Ecological character of the Lake MacLeod Wetland of International Importance

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Disclaimer

In undertaking this work the authors have made every effort to ensure the accuracy of the information used. Any conclusions drawn or recommendations made in the report are done in good faith and the consultants take no responsibility for how this information and the report are used subsequently by others. Note also that the views expressed, and recommendations provided, in this report do not necessarily reflect those of persons or organisations that have contributed their views or other materials.

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Cover photographs

The photographs used in the collage on the front cover were kindly provided by the following:

From the top of the collage, photos 1, 2, 4 and 5: Dampier Salt Limited, Photograph 3, (the late) Colin Davis, Australasian Wader Study Group.

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1. Introduction

The listing of a site as a Wetland of International Importance (Ramsar site) carries with it a number of obligations, including management of the site to retain its 'ecological character'. Ramsar Convention signatories are also expected to have mechanisms in place to help detect threats that are likely to, or may, alter the 'ecological character' of the wetland. Describing the 'ecological character' of a Ramsar site is therefore a fundamental step so that a baseline condition is documented and can then be used to guide management actions and monitoring.

The Ramsar Convention has defined 'ecological character' and 'change in ecological character' as shown below. It has also provided guidelines for management planning, establishing monitoring programs and undertaking risk assessments, however, there is at present no method recommended by the Convention for describing ecological character.

Ramsar's definitions:

> *Ecological character is the sum of the biological, physical and chemical components of the wetland ecosystem, and their interactions, which maintain the wetland and its products, functions and attributes.*
>
> *Change in ecological character is the impairment or imbalance in any biological, physical and chemical components of the wetland ecosystem, or in their interactions, which maintain the wetland and its products, functions and attributes.*

In Australia, the Commonwealth Government's *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act), provides the legal framework for ensuring that the 'ecological character' of Ramsar sites is retained. The EPBC Act establishes a Commonwealth process for the referral, and possible assessment, of proposed actions that may have a significant negative impact on '*matters of national environmental significance'*, among which are Ramsar sites. Detailed descriptions of 'ecological character' are therefore central to the effective implementation of the EPBC Act, which is designed to ensure Australia is meeting its site management obligations under the Ramsar Convention.

Through the initiative of Dampier Salt Limited, with the encouragement and support of WWF Australia and the Western Australian Department of Conservation and Land Management, it is proposed that part of Lake MacLeod (see Figures 1 and 2) be nominated for Ramsar designation. A plan of management for the lake, including the area proposed for Ramsar listing, has been prepared. The plan of management contains a summary form of this description of ecological character.

2. Approach taken

Wetland ecosystems are complex and dynamic, changing in composition and structure over time, both gradually in response to natural successional processes, and rapidly due to disturbance, both human-induced and natural (e.g. cyclones). The structure, composition, and dynamics of an ecosystem reflect the historical patterns of disturbance and management (Wallington *et al*. 2005). These fluctuations in ecosystems, both natural and human-induced, have serious implications for the management of ecosystems, such as Ramsar sites.

A fundamental feature of ecosystems is their variability, and the temporal dynamics of any system means it cannot be expected to remain static. Describing the ecological character of a site must take this into consideration – and ranges of acceptable variation or change for the components and processes which make the site noteworthy must be defined in order that unacceptable changes can be detected rapidly and then addressed.

It is possible to identify a limited set of biological characteristics, ecological processes and interactions with the physical environment, and their causal links, that are largely responsible for the ecological character of wetland ecosystem. The approach taken here for describing the ecological character of the Lake MacLeod Ramsar site is based on documenting the ecosystem drivers, and the related ecological and hydrological processes, that work together to support the species, assemblages and ecological communities that together allow the site to meet several of the criteria for nomination as a Wetland of International Importance. The Ramsar Information Sheet for the site (see Appendix A) provides the justification for the site being considered a Ramsar site and offers points of reference when sourcing information for describing the ecological character of the site.

The approach taken to describing the ecological character of the Lake Macleod Ramsar site can be broken down into six steps as follows:

Step 1 (section 3.1): Provide an overview of the site; its' location, climate, hydrology, special biological, ecological and other values.

Step 2 (section 3.2): Document the underlying 'drivers' of the system; those ecological, hydrological, chemical and other processes that combine to determine where certain wetland types and habitats occur in the system, and in turn where the significant biological assets will be found (see Step 4).

Step 3 (section 3.3): Link the ecological drivers and processes to the significant biological assets and the key wetland types and habitats considered pivotal to the value of the site as a Wetland of International Importance.

Step 4 (section 3.3 also): Document the significant biological assets of the site; its' plant and animal species and the unique ecological communities and assemblages which provide the biological justification for why the area is considered globally important. For each of these significant biological assets, attempt to quantify their presence, either in terms of population numbers or area covered (See section 3.3 for detail). This component of the description of ecological character focuses on the structural and compositional aspects of the site, the flora and fauna which occur at the site, in response to the spatial context of the ecosystem. It also describes the ecological, hydrological and other processes operating within the wetland that link the significant biological assets with the system drivers.

Step 5 (section 3.4): Draw together the findings from steps 2, 3 and 4 to define the ecological character management benchmarks with baseline conditions and short and long term limits of acceptable change.

Step 6 (section 3.5): Describe the ecosystem services provided by the site and how they relate to the ecological character management benchmarks.

Step 7 (section 3.6): Identify priority knowledge gaps for future attention. These will, in most part, be identified through the preceding steps.

Documenting short and long-term natural variations in the system

To adequately describe the ecological character of a wetland it is important to document the natural ranges of variation of the internal components that will be monitored to establish if there is change occurring. All ecosystems are variable, and changes occur over some particular range of variation for each component, process and function. When an ecological system is subjected to fluctuations outside the natural range of variability associated with that system, such as through drought or human-induced impact, the wetland and its components are likely to experience fundamental changes in structure, composition, and function. Once a certain critical threshold is passed then the ecosystem may not be able to return to its original state (see the definition of *'change in ecological character'* – section 1).

Understanding ranges of natural variation therefore becomes an important aspect of managing the wetland – it is important to understand what acceptable and unacceptable change is for the elements that make up the ecological character. Ideally, it would be best to set acceptable ranges of variation or benchmark statements at the time of Ramsar listing (or as soon as possible thereafter) as it is against these quantitative descriptions that management actions and monitoring programs are established. In doing this there has to be acknowledgement that wetland ecosystems are highly dynamic and will change over time. A static description of ecological character is not valid, as wetlands are not static systems. Quantitative descriptions of the elements of ecological character considered important should be the objective when listing a site, which include ranges of natural variation. However, in many cases there will be insufficient data to provide these quantitative ranges at the outset. Thus, describing ecological character will identify knowledge gaps that require further investigation over time in order to add robustness to the description and the associated management regime.

