events in the Peel Inlet, Harvey Estuary and the estuarine portions of the Serpentine and Murray Rivers (1999-2012).

Figure D110: Total number of fish killed per event in the Peel-Harvey Estuary and estuarine reaches of the Serpentine and Murray Rivers (1999-2012)
The monthly frequency of fish kill events shows that most occur during summer and autumn (Figure D111).

![Monthly frequency of fish kill events](image)

**Monthly frequency of fish kill events (1999–2012)**

Declining numbers of fish killed per event does not appear to be related to declining numbers of fish as catch rate data of most commercial species suggests that fish numbers are stable.

### 3.2.10 Marine mammals

**Peel-Harvey Estuary**

Bottlenose Dolphins (*Tursiops aduncus*) have been a long term feature of the Peel-Harvey Estuary. However, there have been no recent official publications of data that report on numbers or the health of the populations. The main recorded evidence of dolphins in the Peel-Harvey is on websites and in brochures for dolphin tours ([http://www.mandurahdolphintours.com.au/](http://www.mandurahdolphintours.com.au/)) and recreational groups such as The Canoe Trail Friends of Mandurah and Pinjarra Inc. ([http://www.visitpeel.com.au/images/documents/dolphintalestrails.pdf](http://www.visitpeel.com.au/images/documents/dolphintalestrails.pdf)).

However, research is currently (2014) being conducted by an honours student from Murdoch University, which includes a photo identification catalogue that will assist in estimating dolphin populations in the estuary and a record of the presence of skin lesions to assess the health of the dolphin population in the Peel-Harvey Estuary ([http://mucru.org/our-research/group-members/james-raeside/](http://mucru.org/our-research/group-members/james-raeside/)). This research is a collaborative effort with Bouvard Cruises Mandurah where the vessels provide sighting opportunities.
3.2.11 Birds

Rigorous long term waterbird monitoring data is not available to provide quantitative analysis in trends of populations in the system and waterbird numbers fluctuate significantly between seasons and are influenced by many variables (PHCC 2011). The BirdLife Australia, Shorebirds 20-20 dataset for the six year period 2008-2013, is collected from a snapshot survey on the same day each year which can only provide indicative trends and is unlikely to accurately estimate maximum bird numbers. The Shorebird 20-20 data does confirm that habitat within the components of the Peel-Yalgorup System remains suitable to support high numbers of waterbirds with numbers across the entire Peel-Yalgorup System Ramsar site being greater than 20,000 for all six years of monitoring 2008-2013 and a maximum count in 2013 of over 90,000 waterbirds (Figure D112).

![Peel Yalgorup Ramsar Site](image)

Figure D112: Total waterbird counts for the entire Peel-Yalgorup System Ramsar site from the BirdLife Australia Shorebird 20-20 counts for 2008-2013 (BirdLife Australia 2014).

The LAC of 20,000 waterbirds in 4 out of 5 years is not met using the data from BirdLife Australia 20-20 counts in any of the four wetland components of the system (Figure D113). However, the counts include one of nearly 60,000 waterbirds in the Peel-Harvey estuaries in 2010 and one of 64,000 in the Yalgorup Lakes in 2013 which raises the average of the Peel-Harvey estuaries to >20,000 waterbirds and close to that figure for the Yalgorup Lakes and it is reasonable to assume that more intensive waterbird monitoring would confirm that these high numbers are supported in these system most years.

Waterbird numbers have been very low in Lake Mealup, almost certainly due to acidification processes following extended periods of drying out and exposure of lake sediments. Recent restoration of near natural hydrological regime and water quality through the redirection of the Mealup Main Drain into Lake Mealup should facilitate a return to expected populations of waterbirds.

It is known that many of the smaller lake systems surrounding the Peel and Harvey estuaries act as refuges during drought conditions inland and it would be expected that the waterbird numbers using the estuaries would also be higher during low rainfall years. Thus waterbirds are not necessarily an
indicator of the health of the estuaries and peripheral lake systems, but rather a reflection of water availability and condition in inland areas of the state and population number.

**Figure D113**: Total waterbird counts for components of the Peel-Yalgorup System Ramsar site from the BirdLife Australia Shorebird 20-20 counts for 2008-2013 (Birdlife Australia 2014).

Using the Shorebird 20-20 waterbird counts, five species had counts that were regularly (at least two-thirds of the surveyed years) greater than the 1% threshold, those being Hooded Plover, Red-necked Stint, Fairy Tern, Black-winged Stilts and Australian Shelduck (Table D44). As detailed previously, these bird counts were not designed to provide maximum bird counts, but rather serve to indicate the continued presence of these species and confirm that the habitat remains able to support these species. The Banded Stilt was recorded above the 1% threshold on three of the six years, while there are three species that were not above the 1% threshold in any of the six surveyed years, these being Australasian Shoveler, Eurasian Coot and Grey Teal and a further two species that were recorded in numbers above the LAC in only one year out of the six surveyed, those being Red-necked Avocet and Musk Duck. These species should be targeted in more intensive waterbird monitoring to confirm their status (Table D44).

The Shorebird 20-20 data for the Fairy Tern (Sternula nereis nereis) has been presented (Figure D114) to demonstrate further, the applicability of recognising the additional criteria #2. A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or Threatened Ecological Communities. The Fairy Tern is listed as Vulnerable under the EPBC Act 199 and was recorded at the Peel-Harvey Estuary in five out of the six years in the BirdLife Australia Shorebird 20-20 survey and in two years at the Yalgorup Lakes (Figure D114).

A review of the bird species currently listed under international migratory agreements indicate that 44 bird species recorded within the Ramsar site are now listed under JAMBA, CAMBA, ROKAMBA and/or the Bonn Convention.
Table D44: Population counts using Shorebird 20-20 data for 2008-2013 for species identified as having >1% of species population.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>1%</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>% years&gt;1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hooded Plover</td>
<td>45</td>
<td>8</td>
<td>102</td>
<td>107</td>
<td>78</td>
<td>57</td>
<td>79</td>
<td>83</td>
</tr>
<tr>
<td>Sharp-tailed Sandpiper</td>
<td>1,600</td>
<td>890</td>
<td>2,507</td>
<td>6,009</td>
<td>28</td>
<td>257</td>
<td>1,583</td>
<td>33</td>
</tr>
<tr>
<td>Red-necked Stint</td>
<td>3,200</td>
<td>1,881</td>
<td>6,191</td>
<td>4,477</td>
<td>4,632</td>
<td>4,511</td>
<td>4,330</td>
<td>83</td>
</tr>
<tr>
<td>Curlew Sandpiper</td>
<td>1,400</td>
<td>2</td>
<td>135</td>
<td>16</td>
<td>1</td>
<td>0</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Banded Stilt</td>
<td>3,700</td>
<td>11,310</td>
<td>0</td>
<td>26,824</td>
<td>3,129</td>
<td>1</td>
<td>39,202</td>
<td>50</td>
</tr>
<tr>
<td>Red-capped Plover</td>
<td>950</td>
<td>545</td>
<td>214</td>
<td>1,675</td>
<td>547</td>
<td>659</td>
<td>1,452</td>
<td>33</td>
</tr>
<tr>
<td>Red-necked Avocet</td>
<td>1,100</td>
<td>250</td>
<td>299</td>
<td>1,984</td>
<td>62</td>
<td>36</td>
<td>316</td>
<td>17</td>
</tr>
<tr>
<td>Fairy Tern</td>
<td>15</td>
<td>7</td>
<td>96</td>
<td>125</td>
<td>192</td>
<td>105</td>
<td>51</td>
<td>67</td>
</tr>
<tr>
<td>Musk Duck</td>
<td>250</td>
<td>0</td>
<td>8</td>
<td>29</td>
<td>16</td>
<td>13</td>
<td>318</td>
<td>17</td>
</tr>
<tr>
<td>Australasian Shoveler</td>
<td>250</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Eurasian Coot</td>
<td>10,000</td>
<td>20</td>
<td>214</td>
<td>13</td>
<td>45</td>
<td>28</td>
<td>109</td>
<td>0</td>
</tr>
<tr>
<td>Grey Teal</td>
<td>20,000</td>
<td>2,705</td>
<td>953</td>
<td>10,020</td>
<td>1,215</td>
<td>1,335</td>
<td>9,403</td>
<td>0</td>
</tr>
<tr>
<td>Australian Shelduck</td>
<td>1,100</td>
<td>3,379</td>
<td>4,168</td>
<td>2,635</td>
<td>1,759</td>
<td>10,876</td>
<td>6,970</td>
<td>100</td>
</tr>
<tr>
<td>Black-Winged Stilts</td>
<td>1,000</td>
<td>909</td>
<td>2,945</td>
<td>3,619</td>
<td>1,844</td>
<td>434</td>
<td>4,325</td>
<td>67</td>
</tr>
</tbody>
</table>
Peel-Harvey Estuary

Banded Stilt

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Banded Stilt in 3 out of 5 years is likely met. Total numbers of Banded Stilt were above the LAC of 3,700 for three of the six years, but in each of those three years the numbers were well above the LAC at 11,290 in 2008, 26,824 in 2010 and 38,567 in 2013. The mean count for the six year period was 5,691 and a standard error of 3,425 indicating the large variability in the population between years. The result is evidence that the LAC is not a good indicator of condition of the system and reflects that Banded Stilt are significant opportunists for breeding events that take place in often remote wetland systems, many years apart. Amending the LAC should be considered pending more intensive monitoring.

Red-necked Stint (3,200)

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Red-necked Stint in 3 out of 5 years is not met. Total numbers of Red-necked Stint were above the LAC of 3,200 for only two of the six years. The mean count for the six year period was 2,486 and a standard error of 740 indicating the large variability in the population between years. There was a downwards trend in numbers of Red-necked Stint counted in the estuaries, but in the same period, there was an equal increasing trend in numbers recorded in the Yalgorup Lakes, suggesting conditions in these lakes are more conducive for this species. Amending the LAC should be considered pending more intensive monitoring.

Red-capped Plover

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Red-capped Plover in 3 out of 5 years is not met. Total numbers of Red-capped Plovers were above the LAC of 950 for only one of the six years. The mean count for the six year period was 335 and a standard error of 170 indicating the large variability in the
population between years. There was a downwards trend in numbers of Red-capped Plover counted in the estuaries after 2010, but in the same period, there was an equal increasing trend in numbers recorded in the Yalgorup Lakes, suggesting conditions in these lakes is more conducive for this species. Amending the LAC should be considered pending more intensive monitoring.

**Red-necked Avocet**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Red-necked Avocet in 3 out of 5 years is not met. Total numbers of Red-necked Avocet were above the LAC of 1,100 for only one of the six years. The mean count for the six year period was 291 and a standard error of 229 indicating the large variability in the population between years. Besides a population high of nearly 2,000 in 2010, numbers remain below 100 for all other years. Higher numbers of Red-necked Avocet were recorded in the Yalgorup Lakes, for most years, but still below the LAC of 1,100. Amending the LAC should be considered pending more intensive monitoring.

**Fairy Tern**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Fairy Terns in 3 out of 5 years is met. Total numbers of Fairy Terns were above the LAC of 60 for four of the six years. The mean count for the six year period was 84 and a standard error of 19. There was a downwards trend in numbers of Fairy Terns counted in the estuaries after 2011, but is too early to conclude that it is significant change in population.

**Curlew Sandpiper**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Curlew Sandpiper in 3 out of 5 years is not met. Total numbers of Curlew Sandpiper never approached within a magnitude of the LAC of 1,800. The mean count for the six year period was just 13 and a standard error of 9. The counts were extremely low compared to data recorded over a 20 year period for Lake McLarty (1983-2003) where numbers were greater than 1,000 for half the number of years recorded. More intensive monitoring is required before conclusions can be drawn on the population of the Curlew Sandpiper, but it would be one of the priority species for monitoring efforts.

**Sharp-tailed Sandpiper**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Sharp-tailed Sandpiper in 3 out of 5 years is not met. Total numbers of Sharp-tailed Sandpiper were above the LAC of 1,600 for only two of the six years. The mean count for the six year period was 1,552 and a standard error of 855 indicating the large variability in the population between years. There was a downwards trend in numbers of Sharp-tailed Sandpiper counted in the estuaries, but in the same period, there was an equal increasing trend in numbers recorded in the Yalgorup Lakes, suggesting conditions in these lakes is more conducive for this species. Amending the LAC should be considered pending more intensive monitoring.

**Musk Duck (250)**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Musk Duck in 3 out of 5 years is not met. Musk Duck were only
recorded twice and never approached within a magnitude of the LAC of 250. The mean count for the six year period was just 2 and a standard error of 2. Significant numbers of around 250 were recorded in the Yalgorup Lakes in 2013. More intensive monitoring is required before conclusions can be drawn on the population of the Musk Duck, but it would be one of the priority species for monitoring efforts.

**Australasian Shoveler**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Australasian Shovelers in 3 out of 5 years is not met. Australasian Shovelers were only recorded once and never approached within a magnitude of the LAC of 120. The mean count for the six year period was just 2 and a standard error of 2. The counts were extremely low compared to highest annual count data (in Craig et.al. 2004) recorded over a 20 year period for Lake McLarty (1983-2003) where numbers were greater than 200 for every year after 1993.

Significant numbers of around 50 were recorded in Lakes McLarty and Mealup in 2013, but more intensive monitoring is required before conclusions can be drawn on the population of the Australasian Shoveler, but it would be one of the priority species for monitoring efforts.

**Eurasian Coot**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Eurasian Coot in 3 out of 5 years is not met. The counts for Eurasian Coot never approached within a magnitude of the LAC of 10,000. The mean count for the six year period was just 128 and a standard error of 95.

It should be noted that the 2020 count does not target non-shorebird species and more intensive monitoring is required before conclusions can be drawn on the population of the Eurasian Coot, but it would be one of the priority species for monitoring efforts.