Limits of acceptable change

This term is used extensively throughout this report. As used here this term indicates the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland, such as population measures, hectares covered by a particular wetland type, the range of a certain water quality parameter, etc, without indicating a change in ecological character which may lead to a reduction or loss of the values for which the sites 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. For example – if monitoring showed that for a certain significant species the population within the Ramsar site had fallen by say, 5% based on surveys over a suitable time period, then this would require careful examination to establish the cause, and to respond to it through monitoring and adaptive management.

It should be recognised that in order to set limits of acceptable change, there must be an understanding of the existing system attributes against which change can be measured. This often requires long term data sets that accurately reflect the natural variability of the system. There is no substitute for data and as such, expert opinion can only be used as interim advice until such data becomes available from comprehensive, statistically valid monitoring. Where data is lacking then the precautionary approach should be applied by site managers.

Setting meaningful values of acceptable change for biotic components, usually based on population trends, is often very difficult and it is only recently that standard approaches have begun to be developed. For example, Sauer (2003) notes that it is impossible to interpret the biological significance of most population declines in waterbirds estimated from monitoring programs alone. In many cases arbitrary population changes are set as benchmarks or trigger values and estimated population changes that exceed these values are slated for additional investigation. However, without appropriate data on the context of the population change benchmarks, most are meaningless (Sauer, 2003).

For water quality variables (chemical, physical and some biological components) there are accepted guidelines and targets for healthy flowing surface waters. According to the ANZECC guidelines (*Core Environmental Indicators for Reporting on the State of the Environment,* ANZECC 2000), a high conservation value system such as Lake McLeod, should be managed to ensure that there is no significant change (beyond natural variability) to the chemical, physical or biological components of the ecosystem. This supports the principals of the Ramsar definition of ecological character, and the idea of setting limits of acceptable change.

The guidance given regarding limits of acceptable change for Lake MacLeod is provided (in section 3.6) whilst acknowledging the inherent problems in doing this with less than adequate data. For the ecological features of Lake MacLeod which are considered in the ANZECC guidelines (ANZECC 2000), the interim trigger values, where known, are included or the approach for setting interim trigger values is adopted. The method of setting trigger values is based, primarily on the concept of median values and percentiles (rather than means and percentages). This is due to the high variability that can occur in water quality parameters and is an attempt to capture this variability in a meaningful manner. These values should not be seen as threshold values, but only as interim values. These interim values must be refined and developed as more information about the system becomes available.

Ecosystem services

This term has gained in currency over recent years as a way to indicate that natural systems provide a range of services and benefits for humans. These can be broken down into various categories such as provisioning services (providing freshwater for example), regulating services (such as moderating local climate), cultural services (like observing nature or cultural significance for Indigenous people) and supporting services (including the cycling of nutrients within the environment or supporting biodiversity). In this description of ecological character an indication has been provided of these various ecosystem services (Section 3.5). The primary value of this information is to indicate to the managers of the site, where they have a range of ecosystem services, to be mindful of these when implementing the plan of management.

Knowledge gaps

In many places in the sections following in this report the term ‘knowledge gap’ has been used. In some cases this simply means that no-one has, as yet, carefully documented the distribution of significant species or an ecological community within the Ramsar site. In other cases, the use of the term ‘knowledge gap’ is meant to convey that at present science is yet to fully describe a certain ecological process or similar more technical aspect of the systems’ mechanics. Again, it is hoped that as a follow-up response to this report, some of these priority ‘knowledge gaps’ will be investigated.

3. Description of ecological character

The description as set out below follows the seven steps outlined in the preceding section.

3.1 Overview of the site including the significant biological assets (Step1)

Lake MacLeod lies approximately parallel to the Carnarvon-Ningaloo coast of Western Australia (Figure 1). It covers an area of approximately 2000 km^2, is a predominantly dry lakebed, which is episodically filled from the Lyndon and Minilya rivers and other tributaries after heavy rains. In the north west of the lake bed lie what are commonly known as the “Northern Ponds”. This area is a unique environment as it is a permanent saline wetland system, fed by the underground seepage of seawater travelling 18 km inland before rising in the “vents” (Dampier Salt Limited, 2000).

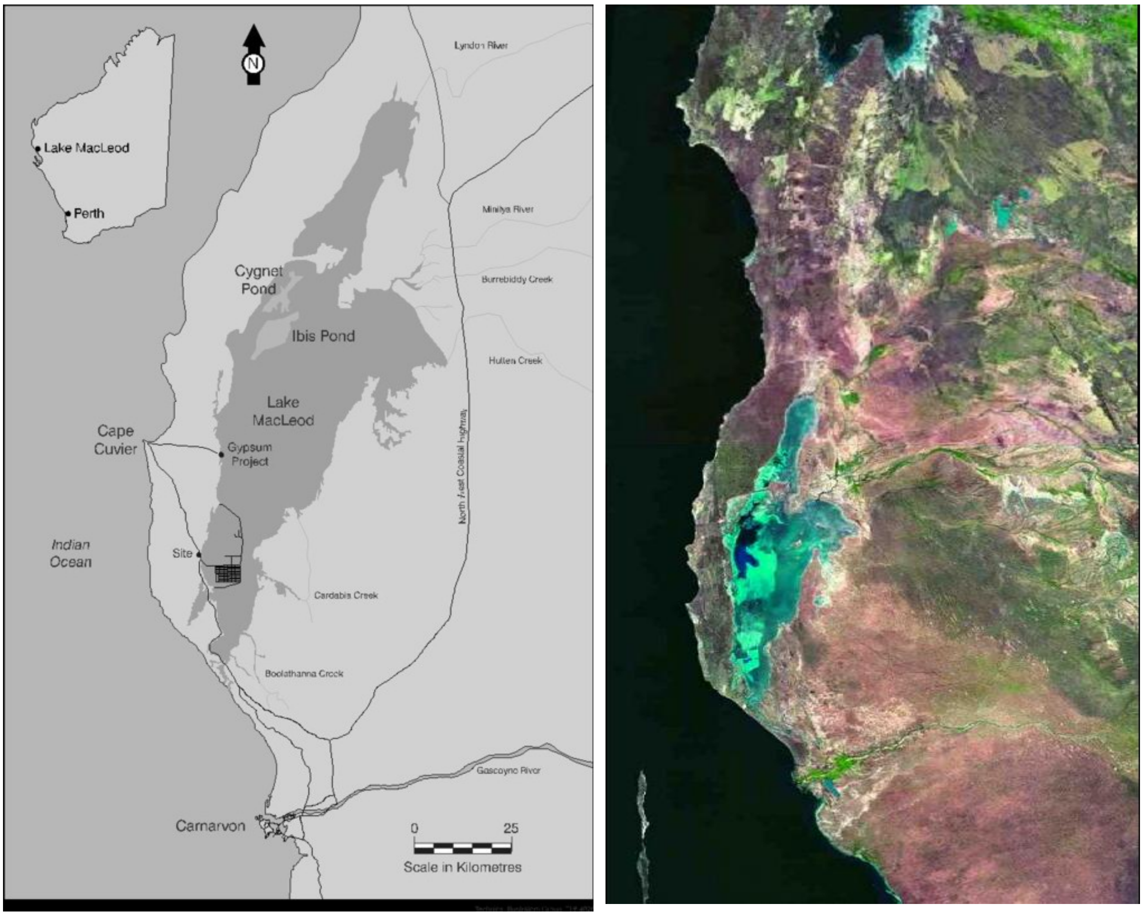

Figure 1: Map and aerial photograph showing the location of Lake Macleod (Source: DSL, 2000)

The closest population centre to the Lake MacLeod Ramsar site is Carnarvon, approximately 100 kilometres to the south. Lake MacLeod is approximately 120 kilometres long and for most of its length is around 10 kilometres wide. At its widest point it is 40 kilometres. The lake surface is at an elevation of three to four metres below sea level. The surface of the lake is normally dry from

September to June, though winter or summer rains can result in the lake being wholly or partially covered by water.

As shown by Figure 2, the area of Lake MacLeod proposed for nomination as a Ramsar wetland is centred around the Northern Ponds. This is an area of approximately 6000 ha and comprises two distinct lakes: Cygnet and Ibis Ponds. Other smaller wetlands are also found in the surrounding lake bed. These permanent wetlands support the largest inland mangrove populations of *Avicennia marina* in the world. The mangroves have been isolated from coastal population for approximately 6000 years, and exist in environmentally stressful conditions, tolerating extremely high salinities (Dampier Salt Limited, 2000).

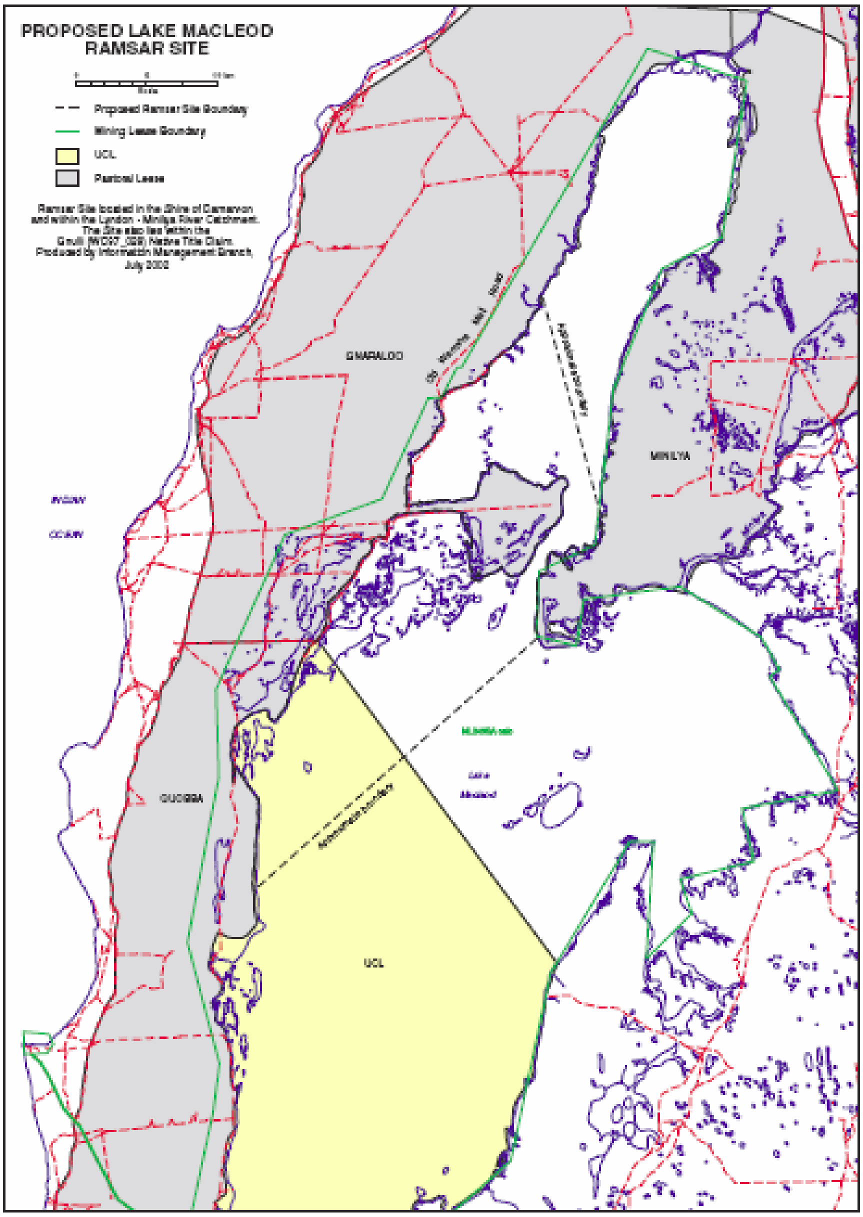

Figure 2: Map showing the portion of Lake MacLeod proposed for Ramsar listing (Source: Ramsar Information Sheet – Appendix A)

The greater part of Lake MacLeod periodically receives freshwater from the Lyndon and Minilya Rivers and Cardabia and Boolathana Creeks; the latter being a distributary of the Gascoyne River which originates 620 kilometres to the east south-east and has a surface catchment of 73,000 square kilometres. Surface inflow from the smaller rivers is intermittent and may affect only the vicinity of the river mouths, not spreading as far as the Northern Ponds Ramsar area.

Major flooding from the Gascoyne River occurs infrequently, with significant historical flows to the lake occurring in 1960, 1961, 1980, 1995 and 2000. The 2000 flood was the largest recorded over this period with water contributed by all rivers and local rainfall. Most floods occur during the cyclone season (February-March) and in mid-winter (May-June) (Logan 2001).