**Grey Teal**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Grey Teal in 3 out of 5 years is not met. The counts for Grey Teal never approached within a magnitude of the LAC of 20,000. The mean count for the six year period was just 2,725 and a standard error of 1,289. Significant numbers are being recorded in the Yalgorup Lakes of up to 7,400, but more intensive monitoring is required before conclusions can be drawn on the population of the Grey Teal. It would be one of the priority species for monitoring efforts.

**Lakes Goegrup and Black**

These two lakes support many waterbird species at numbers similar to Lake McLarty (Figure D112). Table D45 shows those species with counts of at least 100 from the BirdLife Australia Shorebird 20-20 data. These two lakes are particularly important for Silver Gulls, Black-winged Stilts and in certain seasons provide refuge for Australian Shelduck and Banded Stilts. There are no trends that suggest these lakes are not continuing to support these species and the highest counts of Black-winged Stilts, Australian Shelduck and Banded Stilts over the six year period were counted in 2013.

**Table D45 : Population counts from Goegrup and Black Lakes using Shorebird 20-20 data for 2008-2013 for species having count >100.**


### Waterbirds>100

<table>
<thead>
<tr>
<th>Species</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian Pelican</td>
<td>139</td>
<td>123</td>
<td>75</td>
<td>121</td>
<td>60</td>
<td>262</td>
<td>130</td>
</tr>
<tr>
<td>Black-Winged Stilts</td>
<td>263</td>
<td>904</td>
<td>757</td>
<td>646</td>
<td>97</td>
<td>1,720</td>
<td>731</td>
</tr>
<tr>
<td>Pacific Black Duck</td>
<td>176</td>
<td>317</td>
<td>255</td>
<td>76</td>
<td>125</td>
<td>72</td>
<td>170</td>
</tr>
<tr>
<td>Red-Capped Plover</td>
<td>193</td>
<td>0</td>
<td>118</td>
<td>65</td>
<td>0</td>
<td>0</td>
<td>63</td>
</tr>
<tr>
<td>Red-necked Stint</td>
<td>100</td>
<td>0</td>
<td>65</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>Silver Gull</td>
<td>550</td>
<td>1,162</td>
<td>1,113</td>
<td>2,025</td>
<td>313</td>
<td>922</td>
<td>1,014</td>
</tr>
<tr>
<td>Australian Shelduck</td>
<td>15</td>
<td>605</td>
<td>65</td>
<td>37</td>
<td>6</td>
<td>1,188</td>
<td>319</td>
</tr>
<tr>
<td>Little Black Cormorant</td>
<td>13</td>
<td>160</td>
<td>67</td>
<td>124</td>
<td>77</td>
<td>615</td>
<td>176</td>
</tr>
<tr>
<td>Australian Wood Duck</td>
<td>0</td>
<td>0</td>
<td>134</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>Grey Teal</td>
<td>86</td>
<td>10</td>
<td>111</td>
<td>149</td>
<td>50</td>
<td>214</td>
<td>103</td>
</tr>
<tr>
<td>Banded Stilts</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>635</td>
<td>106</td>
</tr>
<tr>
<td>Little Pied Cormorant</td>
<td>13</td>
<td>0</td>
<td>59</td>
<td>2</td>
<td>77</td>
<td>201</td>
<td>59</td>
</tr>
</tbody>
</table>

---

**Yalgorup Lakes**

**Banded Stilt**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Banded Stilt in 3 out of 5 years is not met. Total numbers of Banded Stilt were above the LAC of 3,000 for only two of the six years, although the count in 2011 was just 100 birds short of making the LAC and the total count in 2013 was over a magnitude greater than the LAC. The mean count for the six year period was 7,604 and a standard error of 5,599 indicating the large variability in the population between years. The result is evidence that the LAC is not a good indicator of condition of the system and reflects that Banded Stilt are significant opportunists for breeding events that take place in often remote wetland systems, many years apart. Amending the LAC should be considered pending more intensive monitoring, although this species is never going to be a sensitive measure of the conditions existing in the Peel-Yalgorup System.

**Red-necked Stint**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Red-necked Stint were never recorded above the LAC of 3,200. The mean count for the six year period was 1,412 and a standard error of 416 indicating the large variability in the population between years. There was a general upwards trend in numbers of Red-necked Stint recorded in the Yalgorup Lakes, with a maximum count recorded of 2,730 in 2012. Amending the LAC should be considered pending more intensive monitoring.

**Hooded Plover**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Hooded Plover in 3 out of 5 years is met. Total numbers of...
Hooded Plover were above the LAC of 60 for four of the six years. The mean count for the six year period was 72 with a standard error of 13. No general trends are evident for the population of Hooded Plovers using the Yalgorup Lakes and the numbers are ranging between 60 and 105 from 2009 through 2013.

**Musk Duck**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Musk Duck in 3 out of 5 years is not met. Total numbers of Musk Duck were above the LAC of 250 for only one of the six years. The mean count for the six year period was 55 with a standard error of 38 indicating the large variability in the population between years. Amending the LAC should be considered pending more intensive monitoring.

**Australian Shelduck**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Australian Shelduck in 3 out of 5 years is not met. Total numbers of Australian Shelduck were above the LAC of 2,400 for only two of the six years, although the count in 2009 was just under the LAC and the total count in 2012 was over four times greater than the LAC. The mean count for the six year period was 3,366 with a standard error of 1,423 indicating the large variability in the population between years and the lack of sensitivity of this LAC for indicating condition of the system. More intensive monitoring is required before conclusions can be drawn on the population of Australian Shelduck in the Yalgorup Lakes.

Waterbirds are not necessarily an indicator of the health of the estuaries, but rather a reflection of condition in inland areas of the state.

**Lakes McLarty and Mealup**

**Banded Stilt**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Banded Stilt in 3 out of 5 years is not met. Banded Stilt were only recorded for one of the six years. It is known that Banded Stilt are significant opportunists for breeding events that take place in often remote wetland systems, many years apart. Amending the LAC should be considered pending more intensive monitoring. The lack of recorded sightings in the Shorebird 20-20 surveys is a result of the single snapshot taken each year. The data recorded in 24 years of highest count data for Lake McLarty (Craig et.al. 2004), indicated that Banded Stilt were observed in 15 of the 24 years and there was a mean of 294. Amending the LAC should be considered pending more intensive monitoring, although this species is never going to be a sensitive measure of the conditions existing in the Peel-Yalgorup System.

**Red-necked Stint**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Red-necked Stint in 3 out of 5 years is not met. Red-necked Stint were only recorded in two of the six years and neither of these counts were close to the LAC, although the largest count of 2,300 occurred in 2013. Amending the LAC should be considered pending more intensive monitoring.
**Red-capped Plover**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Red-capped Plovers in 3 out of 5 years is not met. Total numbers of Red-capped Plovers did not come close to the LAC of 950. The mean count for the six year period was only 65 with a standard error of 28. Amending the LAC should be considered pending more intensive monitoring.

**Red-necked Avocet**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Red-necked Avocet in 3 out of 5 years is not met. Red-necked Avocet were recorded in only one of the six years. Amending the LAC should be considered pending more intensive monitoring.

**Curlew Sandpiper**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Curlew Sandpiper in 3 out of 5 years is not met. Curlew Sandpiper were recorded in only one of the six years.

The counts were extremely low compared to data recorded over a 20 year period for Lake McLarty (1983-2003) where numbers were greater than 1,000 for half the number of years recorded. More intensive monitoring is required before conclusions can be drawn on the population of the Curlew Sandpiper, but it would be one of the priority species for monitoring efforts. Amending the LAC should be considered pending more intensive monitoring.

**Black-winged Stilt**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Black-wing Stilts in 3 out of 5 years is not met. Black-wing Stilts were recorded for only three of the six years and the counts never approached within a magnitude of the LAC of 20,000. The mean count for the six year period was just 279 with a standard error of 231. Black-wing Stilts are being recorded each year in the Peel and Harvey estuaries and the Yalgorup Lakes with numbers up to 2,848 in the estuaries and a mean count of 2,848. More intensive monitoring is required before conclusions can be drawn on the population of the Black-wing Stilts, but the LAC should be considered for amendment, pending more intensive monitoring. It would be one of the priority species for monitoring efforts.

**Sharp-tailed Sandpiper**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Sharp-tailed Sandpiper in 3 out of 5 years is not met. Sharp-tailed Sandpipers were recorded for only one of the six years in the Lakes McLarty and Mealup with a count of 555 in 2013. Sharp-tailed Sandpiper are being recorded each year in the Peel and Harvey estuaries with numbers up to 6,007 in the estuaries and a mean count of 1,552. More intensive monitoring is required before conclusions can be drawn on the population of the Sharp-tailed Sandpiper, but the LAC should be considered for amendment, pending more intensive monitoring.
**Australian Shelduck**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Australian Shelduck in 3 out of 5 years is not met. Australian Shelducks were recorded for only one of the six years. More intensive monitoring is required before conclusions can be drawn on the population of Shelduck in the Yalgorup Lakes. Australian Shelduck are being recorded each year in the Peel and Harvey estuaries and with numbers up to 3,359 and a mean count of 1,146 and in the Yalgorup Lakes with a maximum count of over 10,000 in 2012 and a mean count of 3,366. The LAC should be considered for amendment, pending more intensive monitoring.

**Eurasian Coot**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC of 1% of the total global population of Eurasian Coot in 3 out of 5 years is not met. Eurasian Coot were only recorded in two of the six years and the counts never approached within a magnitude of the LAC of 10,000.

More intensive monitoring is required before conclusions can be drawn on the population of the Eurasian Coot, but it would be one of the priority species for monitoring efforts. The LAC should be considered for amendment, pending more intensive monitoring.

### 3.2.12 Social and cultural values

#### Recreational and Tourism

The recreational boating, commercial fishing, tourism and residential land value has been estimated (Economic Consulting Services, 2008). The annual value of the Peel region waterways is estimated to be between around $360 million and $1,350 million. This annual value has a net present (2008) value of between about $5,200 million and $19,930 million using a 7% discount rate. The total is highly sensitive to the value of the boating sector and more work is required to refine this estimate.

#### Real estate

Land values on the edge of the estuary have risen considerably after the Dawesville Cut was created in 1994 such that they were estimated at $140,000 in 1992, $200,000 in 1996 and $1,300,000 in 2007 (Economic Consulting Services, 2010). The rate at which land values rose beside the estuary was greater than for sites beside the ocean.

### 3.3 ASSESSMENT OF CURRENT CONDITION AGAINST RAMSAR VALUES

This Section addresses the current condition of the site relative to the criteria it was listed against. The table below (replicated from Section 2.1 with an additional column) may be useful. It should be noted that the listing in December 2009 under the EPBC Act of the *Thrombolite (microbialite) Community of a Coastal Brackish Lake (Lake Clifton)* as Critically Endangered and in 2011 of the Fairy Tern (*Sternula nereis nereis*) as Vulnerable, qualifies the Peel-Yalgorup System Ramsar site as meeting a further seventh criteria i.e. Criteria # 2 - A wetland should be considered internationally
important if it supports vulnerable, endangered, or critically endangered species or Threatened Ecological Communities.

The listing criteria have been updated to reflect this change.
Table D46 : Ramsar listing criteria and justification.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Justification</th>
<th>Assessment against current condition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near natural wetland type found within the appropriate biogeographic region.</strong></td>
<td>The site includes the largest and most diverse estuarine complex in south-western Australia and also particularly good examples of coastal saline lakes and freshwater marshes.</td>
<td>This criteria is still met as the Peel-Harvey Estuary system is the largest and most diverse estuarine system in south-western Australia and the complex of freshwater lakes on the south-east side of Harvey Estuary and the salt lake chains on the west side are still particularly good examples of these wetland types in Western Australia.</td>
</tr>
<tr>
<td><strong>2: A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or Threatened Ecological Communities.</strong></td>
<td>The site supports the critically endangered Thrombolite (microbialite) Community of a Coastal Brackish Lake (Lake Clifton), the vulnerable Subtropical and Temperate Coastal Saltmarsh community and the vulnerable Fairy Tern (Sternula nereis nereis).</td>
<td>The Thrombolite community in Lake Clifton remain actively growing. The Fairy Tern was recorded in five of the six years of the Shorebird 20-20 surveys 2008-2013. The saltmarsh community is recorded in botanical surveys of the Peel-Harvey Estuary.</td>
</tr>
<tr>
<td><strong>3: A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.</strong></td>
<td>The site is one of only two locations in south-western Australia and one of very few in the world where living thrombolites occur in inland waters.</td>
<td>This criteria is still met as the nationally listed Threatened Ecological Community ‘Lake Clifton Thrombolites’ remains intact and biologically active.</td>
</tr>
</tbody>
</table>
### Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions

The basic description of this criterion implies a number of common functions/roles that wetlands provide and the following apply at Peel-Yalgorup Ramsar site, in most if not all cases both at the date of listing and at present:

- the critical life stage of migration: annual use by large numbers of many species of migratory animals;
- the critical life stage of drought refuge: seasonal influx of large numbers of waterbirds from dried out wetlands in surrounding areas, and periodic massive influx from wider regions during drought;
- the critical life stage of breeding: regionally and nationally significant colonies of cormorants occurred in the 1980s in paperbark swamp in Carraburmup Swamp Nature Reserve (Jaensch et al. 1988) on the south-east side of Peel Inlet (and part of the Ramsar site) and small breeding colonies of pelicans breed now and then on islets in Peel Inlet; in addition, the Yalgorup Lakes are a significant site bioregionally for breeding of Hooded Plover (Birds Australia 2005);
- breeding also applies to fishes, crabs and prawns; and
- the critical life stage of moulting: Shelduck and Musk Ducks that congregate on the open waters of the Ramsar site outside the breeding season are engaging in moult (hence, the birds are flightless for a short period).