Water from the Indian Ocean passes underground 18 kilometres through coastal limestone and under hydrostatic pressure rises up in the site's sinkholes, which are slightly below sea level. Water flows southwards from several principal points of discharge within the sinkhole network, through the channel system to the main permanent lake. Water periodically overflows across a broad mudflat to the terminal permanent lake. Water discharging from minor sinkholes terminates in adjacent saline marshes. Water in the sinkholes may be several metres deep; water in the Northern Ponds system can be in the order of one metre in depth. Average water depth is estimated to have been 1.4 metres during the 2000 flood.

Water emerging from the sinkholes has the salinity of seawater but is hypersaline to brine when it reaches the terminal lagoon. River floodwaters are initially fresh, but become brackish or saline on mixing with the lake waters during flood events.

Significant biological assets (SBAs)

The Northern Ponds are regarded as having the greatest biodiversity values within Lake MacLeod. This area encompasses the series of sinkholes or vents, typically tens of metres wide. The sinkholes are connected by channels, between a few metres and hundreds of metres wide, to a system of permanent wetlands, marshes and mudflats. The area of inundation can vary substantially, depending on evaporation, rainfall and prevailing winds, and during summer might occupy approximately 5,000 hectares.

Within this area, Grey Mangroves *Avicennia marina* fringe the sinkholes, channels and permanent lakes although small patches of mangrove are also scattered across the surrounding greater lake bed. The mangrove community is the largest (covering 22.5 ha) of only two inland occurrences in Western Australia (Johnstone 1990); the other is at Mandora Salt Marshes which is within the Eighty Mile Beach Ramsar Site. Low shrubland of samphire (*Halosarcia sp.*) occurs near the high water mark of the (greater) lake. The alga *Dunaliella salina* forms mats covering parts of the mudflats within the wetland complex. The surrounding areas support low and open acacia-shrubland. Figure 3 shows the distribution of these habitats within the site.

Lake MacLeod is one of the most important sites for migratory shorebirds in Australia. Large aggregations of migratory shorebirds have been counted within the Ramsar site (see Appendix A for details over the years 1987 to 2004), mainly on the shallows and mudflats associated with the permanent ponds and lakes. The number of waterbirds counted at the site has exceeded 50,000 for the surveys undertaken since 2000. These same surveys have recorded 70 waterbird species to date: 28 of these being listed under Australia's bilateral treaties on migratory birds with Japan and/or China. It is probable that many of the shorebirds are using the lake as a stop-over site during their journey from north-western to south-western and perhaps south-eastern Australia.

Plate 1: Lake MacLeod at times supports very large aggregations of waterbird species. During the survey of 2004 (Hassell, 2004) an estimated 100,000 Banded Stilts were observed there. Photograph by Tony Kirkby.

Lake MacLeod, and the broader Carnarvon basin, is considered significant for aquatic invertebrates in that it appears to have a number of Gondwanan relics, which may be a feature of arid areas. Also the Carnarvon Basin appears to be a zone where Bassian and Torresian biotic elements meet, with many range extensions recorded for invertebrate species. Results from the wetland plant and invertebrate surveys (Burbidge *et al*. 2000) showed a high proportion of “rare” species - only found in a single location – which may be a reflection of limited sampling in the area, and for the invertebrates poorly understood and unpredictable distributions (Halse *et al*. 2000). The surveys undertaken in the early 1990s collected 51 species of invertebrates (macro and microinvertebrates) with the communities present being distinct from other wetlands sampled in the Carnarvon basin (Halse *et al.* 2000). These surveys have shown Lake Macleod has a “...'unique' combination of marine, estuarine and inland water characteristics that make ...” it special (Halse, pers comm., 2005).

In terms of the food web at Lake MacLeod, the invertebrates are a keystone group. “The Shorebirds feed on mudflat and shallow water benthic invertebrates (of both inland and marine origin) and these invertebrates, together with planktonic algae, are the food source for the lake's abundant fish population. Many of the more resident bird species at the lake (pelicans, cormorants, terns and gulls) feed on fish, as do some of the large wading birds present.” (Halse, pers comm., 2005).

In addition to invertebrates, four species of native fish have been recorded. The Flag-tailed grunter (*Amniataba caudavittus)* and the Estuarine hardyhead (*Craterocephalus pauciradiatus*) exist in large schools near the vents. The fish live mainly in the areas around the vents where the salinity of marine water upwelling is close to that of sea water.

The Ramsar Information Sheet (RIS) for Lake MacLeod (see Appendix A) indicates that the site qualifies as a Wetland of International Importance against five of the available eight criteria; namely, 1, 3, 4, 5 and 6. These criteria are shown in Table 1 below with a summary of how they relate to the significant biological assets of the site.

Table 1: The relationship between the Ramsar site criteria and the significant biological assets of Lake MacLeod (see Figure 4 also)

Ramsar criteria	Significant biological assets (SBA)
Criterion 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.	Supporting the largest inland community of Grey Mangrove; Unique wetland bioregionally as well as internationally due to combination of mangroves, mudflats, saltmarshes etc in an arid region.
Criterion 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.	See criteria 1, 4, 5 and 6, all of which mean the site also qualifies against this one.
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.	Important stopover site for migratory shorebirds – see Criteria 5 and 6 below. Seven waterbird species have been recorded breeding at the site.
Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 of more waterbirds.	Supports large aggregations of waterbirds that regularly exceed 20,000.
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.	Supports six waterbird species in numbers that regularly exceed the 1% population or sub-population level for that species.

In addition to the above SBA's that in the RIS are related directly to specific Ramsar criteria, the RIS also includes among the notable fauna the following:

Native fish:
To date four species of native fish have been recorded in the areas around the vents where salinities of marine water upwelling are close to that of sea water. One of these species, the Spangled perch (*Leiopotherapon unicolour*) was not found there until after the flooding event of 2000, and it is thought the fish may have come from one of the tributary rivers during these high flows. Other native fish species recorded in the vents and ponds of Lake Macleod include the Flag-tailed grunter (*Amniataba caudavittus)* and the Estuarine hardyhead (*Craterocephalus pauciradiatus*); these occurring in large schools near the vents.

Dead specimens of the sea-mullet (*Mugil cephalus*) have also been found on the exposed mud banks and may have brought there by birds.

Aquatic invertebrates and phytoplankton:
As was noted in the RIS (see Appendix A), surveys at Lake Macleod have suggested that the macro-invertebrate fauna is dominated by salt tolerant freshwater species. Some are of freshwater origin, adapted to live in hypersaline environments, while others are typically marine species. Above it was observed that Lake MacLeod, and the broader Carnarvon basin, is considered significant for aquatic invertebrates in that it appears to have a number of Gondwanan relics, which may be a feature of arid areas. Surveys from the early 1990s collected 51 species of macro and microinvertebrates; the communities present being distinct from other wetlands sampled in the Carnarvon basin (Halse *et al.* 2000).

In sections 3.3.1-5 the significant biological assets referred to in Table 1 above, as well as native fish and the aquatic invertebrates and phytoplankton are considered further.

3.2 Ecosystem drivers and features of the site (Step 2)

There are a number of fundamental or universal drivers (such as hydrology, climate, soils/geomorphology etc - see Figure 3 below) that determine the ecological processes and functions found at a particular wetland site. While the way these drivers operate and are expressed can vary from site to site, they provide a ready-made and common entry point through which it is possible to examine, describe and compare the '*ecological character'* of wetland systems. It is possible to assign the key ecological processes and interactions (called features here) to each of these fundamental ecosystem drivers in order to assemble a detailed understanding of *'ecological character'*; upon which management actions and monitoring can be based.

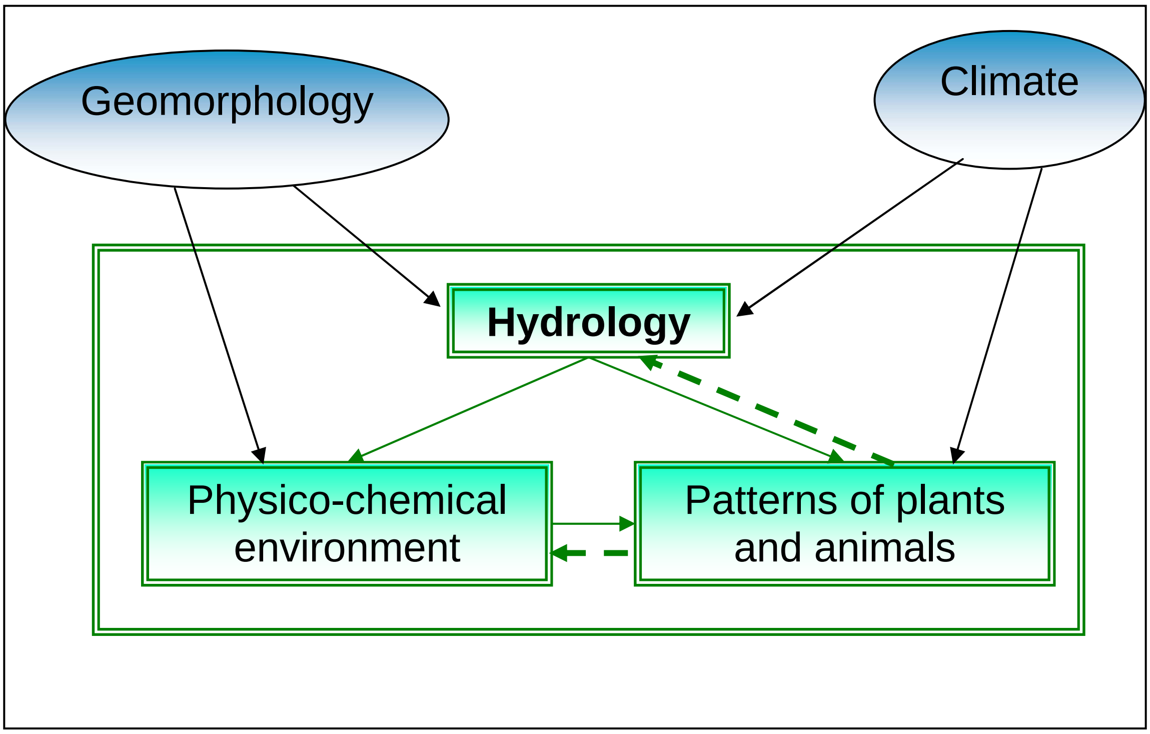

Figure 3: Universal drivers of wetland ecological character (Adapted from Mitsch and Gooselink, 2000). The inner box represents the wetland ecosystem.

For Lake MacLeod the geomorphology, patterns of water delivery and period of inundation are key features of the system.

Lake MacLeod is a coastal saline lake covering approximately 2000 km^2 of which around 6000 ha has permanent water, the rest being episodically filled by freshwater during high rainfall events. The permanent water is maintained by subterranean connection to the Indian Ocean forming the area known as the Northern Ponds. Freshwater enters Lake MacLeod from the catchments of the Lyndon River, Cardabia Creek, Minilya River, Gascoyne River and Boolathana Creek. Direct precipitation may also contribute significantly to water supply in wetter years (Environment Australia, 2001).

Water from the ocean passes underground through coastal limestone and under hydrostatic pressure rises up in sinkholes in the north west of the lake bed. Water from several main sites of discharge within the sinkhole network flows south through channels to a permanent lakes, and periodically overflows across a broad mudflat to a terminal permanent lake. Each day there is a two-way exchange of water across the mudflat in spring and potentially in other seasons depending on prevailing winds. Water discharging from minor sinkholes terminates in adjacent saline marshes. The sinkholes, channels, permanent lakes and marshes are collectively referred to as the "Northern Ponds" or "inner wetlands" (Environment Australia 2001) and are situated in the otherwise normally dry bed of Lake MacLeod.

Upwelling of seawater is continuous and discharge rate varies during the day, apparently under influence of twice-daily tides. Consequently the sinkholes, outflow channels and lakes are permanent, though the southern lake varies in area. Surface inflow from the Lyndon and Minilya Rivers is episodic with potentially substantial discharge, or near-seasonal inflows with only localised flooding of the Lake MacLeod bed. Flooding from the Gascoyne River is infrequent, probably once in ten years, but it can cause the lake to be extensively inundated (e.g. 1989) or to fill (e.g. 1980) (Environment Australia, 2001). These freshwater inputs from rivers and creeks provide carbon substrates and organic nutrients to drive the macroinvertebrate populations found on the mudflats.

The sinkholes are several metres deep. The central lake can reach up to around 1m depth, the southern lake to about 1.5m and the marshes tend to be less than 0.5m deep. During floods the level of inundation can be more uniform across the whole lake.

Water salinity varies across the wetland with the sinkholes reported as being mesosaline, hypersaline to brine in the southern lake and fresh to hyposaline in the marshes. Surface water covering the whole lake is probably fresh initially, becoming increasingly saline as it dries. Evaporation rates and freshwater inputs could create a short term salinity gradient across sections of the wetland.