All of the functions/roles that have been used to justify Criterion 4 in supporting plant and/or animal species at critical life stages and in providing drought refuge still apply for the Ramsar site.

- Supports migratory waterbirds (44 bird species listed under international migratory agreements), particularly the Red-necked Stint and Sharp-tailed Sandpiper in large numbers (Shorebirds 20-20).
- Supports Australian Shelduck and Musk Duck during moulting.
- Supports breeding events for cormorants, pelicans and Hooded Plovers – (pers. comm. BirdLife Australia 2014)
- Acts as a drought refuge for waterbirds (Shorebirds 20-20)
- Supports breeding of fish, crabs and prawns as detailed in earlier sections

### Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.

The site comprises the most important area for waterbirds in south-western Australia, supporting in excess of 20,000 waterbirds annually, with greater than 150,000 individuals recorded at one time (February 1977). Numbers exceeding 20,000 birds have been recorded in all comprehensive surveys conducted in the 1990s in the Peel-Harvey Estuary.

More than 20,000 waterbirds were detected in all of the 6 years from the BirdLife Australia 20-20 data and it is likely that maximum waterbird numbers are much greater than 20,000 each year.
<table>
<thead>
<tr>
<th>Criterion</th>
<th>Justification</th>
<th>Assessment against current condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>6: A wetland should be considered internationally important if it regularly supports one percent of the individuals in a population of one species or subspecies of waterbird.</td>
<td>According to the 4th edition of Waterbird Population Estimates, the site regularly supports 1% of the population of: Red-necked Avocet (<em>Recurvirostra novaehollandiae</em>), Red-necked Stint (<em>Calidris ruficollis</em>), Red-capped Plover (<em>Charadrius ruficapillus</em>), Hooded Plover (<em>Thinornis rubricollis</em>), Black-winged Stilt (<em>Himantopus himantopus</em>), Banded Stilt (<em>Cladorhynchus leucocephalus</em>), Curlew Sandpiper (<em>Calidris ferruginea</em>), Sharp-tailed Sandpiper (<em>Calidris acuminata</em>), Fairy Tern (<em>Sterna nereis</em>), Musk Duck (<em>Biziura lobata</em>), Grey Teal (<em>Anas gracilis</em>), Australasian Shoveler (<em>Anas rhynchos</em>), Australian Shelduck (<em>Tadorna tadornoides</em>) and, Eurasian Coot (<em>Fulica atra</em>).</td>
<td>Data has not been collected to categorically demonstrate this criteria is met. However, the BirdLife Australia 20-20 data indicated that three species were detected at numbers greater than the 1% threshold in over half of the years surveyed (2008-2013).</td>
</tr>
<tr>
<td>8: A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.</td>
<td>The Ramsar site is important as a nursery and/or breeding and/or feeding ground for at least 50 species of fish as well as the commercially significant Blue Swimmer Crab (<em>Portunus pelagicus</em>) and Western King Prawn (<em>Penaeus latisulcatus</em>). In addition, the Peel-Harvey Estuary is a migratory route for the Pouched Lamprey (<em>Geotria australis</em>).</td>
<td>Evidence supports that the criteria is still met for fish (Veale, 2013) and crabs (Fletcher &amp; Santoro, 2013) and for <em>Geotria australis</em> (David Morgan, Murdoch University, pers. comm.) but not prawns (see 3.2.8).</td>
</tr>
</tbody>
</table>
4 Limits of acceptable change

4.1 INTRODUCTION

Limits of acceptable change are defined by Phillips (2006) as:

“...the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. This may include population measures, hectares covered by a particular wetland type, the range of certain water quality parameter, etc. The inference is that if the particular measure or parameter moves outside the ‘Limits of Acceptable Change’ this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed. In most cases, change is considered in a negative context, leading to a reduction in the values for which a site was listed”.

Limits of acceptable change and the natural variability in the parameters for which limits are set are inextricably linked. Phillips (2006) suggested that Limits of Acceptable Change should be beyond the levels of natural variability. Setting limits in consideration with natural variability is an important, but complex concept. Wetlands are complex systems and there is both spatial and temporal variability associated with all components and processes. Defining this variability such that trends away from ‘natural’ can be detected with sufficient time to instigate management actions to prevent an irrevocable change in ecological character is far from straight forward.

It is not sufficient to simply define the extreme measures of a given parameter and to set Limits of Acceptable Change beyond those limits. There are many examples where a parameter could change in ways that are detrimental to the ecological character of the site but do not result in a change in the maximum or minimum values. For example, in the case of salinity in Lake Clifton, this is a parameter that is intimately associated with the ecological character of the lake and maintaining the thrombolite communities. If the simple approach of drawing boundaries around this time series were taken, Limits of Acceptable Change might be written, as “salinity must be between 15 and 32 ppt”. However, the variability in salinity at this site may be important and a constant 32 ppt would change the ecological character of the site (with the possible demise of the thrombolites) while a constant 15 ppt may also change the wetland such that salt tolerant species are replaced by those more adapted to freshwaters.

A method of detecting change in pattern and setting limits that indicate a trend away from natural variability (be that positive or negative) is required. This may mean accounting for changes in the frequency and magnitude of extreme events, changes in the temporal or seasonal patterns and changes in spatial variability as well as changes in the mean or median conditions. Added to this is the need to be able to detect changes in the key determinants of ecological character prior to irrevocable changes in wetland ecology.

In a perfect world with complete scientific and ecological knowledge, Limits of Acceptable Change could be set to match the tolerances or optimum conditions for the key biological components and processes for which the site was listed. In this manner, limits could be set within these specific tolerances and ecological character maintained. However, this information is rarely available for the most well studied species, let alone the more cryptic organisms.
In the absence of this complete knowledge, a conservative approach is most often adopted. It is in this context that the precautionary principle, originally appearing in the United Nations World Charter for Nature in 1982, has been adopted. The principle states:

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

Limits of acceptable change are to be used in the management of the system to maintain ecological character. In order to detect if the Limits of Acceptable Change are being met monitoring against these limits needs to occur. As such it is neither practical nor desirable to set limits for every component and process within a wetland system. Accordingly, components and processes for which Limits of Acceptable Change can be established are those:

- for which there is adequate information to form a baseline against which change can be measured;
- for which there is sufficient information to characterise natural variability;
- that are primary determinants of ecological character;
- that can be managed; and
- that can be monitored.

There are a number of critical components and processes within the Peel-Yalgorup System Ramsar site that do not meet these criteria. An example of this would be the thrombolites at Lake Clifton. It is not possible to measure the condition of these communities directly and it is likely that any change in extent of the thrombolites (i.e. death of individual mounds) would signify irrevocable change. In an attempt to address this situation, a hierarchical approach to establishing Limits of Acceptable Change was adopted.

This approach sets short term Limits of Acceptable Change (with a corresponding intensive monitoring program) on the key abiotic factors within the system. Abiotic components and processes impose a strong influence on the biotic components of wetland systems and are often considered the primary control factors (Mitsch and Gosselink 2000; Batzer and Sharitz 2006). These are usually the easiest to monitor and change can be detected in the short term (within 1 or 2 years). The approach adopted with respect to abiotic components, follows the ANZECC (2000) guidelines for water quality in freshwater and marine systems. A set of guideline or trigger values has been established for key components, based on site specific information, where possible, and using general values for Australian ecosystems in situations where there is insufficient data for the local system. In the case of the Peel-Yalgorup System there are some data upon which baselines can be set and trigger values established (e.g. salinity, nutrients) and for others, general values have been used.

The second set of parameters for which Limits of Acceptable Change can be set, is the primary responses to the abiotic components and processes. This includes primary production, littoral vegetation extent and condition and the distribution and condition of aquatic plants. The focus is on the identified key determinants of ecological character. Limits are set against baseline data and the habitat requirements of key fauna. The Limits of Acceptable Change for these parameters are set at time scales reflecting the different response times of the flora communities. For example, phytoplankton, which can respond rapidly, has shorter-term Limits of Acceptable Change than woody vegetation communities.
Finally the key biological components are considered. For most of these quantitative Limits of Acceptable Change are difficult to determine, either due to a lack of baseline data, inherent high levels of natural variability, or in the case of many waterbird species, factors outside the site affecting their distribution and abundance observed at the site. Maintaining the conditions of the abiotic environment and the primary producers should protect these faunal components and processes.

Limits of acceptable change for each of the wetland types in the Peel-Yalgorup System Ramsar site have been established for each of the key determinants of ecological character. In addition to components that have been identified as ‘primary determinants’ of ecological character, limits have also been set for components that are considered to be under threat, such as pH in the Peel-Harvey, which have been identified as a potential threat through the disturbance of acid sulfate soils.

Since the development of the ECD for the Peel-Yalgorup Ramsar site in 2007, there has been a change in the way the Limits of Acceptable Change are developed and applied. Limits of Acceptable change are now a tool for assessing change in character and are set at a level that would indicate a potential change in character. The LACs for the Peel-Yalgorup site have been set more at the level of management triggers, whereby exceedance of a LAC is indicative of a trend, but not a change in character. LAC can be updated as new information becomes available to ensure they more accurately reflect the natural variability (or normal range for artificial sites) of critical components, processes, benefits or services of the Ramsar wetland. The formal process for this is via the Ramsar Rolling Review, which is a three yearly assessment of ecological character at each Ramsar site. It is likely that the LAC for the Peel-Yalgorup site will be updated in the next Ramsar Rolling Review to be more in line with LAC for other Ramsar sites in Australia.

### 4.2 LIMITS OF ACCEPTABLE CHANGE

The Ecological Character Description for the Peel-Yalgorup Ramsar site was published in 2007 (Hale and Butcher 2007) and established Limits of Acceptable Change to reflect a new established condition baseline post Dawesville Channel opening (Table D47).

**Table D47 : Limits of acceptable change for the Peel-Harvey Estuary.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Baseline/supporting evidence</th>
<th>Limits of acceptable change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abiotic components</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrients</td>
<td>Total phosphorus limits have been set by the Water Quality Improvement Plan (EPA 2008)</td>
<td>TP &lt; 30 μg/L (maximum)</td>
</tr>
<tr>
<td></td>
<td>Dissolved inorganic nutrients, which are the form available for uptake. Current baseline suggests peaks in winter, but low concentrations during summer and autumn.</td>
<td>PO₄, NH₄, NOₓ - median concentrations &lt; 10 μg/L</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>Limits have been set by the Water Quality Improvement Plan (EPA 2008).</td>
<td>70-80 % saturation</td>
</tr>
<tr>
<td>pH</td>
<td>Although marine systems have a large buffering capacity, disturbance of acid sulfate soils have the potential to lower pH values. Baseline conditions indicate pH</td>
<td>pH &gt; 7 at all times</td>
</tr>
</tbody>
</table>
**Strategic Assessment for the Perth and Peel Regions**

<table>
<thead>
<tr>
<th>Salinity</th>
<th>Typically 7.3 to 8.5.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Although the marine influence on the estuary cannot be managed, seasonal salinity fluctuations are important for biota. Fish such as the long-headed river goby require salinities of &lt; 30 ppt to trigger spawning. Some waterbirds require fresh drinking water (&lt; 3 ppt).</td>
</tr>
<tr>
<td></td>
<td>Winter salinity in the centre of the Peel Inlet and Harvey Estuary &lt; 30 ppt for a minimum of 3 months. Water in the Harvey River mouth over winter &lt; 3 ppt.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary responses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phytoplankton</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Seagrass</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Macroalgae</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Samphire</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Paperbark</strong></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key species and communities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Invertebrates</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fish</strong></td>
</tr>
</tbody>
</table>
Whiting, Cobbler, Black Bream) this information is not able to be reported publicly at this time.

Waterbirds

The Peel-Harvey Estuary:
• supports > 20,000 waterbirds regularly;
• supports > 1% of the population of 12 species; and
• supports breeding of 11 species.

However, waterbird numbers are highly variable and there has been no systematic, long term monitoring of these birds within the estuary to enable a numerical baseline to be set.

In addition, the high natural variability and strong influence of external factors for most waterbirds presents difficulties when setting Limits of Acceptable Change.

In addition, due to incomplete records, many of the bird species that qualified for the > 1% of the population were based on a small number of observations or counts. It is recommended that this criterion is revised and the limit of acceptable change revised as more data becomes available.

It is recommended that these measures be treated as ‘trigger values’ rather than absolute measures. In interpreting results, consideration should be given to climatic patterns and their potential effect on bird numbers in the Ramsar site.

Support > 20,000 total waterbirds in 4 out of 5 years.

Support > 1% of the population of the following birds 3 out of 5 years:
- Banded Stilt (3,000)
- Red-necked Stint (3,200)
- Red-capped Plover (950)
- Red-necked Avocet (1,100)
- Fairy Tern (60)
- Curlew Sandpiper (1,800)
- Sharp-tailed Sandpiper (1,600)
- Musk Duck (250)
- Australasian Shoveler (120)
- Eurasian Coot (10,000)
- Grey Teal (20,000)

Breeding recorded for waterbird species (Pelicans, Little Pied Cormorants, Little Black Cormorants, Black Swan, Grey Teal, Darter and Black-winged Stilt) a minimum of once every three years.