The geomorphic, hydrological and climatic conditions have led to the establishment of the Grey mangrove *Avicennia marina* stands, as well as the other plant communities such as samphire and sedges.

Mangrove communities found along coastlines and estuaries act as sites of sediment accretion. Alterations in the rates of sediment deposition (due to changes in the surrounding catchments) may have significant impacts on the pattern of mangrove distribution within a site. At Lake MacLeod, the site is effectively closed off from the ocean, and the role of freshwater inputs into this system may be considerably more important. For example, it is unclear at present how toxins (excess nutrients and other pollutants) are flushed from the system. Also, as recruitment of mangroves is dependent on tidal dispersal and favourable conditions for several years – it is unclear if recruitment is possible from within the existing community, or if dieback after cyclonic events will result in the permanent loss of this habitat. The lack of tidal influences on aeration, flushing of soils and transport of nutrients is also unknown within this system.

The mangroves and hydrology of the system (movement of water across the mudflats) have created structural habitat types which tend to support high numbers of waterbirds. The site is considered one of the most significant for waterbirds in Australia. The mudflats, algal mats, phytoplankton and associated secondary consumers (micro and macroinvertebrates) and fish populations around the sinkholes provide ample resources for a range of waterbird species (see section 3.3).

The summary above and the more detailed descriptions given in the Ramsar Information Sheet (Appendix A) and in section 3.3 (for the SBAs) assist in developing a simplified conceptual model for the wetland system (Figure 4 below). This identifies the significant biological assets, the ecological and hydrological processes that support these species and communities, and the underlying system drivers. Table 2 following describes the key ecological features associated with the drivers of geomorphology, climate and hydrology in greater detail.

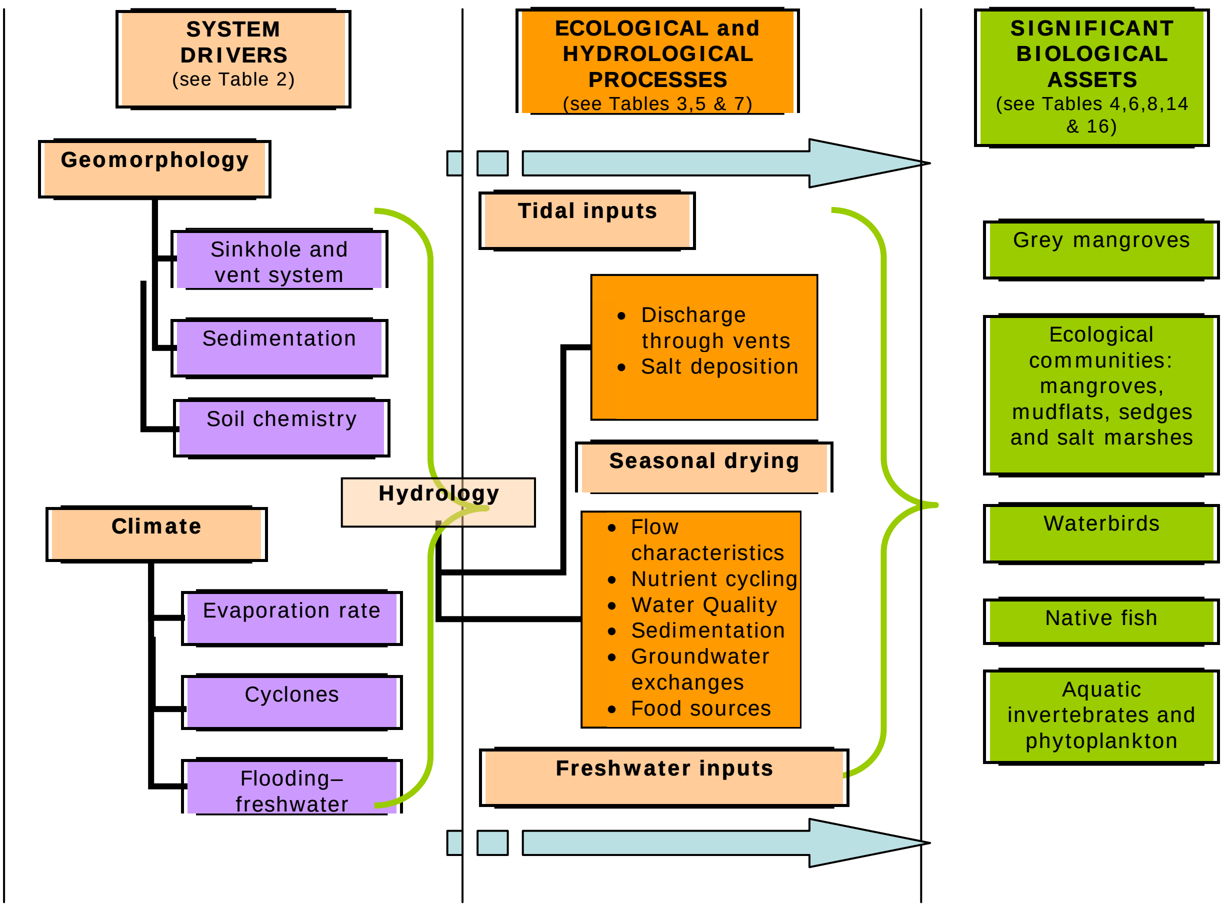

Figure 4: Simplified conceptual model of the Lake MacLeod ecosystem showing the system drivers, and key ecological features associated with each, and the ecological and hydrological processes which maintain the significant biological assets.