Table D48: Limits of acceptable change for Yalgorup Lakes

<table>
<thead>
<tr>
<th>Component</th>
<th>Baseline/supporting evidence</th>
<th>Limits of acceptable change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abiotic components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrients</td>
<td>Dissolved inorganic nutrients are those that are available for plant uptake and therefore the most indicative of trophic status. Lane and Davies (1993) collected some information from Lake Clifton and this forms the baseline for this limit. It is likely that the limit will need to be refined as more data is collected.</td>
<td>PO4, NH4, NOx - median concentrations &lt; 10 μg/L</td>
</tr>
<tr>
<td>Salinity</td>
<td>Although many of the lakes are hypersaline, the</td>
<td>Lake Clifton salinity &lt; 35 ppt maximum</td>
</tr>
</tbody>
</table>
Strategic Assessment for the Perth and Peel Regions

<table>
<thead>
<tr>
<th>Groundwater discharge</th>
<th>thrombolite communities are reliant on freshwater. and &lt; 25 ppt during winter and spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Yalgorup Lakes are within a landscape considered at high risk from acid sulfate soils. Thrombolites rely on alkaline conditions for growth. Natural pH is between 7.2 and 8.5.</td>
</tr>
<tr>
<td></td>
<td>pH &gt; 7 at all times</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytoplankton</td>
</tr>
<tr>
<td>Macroalgae</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key species and communities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invertebrates</td>
</tr>
<tr>
<td>Fish</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waterbirds</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Yalgorup Lakes:</td>
</tr>
<tr>
<td>- support &gt; 1% of the population of five species; and</td>
</tr>
<tr>
<td>- supports breeding of eight species.</td>
</tr>
<tr>
<td>The high natural variability and strong influence of external factors for most waterbirds presents difficulties when setting Limits of Acceptable Change.</td>
</tr>
<tr>
<td>Breeding records for some species are well documented (e.g. Hooded Plover) but for others are based on isolated incidents. The Limits of Acceptable Change have been set for species regularly observed breeding at the site only. This should be revised when further information becomes available.</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td></td>
</tr>
</tbody>
</table>
The thrombolites are a significant ecological community. However, it is not possible to measure their condition directly, with the exception of bleaching and death. It is recommended that abiotic factors be used as a surrogate for managing these communities.

No loss of thrombolites at Lake Clifton.

### Table D49: Limits of acceptable change for Lakes McLarty and Mealup

<table>
<thead>
<tr>
<th>Component</th>
<th>Baseline/supporting evidence</th>
<th>Limits of acceptable change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abiotic components</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Nutrients**    | Dissolved inorganic nutrients are those that are available for plant uptake and therefore the most indicative of trophic status. However this is data deficient at Lakes McLarty and Mealup and likely to be highly seasonal as water levels fluctuate. As a consequence, trigger values for south-west Australian wetlands have been adopted (ANZECC 2000). | PO4 < 30 μg/L  
|                  |                                                                                                                                                                                                                           | NH4, < 40 μg/L  
|                  |                                                                                                                                                                                                                           | NOx < 100 μg/L  
|                  |                                                                                                                                                                                                                           | All to be applied only when water levels are > 500mm.                                                             |
| **Salinity**     | These represent the only freshwater systems within the Ramsar site. However, salinity will fluctuate as water levels rise and fall. Salinity should be based on the tolerances of the water dependant species and as such should be measured at times when these communities are inundated | Salinity under rush and sedge communities < 1 ppt.  
<p>|                  |                                                                                                                                                                                                                           | Salinity under paperbark communities &lt; 0.5 ppt.                                                                |
| <strong>pH</strong>           | McLarty and Mealup are within a landscape considered at high risk from acid sulfate soils. Natural pH is between 7.2 and 8.5 for McLarty, but has declined to between 3.1 and 4 for Lake Mealup. As such a limit for Lake Mealup has not been set, but will need to be based on further investigative work | pH &gt; 7 at all times in Lake McLarty.                                                                                   |
| <strong>Groundwater discharge</strong> | Data deficient.                                                                                                                                                                                                              | A surrogate based on water levels in the lakes may be able to be developed.                                       |
| <strong>Primary responses</strong> |                                                                                                                                                                                                                           |                                                                                                                                 |
| <strong>Phytoplankton</strong> | Data deficient.                                                                                                                                                                                                             | Baseline must be set before limits can be made.                                                                     |
| <strong>Aquatic plants</strong> | Reports of <em>Lemma</em> growth across the water surface which could be a response to eutrophication. Prolonged and extensive growth could reduce dissolved oxygen concentrations | Greater than 50% of open water not covered in floating aquatic plants.                                                    |
| <strong>Littoral</strong>     | Dominated by freshwater reeds, but encroachment                                                                                                                                                                              | <em>Typha</em> limited to &lt; 20 % of the wetland                                                                          |</p>
<table>
<thead>
<tr>
<th>vegetation</th>
<th>of <em>Typha</em> cited as a problem at both wetlands. Sedges are an important habitat component for some waterbirds</th>
<th>area</th>
<th>Freshwater sedges covering a minimum of 20% of the wetland area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paperbark</td>
<td>Fringing freshwater paperbark community which is an important habitat for waterbirds. No quantitative information.</td>
<td>No decline in paperbark health. No net loss of extent of paperbark community.</td>
<td></td>
</tr>
</tbody>
</table>

### Key species and communities

#### Invertebrates

Insufficient information to set a baseline for most invertebrate communities. These organisms form a large component of the food source for many of the waterbirds at the lakes.

Limit of acceptable change not able to be set. However, invertebrate populations sufficient to sustain waterbird populations should be maintained.

#### Waterbirds

Lakes McLarty and Mealup:
- support > 20,000 waterbirds regularly;
- support > 1% of the population of ten species; and
- support breeding of 12 species.

However, waterbird numbers are highly variable and there has been no systematic, long term monitoring of these birds within the estuary to enable a numerical baseline to be set.

In addition, the high natural variability and strong influence of external factors for most waterbirds presents difficulties when setting Limits of Acceptable Change.

Due to incomplete records, many of the bird species that qualified for the > 1% of the population were based on a small number of observations or counts. It is recommended that this criterion is revised and the limit of acceptable change revised as more data becomes available.

In addition, breeding records for some species are well documented (e.g. Dusky Moorhen and Purple Swamphen) but for others are based on isolated incidents. The Limits of Acceptable Change have been set for species regularly observed breeding at the site only. This should be revised when further information becomes available.

It is recommended that these measures be treated as ‘trigger values’ rather than absolute measures. In interpreting results consideration should be given to climatic patterns and their potential effect on bird numbers in the Ramsar site.

Support > 20,000 total waterbirds in 4 out of 5 years.

Support > 1% of the population of the following birds 3 out of 5 years:
- Banded Stilt (2,100)
- Red-necked Stint (3,200)
- Red-capped Plover (950)
- Red-necked Avocet (1,100)
- Curlew Sandpiper (1,800)
- Black-winged Stilt (3,000)
- Sharp-tailed Sandpiper (1,600)
- Australian Shelduck (2,400)
- Eurasian Coot (10,000)

Breeding recorded for waterbird species (Australian Shelduck, Black Swan, Grey Teal, Pacific Black Duck, Great Crested Grebe, Purple Swamphen, Dusky Moorhen, Spotless Crane, Little Pied Cormorant and Darter) a minimum of once every three years.
### Table D50: Limits of acceptable change for Lakes Goegrup and Black

<table>
<thead>
<tr>
<th>Component</th>
<th>Baseline/supporting evidence</th>
<th>Limits of acceptable change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abiotic components</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrients</td>
<td>Dissolved inorganic nutrients, which are the form available for uptake. Current baseline suggests peaks in winter, but low concentrations during summer and autumn</td>
<td>PO4, NH4, NOx - median concentrations &lt; 10 μg/L.</td>
</tr>
<tr>
<td>Salinity</td>
<td>Although marine systems have a large buffering capacity, disturbance of acid sulfate soils have the potential to lower pH values. Baseline conditions indicate pH typically 7.3 to 8.5.</td>
<td>pH &gt; 7 at all times.</td>
</tr>
<tr>
<td>pH</td>
<td>Although the marine influence on the estuary cannot be managed, seasonal salinity fluctuations are important for biota. Fish such as the long-headed river goby require salinities of &lt; 30 ppt to trigger spawning. Some waterbirds require fresh drinking water (&lt; 3 ppt).</td>
<td>Winter salinity in the centre of the Peel Inlet and Harvey Estuary &lt; 30 ppt for a minimum of 3 months. Water in the Harvey River mouth over winter &lt; 3 ppt.</td>
</tr>
<tr>
<td><strong>Primary responses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phytoplankton</td>
<td>Phytoplankton blooms are common.</td>
<td>Limit should be lower than current conditions, further investigations should be undertaken in order to set realistic limits.</td>
</tr>
<tr>
<td>Samphire</td>
<td>Approximately 83 hectares when mapped in 2006. However, there is no information on the natural variability in this community.</td>
<td>Extent and distribution of samphire within patterns of natural variation.</td>
</tr>
<tr>
<td>Paperbark</td>
<td>Fringing areas of both freshwater (47 ha) and saltwater paperbark (145 ha) communities. These perennial woody vegetation complexes would have low natural variability in extent.</td>
<td>No change in the condition of paperbark communities.</td>
</tr>
<tr>
<td><strong>Key species and communities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Invertebrates</td>
<td>Insufficient information to set a baseline for most invertebrate communities. These organisms form a large component of the food source for many of the waterbirds at the lakes.</td>
<td>Limit of acceptable change not able to be set. However, invertebrate populations sufficient to sustain waterbird populations should be maintained.</td>
</tr>
<tr>
<td>Fish</td>
<td>Fish data for Goegrup is based on records that are &gt; 25 years old. There have been no recent surveys and current populations are unknown.</td>
<td>Baseline must be set before limits can be made.</td>
</tr>
<tr>
<td>Waterbirds</td>
<td>Waterbird records for Lakes Goegrup and Black are patchy and based on isolated surveys. There is no baseline information, although anecdotal</td>
<td>Baseline must be set before limits can be made.</td>
</tr>
<tr>
<td>records that the extensive saltmarsh and open water habitats support waterbird communities.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table D51: Condition assessment against LACs (2007-2014)

The following outlines the criteria used for the assessment of the current condition of the System, the way in which the level of confidence was determined and the trends since 2007.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Confidence</th>
<th>Trend (since ECD drafted - 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 – LAC always met</td>
<td>5 – Highly confident, data available in peer reviewed journals; conference papers.</td>
<td>Improving</td>
</tr>
<tr>
<td>3 – LAC met in a majority of years</td>
<td>4 - Data available through published reports, expert panels, and peer reviewed agency monitoring evaluation.</td>
<td>Stable</td>
</tr>
<tr>
<td>2 – LAC not met in a majority of years</td>
<td>3 - Data available through agency monitoring evaluation.</td>
<td>Degrading</td>
</tr>
<tr>
<td>1 – LAC not met since ECD published</td>
<td>2 – Anecdotal information.</td>
<td>Insufficient data</td>
</tr>
<tr>
<td></td>
<td>1 – Data not available.</td>
<td></td>
</tr>
</tbody>
</table>
Table D52: Condition assessment against Limits of Acceptable Change.

Water quality

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Data analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peel-Harvey Estuary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Nutrients | • Pollution from agriculture and horticulture industries and more recently, horse agistment, particularly around Serpentine River  
• Leakage from municipal sewage treatment sites and private septic systems  
• Urban garden fertilisers | TP < 30 μg/L (maximum). | The LAC of 0.03 mg/L total phosphorus is exceeded in all systems over the period 2000-2011. The Serpentine River has the greatest proportion of samples exceeding the LAC and the Peel Inlet the least. Bottom waters of the Murray also have very high proportions of samples exceeding the LAC. | Condition Score: 1  
Confidence Score: 3  
Trend: Degrading |
| Nutrients | • Pollution from agriculture and horticulture industries  
• Leakage from municipal sewage treatment sites and private septic systems | PO₄, NH₄, NOₓ - median concentrations < 10 μg/L | The LAC of 0.01 mg/L of filtered soluble phosphorus is exceeded only in the Serpentine, in both surface and bottom waters and in all seasons, except for bottom waters in autumn.  
Other systems have concentrations below the LAC at both depths and in all seasons.  
The LAC of 0.01 mg/L of ammonia-ammonium is exceeded in every system in both surface and bottom waters and in all seasons.  
The LAC of 0.01 mg/L oxidised nitrogen is exceeded in each system in both surface and bottom waters in winter. It is also exceeded in the Serpentine and Murray Rivers | PO₄  
Condition Score: 2  
Confidence Score: 3  
Trend: Degrading  
NH₄  
Condition Score: 1  
Confidence Score: 3  
Trend: Degrading
<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Data analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved oxygen</td>
<td>• Urban garden fertilisers</td>
<td>70-80% saturation</td>
<td>The LAC for dissolved oxygen of 70-80% saturation is frequently not met in each system.</td>
<td>NOx Condition Score: 2 Confidence Score: 3 Trend: Degrading</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>pH &gt; 7 at all times</td>
<td>The LAC for pH &gt; 7 is infrequently exceeded in the Serpentine River and in the Harvey Estuary over the period 2000-2011.</td>
<td>Condition Score: 3 Confidence Score: 3 Trend: Stable</td>
</tr>
<tr>
<td>Salinity</td>
<td>Sea level rise</td>
<td>Winter salinity in the centre of the Peel Inlet and Harvey Estuary &lt; 30 ppt for a minimum of 3 months. Water in the Harvey River mouth over winter &lt; 3 ppt.</td>
<td>The LAC for salinity of &lt; 30 ppt for ≥ 3 months, is exceeded in the centre of the Peel Inlet in three of the last ten years (Figure D64). The LAC is also exceeded in the centre of the Harvey Estuary in four of the last ten years (Figure D65). There is no data collected in the Harvey River mouth to verify the LAC of &lt; 3 ppt.</td>
<td>Condition Score: 2 Confidence Score: 3 Trend: Degrading</td>
</tr>
<tr>
<td>Yalgorup Lakes</td>
<td>Nutrients</td>
<td>• Pollution from agriculture and horticulture industries</td>
<td>PO4, NH4, NOx - median concentrations &lt; 10 μg/L</td>
<td>The Australian and New Zealand Guidelines for Fresh and Marine Water Quality establish a trigger level of 1.5 mg/L for TN and 0.06 for TP (ANZECC and ARMCANZ) Condition Score: 2 Confidence Score: 3</td>
</tr>
<tr>
<td>Component</td>
<td>Threats</td>
<td>Limits of acceptable change (LAC)</td>
<td>Data analysis</td>
<td>Condition</td>
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<td>------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
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<td>--------------------------------</td>
</tr>
<tr>
<td>Salinity</td>
<td>Unsustainable abstraction of groundwater resources such as private bore users and over abstraction by licensees Upwelling of highly salinised groundwater Reduced rainfall and increased evaporation</td>
<td>Lake Clifton salinity &lt; 35 ppt maximum and &lt; 25 ppt during winter and spring.</td>
<td>The most recent water sampling from Lake Clifton ([Figure D67](unpublished Whitehead 2015)) indicates seasonal variation in the salinity of Lake Clifton from a minimum around 40 ppt in late winter up to almost 140 ppt at the end of summer ([Figure D67](unpublished Whitehead 2015)). This is a significant concern as the minimum recorded salinity is now well above the LAC. The implications of these hypersaline conditions for the thrombolite community in the lake are still not determined, but with the continuing trend of increasing salinity, there is concern that the conditions will be a limiting factor in the function of the bacterial communities (pers. comm. Mike Whitehead 2015) and fringing vegetation may start to also be impacted, particularly if freshwater seepages stop recharging fringing zones.</td>
<td>Condition Score: 2 Confidence Score: 3 Trend: Degrading</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>pH &gt; 7 at all times</td>
<td>The pH of surface water for Lake Clifton remains above the LAC of pH 7 and there is no significant trend ([Figure D95](unpublished Whitehead 2015)). The water contains a significant level of alkalinity as a result of dissolved carbonates from groundwater ([Whitehead, unpublished data 2015]), which will effectively buffer acidification that may result from exposure of acid sulfate soils in the system.</td>
<td>Condition Score: 4 Confidence Score: 3 Trend: Stable</td>
</tr>
<tr>
<td>Groundwater discharge</td>
<td>Over allocation of groundwater resources Reduced rainfall</td>
<td>LAC not established, but limited depth to groundwater data suggests</td>
<td></td>
<td>Groundwater discharge</td>
</tr>
</tbody>
</table>
### Component | Threats | Limits of acceptable change (LAC) | Data analysis | Condition
---|---|---|---|---

**Nutrients**
- Pollution from agriculture and horticulture industries
- Leakage from wastewater treatment plants, and private septic systems
- Urban garden fertilisers.

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</table>
| | PO₄ < 30 μg/L; NH₄ < 40 μg/L NOₓ - < 100 μg/L; when water levels > 500 mm. | Conversion of LAC into monitored anolytes and limits are as follows: PO₄ < 30 μg/L = FRP < 38.5 μg/L = 0.038 mg/L NOₓ - < 100 μg/L = TON < 100 μg/L = 0.1mg/L NH₄ < 40 μg/L = NH₃-N < 122.5 μg/L = 0.12 mg/L | Lake McLarty
Concentrations of nitrate-N and phosphate-P ranged from 0.1–5 mg/L and 0.1–2 mg/L respectively (Figure D95 Department of Parks & Wildlife 2015). The maximum concentrations of NO³-N are greater than one magnitude above the ANZECC guidelines for moderately disturbed wetlands, while the maximum PO⁴-P concentration is almost twice the magnitude of the ANZECC guidelines. These concentrations coincide with low lake levels and indicate the significant concentration of nutrients that can occur as lake levels drop.
Lake Mealup
Nutrient concentrations in Lake Mealup have been significantly elevated since listing under the Ramsar Convention and in 2009, the total nitrogen concentration was 27 times above the ANZECC guidelines for moderately disturbed wetlands, while the total phosphorus was seven times the ANZECC guidelines (Figure D96).
Construction of the weir on the Mealup Drain in 2011 and diversion of drainage water into Lake Mealup in June 2012, led to a rapid improvement in the concentration of nitrogen in the water column (Figure D96). The improvement was largely the result of the immediate increase in water volume in the lake and a dilution of the nitrogen load. The total nitrogen concentration in Lake Mealup is now between 3.5–6 mg/L TN, still eutrophic and above the ANZECC guidelines, but it has potential to drop further as denitrification processes occur. | Condition Score: 2
Confidence Score: 3
Trend: Degrading |
| | | | |
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**Salinity**

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</table>
| | Salinity under rush and sedge communities < 1 | Both Lakes McLarty (Figure D71) and Mealup (Figure D72) remain freshwater systems with minimum salinities below 1 ppt at maximum depth in mid-spring and maximum salinities approaching 7-11 ppt when water levels are at their lowest in late | Condition Score: 3
Confidence Score: 3 |
<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Data analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>ppt. Salinity under paperbark communities &lt; 0.5 ppt.</td>
<td>summer. There is no apparent trend in salinity for Lake McLarty, although the maximum in the summer of 2012/13 was the highest since recordings began in 2008 and is likely to become higher if lake levels continue to fall. Salinity levels for both Lakes McLarty and Mealup remain above the LAC of 1 ppt during a significant period of inundation and the impacts to fringing vegetation should be monitored to determine condition trends. Similar to Lake McLarty, there was no significant trend in salinity in Lake Mealup, although the highest annual maximums occurred in low rainfall years and until the construction of the weir on the Mealup Drain, the lake levels were falling and this was associated with sharp spikes in salinity. The construction of the weir has allowed for water regimes that more closely mimic the natural regime and water levels are now much higher and this together with the control of <em>Typha orientalis</em> has facilitated better water quality, including salinity that is generally below 2 ppt (Figure D72).</td>
<td>Trend: Stable</td>
<td>Condition Score (post weir): 3 Confidence Score: 3 Trend: Stable</td>
</tr>
<tr>
<td>pH</td>
<td>pH &gt; 7 at all times in Lake McLarty.</td>
<td>Lake McLarty The pH of surface water of Lake McLarty remains above the LAC of pH 7 and there is no significant trend (Figure D83).</td>
<td>Condition Score: 4 Confidence Score: 3 Trend: Stable</td>
<td>Condition Score (post weir): 4 Confidence Score: 3 Trend: Improving</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lake Mealup The pH of surface water of Lake Mealup was of significant concern up until the weir on the Mealup Drain was constructed in November 2011 and water was redirected into the lake in June of 2012. At this point, the pH was regularly between 2.8 and 4 and was related to a drying out of the lake sediments and exposure of acid sulfate soils. Initial re-flooding of the lake sediments led to further decreases in pH as sulphuric acid from exposed sediments became mixed with lake water. However with slashing and flooding death of the <em>Typha orientalis</em>, the organic matter provided the chemical buffering of the sulphuric acids and the pH rose sharply to over pH 6 and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Threats</td>
<td>Limits of acceptable change (LAC)</td>
<td>Data analysis</td>
<td>Condition</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>has steadily climbed to between generally 7-8 and meets a LAC of &gt;pH 7 (Figure D84).</td>
<td></td>
</tr>
<tr>
<td>Lakes Goegrup and Black</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Nutrients | • Pollution from agriculture and horticulture industries  
• Leakage from municipal sewage treatment sites and private septic systems  
• Urban garden fertilisers. | PO₄, NH₄, NOₓ - median concentrations < 10 µg/L | Data has not been collected to determine trends in water quality for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, there is a DoW site directly upstream of Goegrup Lake on the Serpentine River which provides the best available information. As this data has not been taken from within the lakes, caution should be applied when drawing conclusions on trends. Goegrup Lake is moderately eutrophic with Total-N between 1.0-3.0 mg/L with peaks around double the ANZECC guidelines for moderately disturbed wetlands of 1.5 mg/L and a trend of increasing Total-N concentration. The maximum Total-P concentration is almost a magnitude above the ANZECC guidelines of 0.06 mg/L, but there is a trend of reduced maximum spikes of Total-P since 2007. | Condition Score: 2  
Confidence Score: 3  
Trend: Stable-Degradation |
| Salinity  | | LACs not established, but suggested surrogates include periods of <30 ppt to facilitate spawning of the long-headed river goby and values<3ppt to provide drinking water for some waterbirds. | Data has not been collected to determine trends in water quality for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, there is a DoW site directly upstream of Goegrup Lake on the Serpentine River which provides the best available information. As this data has not been taken from within the lakes, caution should be applied when drawing conclusions on trends. Salinity data collected from 2002 indicate salinity varies seasonally between minimums around 1 and maximums around 60 ppt. No significant trends are detectable and minimums continue to persist in winter months for approximately 4-6 weeks. | Condition Score: 3  
Confidence Score: 2  
Trend: Stable |
| pH | | pH > 7 at all times | Data has not been collected to determine trends in water quality for Lakes Goegrup and Black since publication of the Ecological Character Description in 2007. However, there is a DoW site directly upstream of Goegrup Lake on the Serpentine River which provides the best available information. As this data has not been taken from within | Condition Score: 4  
Confidence Score: 2  
Trend: Stable |
the lakes, caution should be applied when drawing conclusions on trends. Monthly median pH from 2002-2011 indicates that the monitoring site ranges from neutral in the winter months (pH 7) to alkaline (pH 8.5) in autumn and summer. The seasonal variation appears to be maintained with no evidence of significant trends.

### Phytoplankton

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Data analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peel-Harvey Estuary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phytoplankton</td>
<td></td>
<td>Chlorophyll $a -$ median concentrations &lt; 10 $\mu$g/L</td>
<td>The LAC for chlorophyll $a$ of &lt; 0.01 $\mu$g/mL is frequently exceeded in all of the systems.</td>
<td>Condition Score: 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Confidence Score: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Trend: Stable</td>
</tr>
<tr>
<td><strong>Lakes Goegrup and Black</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phytoplankton</td>
<td></td>
<td>LAC not established</td>
<td>Phytoplankton Blooms are reportedly common</td>
<td>Condition Score: 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Confidence Score: 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Trend: Insufficient data</td>
</tr>
</tbody>
</table>

### Aquatic Plants

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Data analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peel-Harvey Estuary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component</td>
<td>Threats</td>
<td>Limits of acceptable change (LAC)</td>
<td>Data analysis</td>
<td>Condition</td>
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<tr>
<td>-------------</td>
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<td>-----------------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Macroalgae</td>
<td>LAC not established</td>
<td>Insufficient data.</td>
<td></td>
<td>Insufficient data</td>
</tr>
</tbody>
</table>
### Yalgorup Lakes

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Data analysis</th>
<th>Condition Score</th>
<th>Confidence Score</th>
<th>Trend</th>
</tr>
</thead>
</table>
| Macroalgae  | - Pollution from agriculture and horticulture industries  
- Leakage from municipal sewage treatment sites and private septic systems  
- Urban garden fertilisers.                                                                                                                  | No sustained epiphytic macroalgal growth on thrombolites at Lake Clifton.                                                                         | 3               | 3                | Stable     |
|             |                                                                                                                                                                                                       | Macroalgal growth is not sustained on the thrombolites at Lake Clifton as the salinity levels during the lowest water levels are too high to allow for species of macroalga to grow. (Hale and Butcher 2007). |                 |                  |             |

### Lakes McLarty and Mealup

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Data analysis</th>
<th>Condition Score</th>
<th>Confidence Score</th>
<th>Trend</th>
</tr>
</thead>
</table>
| Aquatic plants | - Pollution from agriculture and horticulture industries  
- Leakage from municipal sewage treatment sites and private septic systems  
- Urban garden fertilisers.                                                                                                                  | Greater than 50% of open water not covered in floating aquatic plants.  
Aquatic floating plants are currently not an identified threat within the two Lakes and winter 2014 did not exceed this LAC. | 4               | 3                | Stable     |

### Benthic Plants

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of acceptable change (LAC)</th>
<th>Data analysis</th>
<th>Condition Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yalgorup Lakes</td>
<td>Thrombolites</td>
<td>- Increasing salinity as a result of over</td>
<td>No loss of thrombolites at</td>
<td>There is no targeted monitoring of thrombolite extent. However, recent research has</td>
</tr>
<tr>
<td>Component</td>
<td>Threats</td>
<td>Limits of acceptable change (LAC)</td>
<td>Data analysis</td>
<td>Condition</td>
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<td>-----------</td>
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<td>-----------</td>
</tr>
<tr>
<td></td>
<td>allocation of groundwater, reduced rainfall and increased recharge of brackish and hypersaline groundwater.</td>
<td>Lake Clifton</td>
<td>confirmed that the thrombolites are still biologically and chemically active and while there has not been confirmation of annual growth, seasonal growth has been confirmed. Salinity levels continue to rise which is seen as a potential threat to the survival of the thrombolites at Lake Clifton. The thrombolites at Lake Clifton are actively growing, however, they range in condition and level of activity throughout the lake and over time (Whitehead, in prep). The thrombolite community is extremely dynamic, subject to seasonal variations and fluctuations, including periods of dormancy when conditions are not optimal to facilitate growth. While the community is actively growing, it is facing significant threats associated within increasing phosphorus, reductions in freshwater inflows and an extreme rise in salinity within the Lake. In addition, physical disturbances including unlawful pedestrian and vehicular access onto the Lake is a further pressure on the community.</td>
<td>Confidence Score: 3 Trend: Stable-Degrading</td>
</tr>
</tbody>
</table>
## Littoral vegetation