Table 2: Drivers and their associated key ecological features

Drivers and key ecological and hydrological features	Description
Geomorphology	
Sinkhole and vent system	Lake MacLeod is a coastal playa separated from the sea by the Bejaling Beach Ridges (Wyrwoll *et al.* 2000). The Lake Macleod basin was separated from the ocean by faulting in the late Holocene (Alsharhan and Kendall, 1994), modified by marine and alluvial deposition and wind deflation – the water surface now lies up to 4m below sea level. Ocean water penetrates through the dune system, underground for a distance of around 18km, via a series of fractures and caves, driven by a hydraulic head, to rise in the sinkholes ("vents") in the central west part of the lakebed (Handforth *et al.* 1984 cited in Ellison 2003). This series of "sinkholes, outflow channels and ponds are permanent, though the southern lake varies in area, depending on factors such as rainfall and prevailing winds. The vents are several meters in depth; the central pond is around 1m, and the southern pond around 1.5m" Ellison (2003)
Sedimentation	The lake bed was built from differing patterns of precipitation of calcium carbonate, halite and calcium sulfate along a north south gradient. Halite has ceased to form in the lake other than in the area of the salt work ponds (Alsharhan and Kendall, 1994).
Soil chemistry	Considered a knowledge gap (Ellison 2003) – see comments under competition and role of soil salinity in determining mangrove distribution on the landward side of the Northern Ponds. In general, mangrove distribution in coastal populations is influenced by excessively high or low salinities, or extreme variations which often occur in saltmarsh areas (Harty and Cheng, 2003). The areas marginal to the main lake are saline, calcareous or gypsiferous muds and red duplex soils with surface and subsurface pH of 8 (Wyrwoll *et al*. 2000).
Climate	
Evaporation rates	There is a salinity gradient affected in part by evaporation, with higher salinities being found towards the southern pond. Median and mean annual rainfall at Gnaraloo are 203 mm and 230 mm respectively, mostly falling in May-July. Annual evaporation across the site is c. 2800-3000 mm (Lane, 1986 cited in Ellison and Simonds unpublished). Evaporation rates are important drivers of the water chemistry of the site.
Cyclones	Storm events, such as cyclones, and to lesser extent severe rainfall events, have the potential to have long lasting influence on the Ramsar site, in particular the potential to affect the fringing vegetation (mangroves). Cyclone Steve occurred in March 2000 and had significant affect on the mangrove communities, and also affected the water quality gradients. An average of 86% mortality in the mangrove monitoring plots was recorded post Cyclone Steve compared to 1997-98 rates of 4% (Ellison, 2003). The cyclone was believed to have caused sustained flooding with high water levels maintained in the system for 9 months. The ability of the mangrove community to survive such long periods of inundation without complete mortality is unusual, and it has been suggested that the population may be adapted to survive repeated extended periods of inundation (Ellison 2003).
Flooding and freshwater inputs	Connectivity to the groundwater and its potential role in the hydrology of Lake MacLeod is a knowledge gap.

	Complete understanding of variation in depths across the lake is lacking and is considered a knowledge gap. Freshwater enters Lake MacLeod in the far north-east from Lyndon River and Cardabia Creek, in the east from Minilya River and in the far south-east from distributaries of Gascoyne River such as Boolathana Creek. All catchments are highly disturbed by grazing. Direct precipitation may also contribute significantly to water supply in wetter years (DIWA site information). Flooding from Gascoyne River is infrequent, probably once in ten years, but it can cause the lake to be extensively inundated (e.g. 1989) or to fill (e.g. 1980). The Minilya River floods less than every second year. In between flooding the rivers of the area tend to dry out to remnant pools. Permanent surface water is rare in the region, with areas of flowing waters usually associated with springs or areas of groundwater discharge (Halse et al. 2000).
Hydrology	
Tidal inputs ❖ Discharge through vents ❖ Salt deposition	Sea water discharges from several sinkholes and flows south through channels to the permanent "central lake", and at times also flows south over a broad mudflat to a terminal permanent lake called the southern lake. Each day there is a two-way exchange of water across the mudflat. The hydraulic head through vents is 3-4 metres. Water discharging from minor (e.g. northernmost) sinkholes terminates in marshes. The upwelling of seawater is continuous, although the discharge rate varies during the day, apparently under influence of twice-daily tides. As a result the sinkholes, outflow channels and lakes are permanent, but the area of the southern lake varies. Salt deposition – this is a knowledge gap.
Seasonal drying	As indicated under tidal inputs above, Lake MacLeod has areas that are permanently inundated due to sea-water up-welling through the sinkholes and flowing south. The area on inundation varies with the tides, whether or not there have been additional freshwater inputs (see below) and the rate of evaporation (see above). The estimated average area of inundation in summer is 6000 ha with there being substantial seasonal fluctuations (DSL, 2000).
Freshwater inputs ❖ Flow characteristics ❖ Nutrient cycling ❖ Water quality ❖ Sedimentation	See flooding and freshwater inputs above. Plus "Water in the lake is hypersaline, in October 2000 being measured between 38.4 and 49.5 ppt (compared with 35 ppt for seawater). There appears to be little change in water quality parameters seasonally (wet versus dry seasons – see Table 1 from Ellison, 2003 reproduced in Appendix B). Evaporation rates, coupled with marine water discharge through the vents, appear to be the main determinants of water chemistry. However, superimposed on this is the seasonal influence of freshwater discharge which sets up a short-term gradient in pH, salinity, dissolved oxygen and nutrients in surface water. This gradient has been found to all but disappear by the end of the wet season. Nutrient levels in the lake were found to be low (classified as meso-eutrophic) however, after the flood in 2000, total nitrogen concentrations increased up to ten fold. Nitrogen was established to be 0.9-1.1mg/L in October 2000, expected to be a result of nutrient enriched surface water inflow. The influx of nutrients was observed to have a significant impact on the lake, with severe algal blooms forming and numerous fish deaths towards December 2000." (Streamtec Ecological Consultants cited in DSL, 2000). Algal blooms and fish deaths suggest elevated nutrient conditions in the water column possibly as a result of reduced phosphorus absorption capacity in the sediment (phosphorus saturation of surface soil) and re-release into the water column. Measurement of total phosphorus in incoming water and soil phosphorus mechanics are knowledge gaps. Turbidity has been recorded to vary across the wetland and also with depth. Ellison (2003) suggests this is a consequence of wind direction and wave action possibly causing bank erosion and sediment resuspension.

	Sedimentation rates within the system are a knowledge gap.
Groundwater exchanges	At present the nature of these exchanges is not known, although they are under investigation by DSL to ascertain the linkages between their salt extraction operations and the vents and ponds.

3.3 Ecological and hydrological processes and how they support the significant biological assets (Steps 3 and 4)

3.3.1 Significant biological asset: Grey mangroves

Plate 2 below shows some aspects of the Grey mangrove community at Lake MacLeod while Table 3 considers the key ecological and hydrological processes sustaining this community. See Table 4 below provides further details about the extent and condition of the Grey mangroves at Lake MacLeod.

Plate 2: Grey mangroves at Lake MacLeod. At left, narrow band of mangroves fringing sinkhole (Colin Davis), monitoring mangrove condition (DSL, 2000) and mangrove pneumatophores (Colin Davis).