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peel-Harvey Estuary</td>
<td>• Increased tidal influence&lt;br&gt;• Rising sea levels&lt;br&gt;• Clearing&lt;br&gt;• Inappropriate fire regime</td>
<td>LAC not established</td>
<td>There have been four vegetation assessments of the Peel-Harvey Littoral Vegetation (1994 – Murray et al. 1995), 1995-97 Gibson 2000 (Gibson 2001), 2008 – DEC, 2008) and 2009 – Smith 2009, Hale &amp; Kobryn 2009). Unfortunately these four assessments, have been largely focused on vegetation cover, and all vary slightly in both location and methodology which prevents statistical analysis of data or a detailed determination of trends. While statistical analysis on data to determine trends across the estuary system has not been performed, a decline in vegetation condition including significant deaths of littoral vegetation has been noted. It can also be inferred through the data that a change in abundance and location (retreat of the fringing vegetation) of previous dominate species has occurred. Additional monitoring to confirms this is required. Gibson (2001) specifically monitored littoral vegetation and condition pre and post Dawesville Cut. This study has documented significant decline of the canopy post cut in five of the six riverine and estuarine tree species. On the western shore significant death of fringing vegetation has occurred with <em>Melaleuca raphiophylla</em> (freshwater paperbark) showing the greatest degree of decline. (Gibson 2001). Since the completion of the Dawesville Cut the Peel-Harvey Estuary has changed into a significantly more marine dominated ecosystem which includes a much higher salinity level that is maintained all year around. This has likely had a significant and permanent impact on both the species richness and densities of freshwater littoral vegetation that fringed the Peel-Harvey Estuary and lower reaches of its tributaries.</td>
<td>Condition Score: 2-3&lt;br&gt;Confidence Score: 2&lt;br&gt;Trend: Insufficient data</td>
</tr>
</tbody>
</table>
### Paperbarks

<p>| | | | |</p>
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</thead>
<tbody>
<tr>
<td></td>
<td>LAC not established</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No decline in paperbark</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Lakes McLarty and Mealup

<p>| | | | |</p>
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<tbody>
<tr>
<td>Littoral vegetation</td>
<td>Water regime that encourages <em>Typha</em></td>
<td><em>Typha</em> limited to &lt; 20% of the wetland area. Freshwater sedges covering a minimum of 20% of the wetland area.</td>
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<td></td>
<td></td>
<td>Lake Mealup</td>
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<tr>
<td></td>
<td></td>
<td>Parks and Wildlife have undertaken 44 hectares of <em>Typha</em> control in 2011 and 2012 prior to diverting water into the Lake which has prevented the regrowth of this invasive weed. Percentage cover has been reduced from greater than 45% to less than 1%. The 2009 Littoral and Fringing vegetation mapping (Hale and Kobryn 2009) report identified that Lake Mealup had 58% cover of the lake bed. It was recognised in this report that the majority of this cover was likely the introduced <em>Typha</em>, which was confirmed by onsite weed mapping that identified 45% <em>Typha</em> coverage in the lake.</td>
<td>Condition Score: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lake McLarty</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td><em>Typha</em> control within Lake McLarty has reduced <em>Typha</em> coverage from approximately 20% to less than 5%. The 2009 Littoral and Fringing vegetation mapping (Hale and Kobryn 2009) report identified that Lake McLarty had 20% native fringing vegetation cover of the lake bed.</td>
<td>Condition Score: 4</td>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline paperbark mapping was completed in 2007 of McLarty and Mealup. No</td>
<td>Condition Score: 3</td>
</tr>
</tbody>
</table>
No net loss of extent of paperbark community. Additional monitoring has been undertaken on paperbark health or extent since this time. Following the Lake Mealup recovery action that diverted water into the lake, significant natural regeneration of paperbarks is being observed around the Lake which is likely to significantly increase the extent of the current paperbark community in these locations. Regular reserve inspection has not identified in significant decline or decrease in paperbark health or extent.

<table>
<thead>
<tr>
<th>Lakes Goegrup and Black</th>
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</thead>
<tbody>
<tr>
<td>Samphire</td>
<td>LAC not established</td>
<td>ECD reported 83 Ha mapped in 2006 but no monitoring information available to determine variation or trends</td>
</tr>
<tr>
<td>Paperbark</td>
<td>LAC not established</td>
<td>ECD reported the extent of freshwater as 47 Ha and saltwater as 145 Ha and suggested variation in extent should be low</td>
</tr>
</tbody>
</table>

**Invertebrates**

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peel-Harvey Estuary</td>
<td>Invertebrates</td>
<td>Median CPUE for Blue Swimmer Crabs should not drop below 1.0 kg/trap lift per annum (based on commercial fishing).</td>
<td>When current and historical commercial and fishery-independent datasets were compared over a decade, it was concluded that the stock abundance has remained relatively constant (Johnston et al. 2014). This is in part due to the spawning stock being naturally protected when they exit the estuary over winter to spawn in oceanic waters. Consequently the current levels of fishing in the Peel-Harvey Estuary appear to be sustainable (Johnson et al. 2014). The trap catch between 2002/03 and 2010/11 has fluctuated between 45 and 104 t and catch rates (catch per unit effort) have fluctuated between 0.8 and 1.5 kg/trap lift, but have generally remained above 1.2 kg/trap lift since 2003/04 (Johnston et al. 2014) (Figure D106).</td>
<td>Condition Score: 3, Confidence Score: 4, Trend: Stable</td>
</tr>
<tr>
<td>Component</td>
<td>Threats</td>
<td><strong>Limits of Acceptable Change (LAC)</strong></td>
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<tr>
<td><strong>Lakes Goegrup and Black</strong></td>
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<tr>
<td>Invertebrates</td>
<td></td>
<td>LAC not established</td>
<td>ECD suggests surrogate levels should be established by maintenance levels to retain waterbird populations</td>
<td>Insufficient data</td>
</tr>
<tr>
<td><strong>Yalgorup Lakes</strong></td>
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<tr>
<td>Invertebrates</td>
<td></td>
<td>LAC not established</td>
<td>ECD suggests surrogate levels should be established by maintenance levels to retain waterbird populations</td>
<td>Insufficient data</td>
</tr>
<tr>
<td><strong>Lakes McLarty and Mealup</strong></td>
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<tr>
<td>Invertebrates</td>
<td></td>
<td>LAC not established</td>
<td>ECD suggests surrogate levels should be established by maintenance levels to retain waterbird populations</td>
<td>Insufficient data</td>
</tr>
<tr>
<td><strong>Fish</strong></td>
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<tr>
<td><strong>Component</strong></td>
<td>Threats</td>
<td><strong>Limits of Acceptable Change (LAC)</strong></td>
<td>Data Analysis</td>
<td>Condition</td>
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<tr>
<td><strong>Peel-Harvey Estuary</strong></td>
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<tr>
<td>Fish</td>
<td></td>
<td>LAC not established</td>
<td></td>
<td>Insufficient data</td>
</tr>
<tr>
<td><strong>Lakes Goegrup and Black</strong></td>
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<td>Insufficient data</td>
</tr>
<tr>
<td>Fish</td>
<td></td>
<td>LAC not established</td>
<td></td>
<td>Insufficient data</td>
</tr>
<tr>
<td><strong>Waterbirds</strong></td>
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<tr>
<td><strong>Component</strong></td>
<td>Threats</td>
<td><strong>Limits of Acceptable Change (LAC)</strong></td>
<td>Data Analysis</td>
<td>Condition</td>
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<tr>
<td><strong>Peel-Harvey Estuary</strong></td>
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<td>Component</td>
<td>Threats</td>
<td>Limits of Acceptable Change (LAC)</td>
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<tr>
<td>Waterbirds</td>
<td>Support &gt; 20,000 total waterbirds in 4 out of 5 years</td>
<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of waterbirds were above 20,000 for only two of the six years. Numbers varied during this six year period from a maximum count of 92,665 in 2013 to a minimum count of 11,669 in 2009 with a mean of 24,596. The variation is extremely high with a standard error of 6,688 and no significant trend. However, these data were collected from a snapshot survey conducted on one day each year and will not provide the most accurate indication of maximum waterbird populations for the Peel and Harvey estuaries. The available data indicates that the limit of acceptable change for the Peel and Harvey estuaries is not a realistic LAC and should be considered for amendment pending a more intensive monitoring program. It is known that many of the smaller lake systems surrounding the Peel and Harvey estuaries act as refuges during drought conditions inland and it would be expected that the waterbird numbers using the estuaries would also be higher during low rainfall years. Thus waterbirds are not necessarily an indicator of the health of the estuaries, but rather a reflection of condition in inland areas of the state and population number.</td>
<td>Condition Score: 2</td>
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<td>Support &gt; 1 % of the population of the following birds 3 out of 5 years: Banded Stilt (3000) Red-necked Stint (3200) Red-capped Plover (950) Red-necked Avocet (1100) Fairy Tern (60) Curlew Sandpiper (1800) Sharp-tailed Sandpiper (1600) Musk Duck (250) Australasian Shoveler (120) Eurasian Coot (10,000) Grey Teal (20,000)</td>
<td>Confidence Score: 3</td>
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<td></td>
<td>Banded Stilt (3,000)</td>
<td>Trend: Insufficient Information</td>
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<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Banded Stilt were above the LAC of 3,000 for only two of the six years. The mean count for the six year period was 5,691 and a standard error of 3,425 indicating the large variability in the population between years. It is known that Banded Stilt are significant opportunists for breeding events that take place in often remote wetland systems, many years apart. Amending the LAC should be considered pending more intensive monitoring.</td>
<td>Condition Score: 2</td>
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<td></td>
<td>Red-necked Stint (3,200)</td>
<td>Confidence Score: 3</td>
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<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Red-necked Stint were above the LAC of 3,200 for only two of the six years. The mean count for the six year period was 2,486</td>
<td>Trend: Insufficient Information</td>
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</table>
and a standard error of 740 indicating the large variability in the population between years. There was a downwards trend in numbers of Red-necked Stint counted in the estuaries, but in the same period, there was an equal increasing trend in numbers recorded in the Yalgorup Lakes, suggesting conditions in these lakes are more conducive for this species. Amending the LAC should be considered pending more intensive monitoring.

**Red-capped Plover (950)**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Red-capped Plovers were above the LAC of 950 for only one of the six years. The mean count for the six year period was 335 and a standard error of 170 indicating the large variability in the population between years. There was a downwards trend in numbers of Red-capped Plover counted in the estuaries after 2010, but in the same period, there was an equal increasing trend in numbers recorded in the Yalgorup Lakes, suggesting conditions in these lakes is more conducive for this species. Amending the LAC should be considered pending more intensive monitoring.

**Red-necked Avocet (1,100)**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Red-necked Avocet were above the LAC of 1,100 for only one of the six years. The mean count for the six year period was 291 and a standard error of 229 indicating the large variability in the population between years. Besides a population high of nearly 2,000 in 2010, numbers remain below 100 for all other years. Higher numbers of Red-necked Avocet were recorded in the Yalgorup Lakes, for most years but still below the LAC of 1,100. Amending the LAC should be considered pending more intensive monitoring.
<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Fairy Tern (60)</strong></td>
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<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is met. Total numbers of Fairy Terns were above the LAC of 60 for four of the six years. The mean count for the six year period was 84 and a standard error of 19. There was a downwards trend in numbers of Fairy Terns counted in the estuaries after 2011, but is too early to conclude that it is significant.</td>
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</table>

| **Curlew Sandpiper (1800)** | | | Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Curlew Sandpiper never approached within a magnitude of the LAC of 1800. The mean count for the six year period was just 13 and a standard error of 9. The counts were extremely low compared to data recorded over a 20 year period for Lake McLarty (1983-2003) where numbers were greater than 1,000 for half the number of years recorded. More intensive monitoring is required before conclusions can be drawn on the population of the Curlew Sandpiper, but it would be one of the priority species for monitoring efforts. | | Trend: Insufficient Information |

<p>| <strong>Sharp-tailed Sandpiper (1600)</strong> | | | Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Sharp-tailed Sandpiper were above the LAC of 1,600 for only two of the six years. The mean count for the six year period was 1,552 and a standard error of 855 indicating the large variability in the population between years. There was a downwards trend in numbers of Sharp-tailed Sandpiper counted in the estuaries, but in the same period, there was an equal increasing trend in numbers recorded in the Yalgorup Lakes, suggesting conditions in these lakes is more conducive for this species. Amending the LAC should be considered pending more intensive monitoring. | | Trend: Insufficient Information |</p>
<table>
<thead>
<tr>
<th>Component</th>
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<tbody>
<tr>
<td>Musk Duck (250)</td>
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<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Musk Duck were only recorded twice and never approached within a magnitude of the LAC of 250. The mean count for the six year period was just 2 and a standard error of 2. Significant numbers of around 250 were recorded in the Yalgorup Lakes in 2013. More intensive monitoring is required before conclusions can be drawn on the population of the Musk Duck, but it would be one of the priority species for monitoring efforts.</td>
<td>Trend: Insufficient Information</td>
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<tr>
<td>Australasian Shoveler (120)</td>
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<td></td>
<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Australasian Shovelers were only recorded once and never approached within a magnitude of the LAC of 120. The mean count for the six year period was just 2 and a standard error of 2. The counts were extremely low compared to highest annual count data (in Craig et.al. 2004) recorded over a 20 year period for Lake McLarty (1983-2003) where numbers were greater than 200 for every year after 1993. Significant numbers of around 50 were recorded in Lakes McLarty and Mealup in 2013, but more intensive monitoring is required before conclusions can be drawn on the population of the Australasian Shoveler, but it would be one of the priority species for monitoring efforts.</td>
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<tr>
<td>Eurasian Coot (10,000)</td>
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<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. The counts for Eurasian coots never approached within a magnitude of the LAC of 10,000. The mean count for the six year period was just 128 and a standard error of 95.</td>
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<td>Component</td>
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<td>Limits of Acceptable Change (LAC)</td>
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<td>More intensive monitoring is required before conclusions can be drawn on the population of the Eurasian Coot, but it would be one of the priority species for monitoring efforts.</td>
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<tr>
<td>Grey Teal (20,000)</td>
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<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. The counts for Grey Teal never approached within a magnitude of the LAC of 20,000. The mean count for the six year period was just 2,725 and a standard error of 1,289. Significant numbers are being recorded in the Yalgorup Lakes of up to 7,400, but more intensive monitoring is required before conclusions can be drawn on the population of the Grey Teal. It would be one of the priority species for monitoring efforts.</td>
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<tr>
<td>Breeding recorded for waterbird species (Pelicans, Little Pied Cormorants, Little Black Cormorants, Black Swan, Grey Teal, Darter and Black-winged Stilt) a minimum of once every three years.</td>
<td></td>
<td>No data available</td>
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<tr>
<td>Yalgorup Lakes</td>
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<tr>
<td>Waterbirds</td>
<td>Support &gt; 1 % of the population of the following birds 3 out of 5 years: Banded Stilt (3000) Red-necked Stint (3200) Hooded Plover (60) Musk Duck (250) Shelduck (2400)</td>
<td>Banded Stilt (3,000) Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Banded Stilt were above the LAC of 3,000 for only two of the six years, although the count in 2011 was just 100 birds short of making the LAC and the total count in 2013 was over a magnitude greater than the LAC. The mean count for the six year period was 7,604 and a standard error of 5,599 indicating the large variability in the population between years. It is known that Banded Stilt are significant opportunists for breeding events that take place in often remote wetland systems, many years apart. Amending the LAC should be considered pending more intensive monitoring, although this species is never going to be a</td>
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| Condition Score: 3 | Confidence Score: 3 | Trend: Insufficient Information | | |

<p>| Condition Score: 1 | | | | |</p>
<table>
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<tr>
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<td>sensitive measure of the conditions existing in the Peel-Yalgorup System.</td>
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<tr>
<td>Red-necked Stint (3,200)</td>
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<td></td>
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<td><strong>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Red-necked Stint were never recorded above the LAC of 3,200. The mean count for the six year period was 1,412 and a standard error of 416 indicating the large variability in the population between years. There was a general upwards trend in numbers of Red-necked Stint recorded in the Yalgorup Lakes, with a maximum count recorded of 2,730 recorded in 2012. Amending the LAC should be considered pending more intensive monitoring.</strong></td>
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<tr>
<td>Hooded Plover (60)</td>
<td></td>
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<td><strong>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is met. Total numbers of Hooded Plover were above the LAC of 60 for four of the six years. The mean count for the six year period was 72 with a standard error of 13. No general trends are evident for the population of Hooded Plovers using the Yalgorup Lakes and the numbers are ranging between 60 and 105 from 2009 through 2013.</strong></td>
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<tr>
<td>Musk Duck (250)</td>
<td></td>
<td></td>
<td><strong>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Musk Duck were above the LAC of 250 for only one of the six years. The mean count for the six year period was 55 with a standard error of 38 indicating the large variability in the population between years. Amending the LAC should be considered pending more intensive monitoring.</strong></td>
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<tr>
<td>Australian Shelduck (2,400)</td>
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### Strategic Assessment for the Perth and Peel Regions

**Component**

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<tr>
<th>Component</th>
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<th>Limits of Acceptable Change (LAC)</th>
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<tr>
<td></td>
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<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Shelduck were above the LAC of 2,400 for only two of the six years, although the count in 2009 was just under the LAC and the total count in 2012 was over four times greater than the LAC. The mean count for the six year period was 3,366 with a standard error of 1,423 indicating the large variability in the population between years. More intensive monitoring is required before conclusions can be drawn on the population of Shelduck in the Yalgorup Lakes. Waterbirds are not necessarily an indicator of the health of the estuaries, but rather a reflection of condition in inland areas of the state.</td>
<td>No data available</td>
<td>N/A</td>
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<td></td>
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<td>Successful breeding recorded for waterbird species (Black Swans, Hooded Plover, Red-capped Plover, Banded Lapwing and Great Crested Grebe).</td>
<td>Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of waterbirds counted did not get above 6,500 for these two combined systems with a mean of 1,869. However, these data were collected from a snapshot survey conducted on one day each year and will not provide the most accurate indication of maximum waterbird populations using Lakes McLarty and Mealup. The counts from the Shorebirds 20-20 surveys are significantly lower than those recorded in annual highest counts for Lake McLarty from ornithological surveys (1996-2004) in Craig et al. (2004). These surveys were conducted twice yearly and indicate total highest annual waterbird counts were greater than 20,000 for 6 out of the 24 years reported. While there is enough difference in methodologies to not be able to compare the counts, the difference indicates that the snapshot surveys cannot be relied on to indicate maximum waterbird populations using these two lakes. There was a significant upwards trend in the highest waterbird counts (Craig et al.</td>
<td>No data available</td>
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<tr>
<td>Component</td>
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<td>2004) at Lake McLarty from the from a count of 172 waterbirds in 1982 to a maximum in 1998 of 42,238 waterbirds. The very high variability in waterbird populations utilising this system, (numbers varied by over 30,000 between consecutive years) is evidence that the determinants are multi-factorial. Annual total rainfall and patterns across the state are known to have an effect on the numbers of waterbirds using these two lakes as the system acts as a refuge during drought conditions in the interior of the state. There is a good inverse correlation between annual rainfall and the numbers of waterbirds using the system. Thus waterbirds are not necessarily an indicator of the health of the lakes, but rather a reflection of condition in inland areas of the state. The available data indicates that the limit of acceptable change for Lakes McLarty and Mealup is not a realistic LAC and should be considered for amendment pending a more intensive monitoring program.</td>
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<td><strong>Banded Stilt (3,000)</strong> Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Banded Stilt were only recorded for one of the six years. It is known that Banded Stilt are significant opportunists for breeding events that take place in often remote wetland systems, many years apart. Amending the LAC should be considered pending more intensive monitoring. The lack of recorded sightings in the Shorebird 20/20 surveys is a result of the single snapshot taken each year. The data recorded in 24 years of highest count data for Lake McLarty (Craig et.al. 2004), indicated that Banded Stilt were observed in 15 of the 24 years and there was a mean of 294. Amending the LAC should be considered pending more intensive monitoring, although this species is never going to be a sensitive measure of the conditions existing in the Peel-Yalgorup System.</td>
<td><strong>Condition Score:</strong> 2  <strong>Confidence Score:</strong> 3  <strong>Trend:</strong> Insufficient Information</td>
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<tr>
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<td><strong>Red-necked Stint (3,200)</strong> Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Red-necked Stint were only recorded in two of the six years</td>
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</tbody>
</table>
| Red-capped Plover (950)                |         |                                   | and neither of these counts were close to the LAC, although the largest count of 2,300 occurred in 2013. Amending the LAC should be considered pending more intensive monitoring.                                                                                      | Trend: Insufficient Information  
Condition Score: 2  
Confidence Score: 3  
Trend: Insufficient Information  
Condition Score: 1  
Confidence Score: 3  
Trend: Insufficient Information  
Condition Score: 1  
Confidence Score: 3  
Trend: Insufficient Information  
Condition Score: 2  
Confidence Score: 1  
Trend: Insufficient Information |
| Red-necked Avocet (1,100)              |         |                                   | Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Total numbers of Red-capped Plovers did not come close to the LAC of 950. The mean count for the six year period was only 65 with a standard error of 28. Amending the LAC should be considered pending more intensive monitoring. | Trend: Insufficient Information  
Condition Score: 1  
Confidence Score: 3  
Trend: Insufficient Information  
Condition Score: 1  
Confidence Score: 3  
Trend: Insufficient Information  
Condition Score: 2  
Confidence Score: 1  
Trend: Insufficient Information |
| Curlew Sandpiper (1,800)               |         |                                   | Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Curlew Sandpiper were recorded in only one of the six years. The counts were extremely low compared to data recorded over a 20 year period for Lake McLarty (1983-2003) where numbers were greater than 1000 for half the number of years recorded. More intensive monitoring is required before conclusions can be drawn on the population of the Curlew Sandpiper, but it would be one of the priority species for monitoring efforts. Amending the LAC should be considered pending more intensive monitoring. | Trend: Insufficient Information  
Condition Score: 1  
Confidence Score: 3  
Trend: Insufficient Information  
Condition Score: 2  
Confidence Score: 1  
Trend: Insufficient Information |
<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Limits of Acceptable Change (LAC)</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
</table>
| **Black-winged Stilt (3,000)** |         |                                  | Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Black-wing Stilts were recorded for only three of the six years and the counts never approached within a magnitude of the LAC of 20,000. The mean count for the six year period was just 279 with a standard error of 231. Black-wing Stilts are being recorded each year in the Peel and Harvey estuaries and the Yalgorup Lakes with numbers up to 2,848 in the estuaries and a mean count of 2,848. More intensive monitoring is required before conclusions can be drawn on the population of the Black-wing Stilts, but the LAC should be considered for amendment, pending more intensive monitoring. It would be one of the priority species for monitoring efforts. | Condition Score: 1  
Confidence Score: 3  
Trend: Insufficient Information |
| **Sharp-tailed Sandpiper (1,600)** |         |                                  | Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Sharp-tailed Sandpipers were recorded for only one of the six years in the Lakes McLarty and Mealup with a count of 555 in 2013. Sharp-tailed Sandpipers are being recorded each year in the Peel and Harvey estuaries with numbers up to 6,007 in the estuaries and a mean count of 1,552. More intensive monitoring is required before conclusions can be drawn on the population of the Sharp-tailed Sandpipers, but the LAC should be considered for amendment, pending more intensive monitoring. | Condition Score: 1  
Confidence Score: 3  
Trend: Insufficient Information |
| **Australian Shelduck (2,400)**       |         |                                  | Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Australian Shelducks were recorded for only one of the six years. More intensive monitoring is required before conclusions can be drawn on the population of Shelduck in the Yalgorup Lakes. Australian Shelducks are being monitored each year in the Peel and Harvey estuaries with numbers up to 2,848 in the estuaries and a mean count of 2,848. |                                                                                                                                                   |
### Lakes Goegrup and Black

<table>
<thead>
<tr>
<th>Component</th>
<th>Threats</th>
<th>Data Analysis</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterbirds</td>
<td>LAC not established</td>
<td>• 12 species had counts&gt;100 over 2008-2013</td>
<td>Condition Score: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 1,720 Black-winged Stilts counted in 2013</td>
<td>Confidence Score: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 1,188 Australian Shelduck counted in 2013</td>
<td>Trend: Stable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No trend to suggest declining suitability for waterbirds 2008-2013</td>
<td></td>
</tr>
</tbody>
</table>

**Eurasian Coot (10,000)**

Based on the BirdLife Australia Shorebirds 20-20 dataset for the six year period 2008-2013, the LAC is not met. Eurasian coots were only recorded in two of the six years and the counts never approached within a magnitude of the LAC of 10,000.

More intensive monitoring is required before conclusions can be drawn on the population of the Eurasian Coot, but it would be one of the priority species for monitoring efforts. The LAC should be considered for amendment, pending more intensive monitoring.

Breeding recorded for waterbird species (Australian Shelduck, Black Swan, Grey Teal, Pacific Black Duck, Great Crested Grebe, Purple Swamphen, Dusky Moorhen, Spotless Crake, Little Pied Cormorant and Darter) a minimum of once every three years.

No data available

N/A
### 4.2.1 Summary and conclusions for LACs

Table D53: Summary of the condition against each of the LAC

<table>
<thead>
<tr>
<th>Components and processes</th>
<th>Limits of acceptable change (LAC)</th>
<th>Condition Score</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peel-Harvey Estuary</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nutrients</strong></td>
<td>TP &lt; 30 µg/L (maximum). PO₄, NH₄, NO₃ - median concentrations &lt; 10 µg/L</td>
<td>2–3</td>
<td>stable to degrading</td>
</tr>
<tr>
<td><strong>Dissolved Oxygen</strong></td>
<td>70-80 % saturation</td>
<td>2-3</td>
<td>degrading</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>pH &gt; 7 at all times</td>
<td>3</td>
<td>stable</td>
</tr>
<tr>
<td><strong>Salinity</strong></td>
<td>Winter salinity in the centre of the Peel Inlet and Harvey Estuary &lt; 30 ppt for a minimum of 3 months.</td>
<td>2</td>
<td>degrading</td>
</tr>
<tr>
<td></td>
<td>Water in the Harvey River mouth over winter &lt; 3 ppt.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chlorophyll a</strong></td>
<td>median concentrations &lt; 10 µg/L</td>
<td>2</td>
<td>stable</td>
</tr>
<tr>
<td><strong>Benthic Plants</strong></td>
<td>Seagrass-LACs Not Established</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Macroalgae-LACs not established</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Littoral vegetation</strong></td>
<td>LACs Not Established for extent of Samphire or Paperbarks, but limited data suggests that any reduction in fringing vegetation will be significantly deleterious to the condition of the system</td>
<td>2-3</td>
<td>degrading</td>
</tr>
<tr>
<td>extent and condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Estuarine invertebrates</strong></td>
<td>Median CPUE for Blue Swimmer Crabs should not drop below 1.0 kg/trap lift per annum (based on commercial fishing).</td>
<td>3</td>
<td>stable</td>
</tr>
<tr>
<td><strong>Fish</strong></td>
<td>LACs Not Established</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Waterbirds (preliminary LACs that need review)</td>
<td>Support &gt; 20,000 total waterbirds in 4 out of 5 years</td>
<td>2–3</td>
<td>stable to degrading</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>------------------------------------------------------</td>
<td>-----</td>
<td>------------------</td>
</tr>
<tr>
<td></td>
<td>Support &gt; 1% of the population of the following birds 3 out of 5 years:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Banded Stilt (3000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red-necked Stint (3200)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red-capped Plover (950)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red-necked Avocet (1100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fairy Tern (60)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Curlew Sandpiper (1800)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sharp-tailed Sandpiper (1600)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Musk Duck (250)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Australasian Shoveler (120)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eurasian Coot (10,000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grey Teal (20,000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Breeding recorded for waterbird species (Pelicans, Little Pied Cormorants, Little Black Cormorants, Black Swan, Grey Teal, Darter and Black-winged Stilt) a minimum of once every three years.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yalgorup Lakes</th>
<th>Nutrients</th>
<th>2</th>
<th>degrading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PO₄, NH₄, NO₃ - median concentrations &lt; 10 μg/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salinity</td>
<td>2</td>
<td>degrading</td>
</tr>
<tr>
<td></td>
<td>Lake Clifton salinity &lt; 35 ppt maximum and &lt; 25 ppt during winter and spring.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>4</td>
<td>stable</td>
</tr>
<tr>
<td></td>
<td>pH &gt; 7 at all times</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Groundwater discharge</td>
<td>2-3</td>
<td>Stable to degrading</td>
</tr>
<tr>
<td></td>
<td>LAC not established, but limited depth to groundwater data suggests that hydraulic head has reduced by between 20 – 50cm over the 20 year period since 1995</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LAC not established</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td><strong>Phytoplankton</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Benthic Plants</strong></td>
<td>No sustained epiphytic macroalgal growth on thrombolites at Lake Clifton</td>
<td>3</td>
<td>Stable to degrading</td>
</tr>
<tr>
<td><strong>Thrombolites</strong></td>
<td>No loss of thrombolites at Lake Clifton</td>
<td>3</td>
<td>Stable to degrading</td>
</tr>
<tr>
<td><strong>Invertebrates</strong></td>
<td>LAC not established</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Fish</strong></td>
<td>LAC not established</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Waterbirds</strong></td>
<td>Support &gt; 1 % of the population of the following birds 3 out of 5 years: Banded Stilt (3000) Red-necked Stint (3200) Hooded Plover (950) Musk Duck (250) Australian Shelduck (2400)</td>
<td>2–3</td>
<td>stable to degrading</td>
</tr>
<tr>
<td>(preliminary LACs that need review)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lakes McLarty and Mealup</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nutrients</strong></td>
<td>PO₄ &lt; 30 μg/L</td>
<td>2–3</td>
<td>McLarty-degrading Mealup-Stable-improving</td>
</tr>
<tr>
<td></td>
<td>NH₄ &lt; 40 μg/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO₃ &lt; 100 μg/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>All applied when water levels are &gt; 500mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Salinity</strong></td>
<td>Salinity under rush and sedge communities &lt; 1 ppt.</td>
<td>2</td>
<td>Stable-degrading</td>
</tr>
<tr>
<td></td>
<td>Salinity under paperbark communities &lt; 0.5 ppt.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>pH &gt; 7 at all times</td>
<td>4</td>
<td>Stable</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------</td>
<td>---</td>
<td>--------</td>
</tr>
<tr>
<td>Groundwater discharge</td>
<td>LAC not established</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Phytoplankton</td>
<td>LAC not established</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Aquatic Plants</td>
<td>Greater than 50% of open water not covered in floating aquatic plants.</td>
<td>4</td>
<td>Stable</td>
</tr>
<tr>
<td>Littoral Vegetation</td>
<td>Typha limited to &lt; 20 % of the wetland area.</td>
<td>3</td>
<td>Stable</td>
</tr>
<tr>
<td></td>
<td>Freshwater sedges covering a minimum of 20% of the wetland area.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paperbarks-no net loss in extent or health</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Invertebrates</td>
<td>LAC not established-surrogate indicator is maintenance of waterbird populations</td>
<td>3</td>
<td>stable</td>
</tr>
<tr>
<td>Waterbirds</td>
<td>Support &gt; 20,000 total waterbirds in 4 out of 5 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Support &gt; 1 % of the population of the following birds 3 out of 5 years:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Banded Stilt (3000)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Red-necked Stint (3200)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Red-capped Plover (950)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Red-necked Avocet (1100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Curlew Sandpiper (1800)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Support > 1 % of the population of the following birds 3 out of 5 years:
Breeding recorded for waterbird species (Australian Shelduck, Little Pied Cormorants, Little Black Cormorants, Black Swan, Grey Teal, Darter, Pacific Black Duck, Great Crested Grebe, Purple Swamphen, Dusky Moorhen and Spotless Crake) at a minimum of once every three years.

<table>
<thead>
<tr>
<th>Lakes Goegrup and Black</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nutrients</strong></td>
</tr>
<tr>
<td>PO₄, NH₄, NOₓ - median concentrations &lt; 10 mg/L</td>
</tr>
<tr>
<td><strong>Salinity</strong></td>
</tr>
<tr>
<td>LACs not established – surrogates: periods of &lt;30ppt for spawning of the long-headed river goby and values&lt;3ppt to provide drinking water for some waterbirds</td>
</tr>
<tr>
<td><strong>pH</strong></td>
</tr>
<tr>
<td>pH &gt; 7 at all times</td>
</tr>
<tr>
<td><strong>Phytoplankton</strong></td>
</tr>
<tr>
<td>LAC not established</td>
</tr>
<tr>
<td><strong>Samphire</strong></td>
</tr>
<tr>
<td>LAC not established</td>
</tr>
<tr>
<td><strong>Paperbark</strong></td>
</tr>
<tr>
<td>LAC not established</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Invertebrates</td>
</tr>
<tr>
<td>Fish</td>
</tr>
<tr>
<td>Waterbirds</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
The Peel-Yalgorup System Ramsar site retains those values recognised in all six of the criteria from the 2007 review of the Ramsar Information Sheet. The wetland habitat remains suitable to support high numbers of waterbirds in all parts of the system with perhaps the exception until June 2012, being for Lake Mealup, where all species counts had declined. Recent restoration of near natural hydrological regime, water quality and aquatic vegetation through the redirection of the Mealup Main Drain into Lake Mealup should facilitate a return to expected populations of waterbirds in that wetland.

The Shorebird 20-20 data does confirm that habitat within the components of the Peel-Yalgorup System remains suitable to support high numbers of waterbirds with numbers across the entire Peel-Yalgorup System Ramsar site being greater than 20,000 for all six years of monitoring 2008-2013 and a maximum count in 2013 of over 90,000 waterbirds was recorded.

The data used to verify waterbird populations comes from Australian Birdlife Shorebird 20-20 which is recognised as not designed to provide maximum bird counts, and conclusions are made cautiously, recognising that maximum waterbird usage of the wetlands in the Peel-Yalgorup System is likely to be considerably higher than this data suggests. For instance, Criteria 6, is assumed met based on the annual BirdLife Australia's Shorebird 20--20 counts which confirm that the 1% threshold for Hooded Plover, Red-necked Stint, Banded Stilt, Fairy Tern and Australian Shelduck were reported in two-thirds of the surveyed years 2008-2013. It is also noted that There are three species that were not above the LAC threshold in any of the six surveyed years, these being Australasian Shoveler, Eurasian Coot and Grey Teal and a further two species that were recorded in numbers above the LAC in only one year out of the six surveyed, those being Red-necked Avocet and Musk Duck. These species should be targeted in more intensive waterbird monitoring to confirm their status.

The wetland complex that forms the Peel-Yalgorup Ramsar site continue to provide drought refuge to many waterbird species including 29 species listed nationally under the EPBC Act 1999, the same number identified in the 2007 ECD (Hale and Butcher 2007).

Concerns were raised in 2009 that the condition of the nationally listed Thrombolite community at Lake Clifton had deteriorated to the point where the biogeochemical processes that give rise to the structures were no longer present. However, extensive research since then has confirmed that the Thrombolite forming processes remain active and while microbial composition may have altered in response to changing nutrient and salinity conditions, the Thrombolite community are active and seasonal growth has been confirmed.

The Peel-Yalgorup System remains an important breeding, nursery and feeding ground for at least many species of fish as well as the commercially significant Blue Swimmer Crab. Analysis of current and historical commercial and fishery-independent datasets compared over a decade, indicated that the stock abundance of most species has remained relatively constant. The notable exception being a significant reduction in the catch of Western King Prawns. At the same time water quality has deteriorated in the estuarine reaches of the Murray and Serpentine Rivers since construction of the Dawesville Channel. Consequently fish kill events are a feature of these systems and are most likely caused by low dissolved oxygen due to stratification and/or algal blooms, but they can also result from gills clogged by suspended matter (phytoplankton or sediment), toxic phytoplankton species or toxic gases from anoxic sediments. The highest number of fish kill events in the period 1999-2012 occurred in the Murray River (16), followed by the Serpentine (11) and then Peel Inlet (2). No fish kill events have been noted in the Harvey Estuary during this period. The numbers of fish kill events and the number of fish killed in these events has declined since peaks between 2002-2005, which appears not to be related to declining fish populations, but further research is required to better understand the trends.
The listing in December 2009 under the EPBC Act of the *Thrombolite (microbialite) Community of a Coastal Brackish Lake (Lake Clifton)* as a critically TEC, the listing in August 2013 of the *Subtropical and Temperate Coastal Saltmarsh* as a vulnerable TEC, and in 2011 of the Fairy Tern (*Sternula nereis nereis*) as a vulnerable threatened species, qualifies the Peel-Yalgorup System Ramsar site as meeting a further seventh criteria i.e. Criteria # 2 - *A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or Threatened Ecological Communities.* The proposed addition of this criterion will be addressed through the next revision of the Ramsar Information Sheet in 2015.

Assessment against the Limits of Acceptable Change (LACs) highlights that many of the LACs are being met in the majority of years. However, the assessment also shows that LACs for a number of key components and processes are either never being met, or not being met in the majority of years. These components and processes include:

- **Nutrients (Total-P, Total-N, NOx)** - particularly in the Serpentine and Murray Rivers, Goegrup Lake, Yalgorup Lakes and during low water levels in Lake McLarty.
- **Phytoplankton** – particularly significant in the Serpentine and Murray Rivers and in Goegrup Lake and in the Peel Inlet and Harvey Estuary.
- **Dissolved Oxygen** – particularly in bottom waters and in the Serpentine and Murray Rivers.
- **Salinity** - particularly in the Yalgorup Lakes.
- **Littoral Vegetation** – particularly along fringes of the Peel Inlet and Harvey Estuary and lower reaches of its tributaries.

The areas of most concern are the Serpentine River and Murray River where the greatest proportions of water samples exceed the LAC for Total-P and for Dissolved Oxygen and consequently where the greatest number of fish kills occurs. If the apparent linear trend of declining dissolved oxygen continues, within about 15 years, all channel systems, including the Peel-Harvey Estuary will be anoxic with concentrations of dissolved oxygen below levels tolerated by fish i.e. < 4 mg/L.

The steady increase in salinity and nutrient concentrations in the Yalgorup Lakes is important and particularly the salinity is likely to lead to the deterioration of the Thrombolite formed processes responsible for these communities is the trend is not able to be managed effectively.

Declining water quality in Lake Mealup, particularly pH, up to the construction of the Weir on the Mealup Main Drain and diversion of drainage water into the lake in 2012, appeared responsible for declining waterbird usage. However, since June 2012, water quality, with the exception of Total-P concentration, has improved and now close to natural conditions. It is hoped that as a result the lake will again support significant waterbird populations. Similarly, the return to a more normal hydrological regime in Lake Mealup has led to significant regeneration of Paperbark in the littoral zone of the lake and together with intensive management of the weed, *Typha* in Lake Mealup and Lake McLarty, has improved habitat values of these lakes, which is hoped will contribute to higher waterbird usage.

Evaluation of the available data for the biotic and abiotic components and processes for the Peel-Yalgorup System Ramsar site confirms that the ecological character has not been significantly altered since it was designated a wetland of international significance in 1990. However, significant pressures exist, including reduced rainfall and higher temperatures, together with abstraction of groundwater and land use change, that have the potential to negatively impact on the ecological character of the wetlands that make up this system. Future urbanisation could, to some extent, offset the effects of reduced rainfall with the increasing presence of impervious surfaces leading to a higher percentage of
rainfall entering the Superficial Aquifer as recharge than would occur under native vegetation. In the current climate of diminished rainfall, increased evaporation and a reduction in recharge to groundwater, increased recharge associated with impervious surfaces could help maintain groundwater recharge that in turn maintain many of the components and processes of the system. However urbanisation is also likely to increase nutrient concentrations in the Superficial Aquifer and increase habitat decline, disturbance and predation of waterbirds and spread of plant diseases.

Pressures will continue to build from declines in rainfall, changes to seasonal patterns of rainfall, increasing temperatures, high wind events and evaporation and sea level rise. Wetland systems are already undergoing significant alteration of hydrological regimes from reduced recharge of groundwater and river flows. Future increases in sea level will increase the occurrence of flood events, leading to significant degradation of coastal and fringing vegetation. Pressure from increased flood risk will also be experienced within developed areas under 3-5 metres in elevation, including many new urban development areas. Significant gaps in knowledge of many of the components and processes of the Peel-Yalgorup System Ramsar site still exist and this limits the certainty in describing the condition of the system. Most notably is the lack of information of on the benthic, aquatic and littoral vegetation communities, their extent and condition across the entire system. Information on fish assemblages is known from surveys conducted through Murdoch University, but monitoring of fish population is not conducted and largely estimated from catch rates of commercially viable species. For instance the catch of Western King Prawns has diminished, but details are not available on the current population size or whether conditions within the estuarine system have contributed to the decline. Aquatic invertebrate data is almost totally lacking for any of the wetland systems and yet, they are a key part of the food source for most of the waterbirds, particularly those migratory shorebirds. While BirdLife Australia are consistent in collection of annual bird counts in the Shorebird 20-20 program, the data does not allow accurate indications of waterbird populations in the system. There is no consistent water quality monitoring in Black and Goegrup Lakes while the monitoring in the Yalgorup Lakes, though well done, is based on ad-hoc research programs.
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