Table 3: Key ecological and hydrological processes sustaining the mangrove community of Lake MacLeod

	Description
Tidal inputs	
Discharge through vents	See in Table 2 for more general remarks. In relation to the mangrove communities, the ecological and hydrological roles of the discharge from the vents has been identified as a knowledge gap and considered a priority research area (Ellison, 2003).
Salt deposition	The actual role of soil salinity on the structure and function of the mangrove community remains a knowledge gap. In many mangrove-salt marsh vegetation communities the water content and salinity of soils is a strong determinant of zonation and extent of the two wetland types. Saltmarsh soils tend to have lower water content and higher salinity levels compared to mangrove areas in other parts of the country (e.g. Harty and Cheng, 2003), however the relationship between vegetation types in Lake MacLeod and this important driver is poorly understood. Soil salinity levels are important in competition in saltmarsh wetlands. Mangroves tend to be limited in their landward extent by excessively high or low salinities, or extreme variations which often occur in saltmarsh areas (Harty and Cheng, 2003).

Freshwater inputs	
Flow characteristics	**Water depth:** Grey mangroves have pneumatophores for gas exchange and as such are generally limited to a water depth does not exceed the top of these. **Flows:** Gas, nutrient and water exchanges are reliant on movement of water around the roots of the mangrove.
Nutrient cycling	Bacteria are important flora in mangrove communities playing key roles in controlling the chemical environment of the mangrove communities. Sulfate-reducing bacteria are the main decomposers in anoxic mangrove sediments and are responsible for controlling the iron, phosphorus, and sulfur dynamics, as well as contributing to soil and vegetation patterns. Methanogenic bacteria have been reported as being seasonally abundant in sediments where *Avicennia* species dominate (Kathiresan and Bingham, 2001 and references therein). Decomposition of leaf litter in mangrove ecosystems contributes to the production of dissolved organic matter (DOM) and the recycling of nutrients in the mangrove and adjacent habitats. The organic detritus and nutrients could potentially supply nutrients to the surrounding wetland systems. However, water column nutrient levels in the Lake MacLeod were found to be low (classified as meso-eutrophic). Nitrogen concentrations increased up to ten fold after the 2000 flood, reaching levels of 0.9-1.1mg/L in October 2000, expected to be a result of nutrient enriched surface water inflow. Mangroves require nitrogen and phosphorus (and trace elements) in ionic form for uptake through their root systems. Other investigations (e.g. Camileri, 1989) have shown that crustaceans that graze on the leaf litter of mangroves contribute to nutrient cycling. Soil characteristics such as siltiness, electrical conductivity, pH, and cation exchange capacity are important in supporting mangrove communities however nutrient concentrations are considered the most important. (Kathiresan and Bingham, 2001). Mangroves are typically finely balanced, nutrient sinks with net imports of dissolved nitrogen, phosphorus, and silicon. Bacteria and fungi are important in nutrient cycling in mangrove systems as well as bioturbation by invertebrates. Nutrient fluxes in these environments are closely tied to plant assimilation and microbial mineralization (Alongi, 1996; Middelburg *et al.*, 1996). Nutrients availability may limit growth and production. Varying nutrient concentrations can also change competitive balances and affect species distributions (Chen and Twilley, 1998). As a result, nutrient pulses can create immediate, and impressive, changes in the vegetation.
Water quality	**Salinity:** Although mangroves have specialised adaptations to survive in saline environments, they still require water for metabolic functions such as photosynthesis. Their ability to take-up water is limited by the salinity of the water. Duke et al (1998) cites a salinity tolerance for *Avicennia marina* of15-30ppt, but they also note that tolerances differ for different populations of the same species. The mangroves at Lake MacLeod are unusual and are considered to occur in an extreme environment compared to coastal populations. The Lake MacLeod population is found on the margins of a non-tidal salt lake in an arid climate. It has been suggested that the drier climate coupled with high evaporation rates results in extremely high soil salinities, although there is little to no data actually supporting this. Data on soil structure and chemistry has been collected by Wyrwoll *et al*. (2000), but the sites sampled were not in the immediate vicinity of the northern pond mangrove communities. Salinity stress has also been postulated as the cause of isolated patches of dead mangroves at Lake MacLeod (Dampier Salt Limited, 2000; Ellison 2003). Salinity is also thought to influence the growth of the mangrove population with increasing stunted architecture on the landward

	edges of the populations (Dampier Salt Limited, 2000). The actual role of soil salinity on the structure and function of the mangrove community remains a knowledge gap. **Dissolved oxygen:** Grey mangroves have pneumatophores for gas exchange with the air – but Ellison (2003) suggests that the mangroves at Lake MacLeod may be limited by dissolved oxygen in the water column around their roots as the density of the pheumatophores is considerably higher adjacent to the water , than in mangrove communities found on the open coast. A lack of tidal movement of the water and sediments around the mangroves may result in reduced aeration. Soil oxygen levels and their role in determining condition and extent of the mangroves is a knowledge gap. Dissolved oxygen recordings from Lake MacLeod are given in Appendix B.
Sedimentation	This remains a knowledge gap
Groundwater exchanges	This remains a knowledge gap

Table 4: Extent and condition of the Grey mangrove communities at Lake MacLeod

Significant biological asset: Largest inland community of Grey Mangroves in the world
Qualitative description: Lake MacLeod has the largest area of inland mangroves in the world. The mangrove low closed forest is comprised solely of one species *Avicennia marina* (Forsk.) Vierh., and narrowly fringes the sinkholes, channels and central lake (see Plate 2 below). The width of the mangrove fringe is typically less than 20m with dense tree growth, although there have been recordings of the mangroves extending up to 50 m in places (Ellison and Simmonds unpublished). The mangroves of Lake MacLeod show extremes of environmental stress, with areas of mortality attributed to salinity stress, and unusually high pneumatophore density related to low interstitial oxygen. The lack of true tidal habitat and the arid climate contribute to the unique nature of this community. The spatial extents of the mangroves are controlled by water chemistry and the topography of the wetland margins. Water salinity controls mangrove tree stuntedness, indicated by stunted architecture of trees with increased distance from the water's edge (Ellison and Simmonds unpublished). **Condition:** generally good but significant dieback suffered after cyclone in 2000. **Trend**: recruitment success after the 2000 dieback is unknown. **Importance of the above for other Significant Biological Assets:** See following sub-section.
Quantitative description: 7.5 ha at North Cygnet Pond and 15 ha at South Cygnet Pond plus some scattered in surrounding areas for which not estimate of aerial extent is known. The annual productivity of the mangroves is relatively high, considering the stunted growth habit of the trees and the environmental stress that they tolerate (Dampier Salt Limited, 2000). Annual productivity of the mangrove community at Lake MacLeod is 855 g dry wt/m^2 and an average biomass of 121.3 t/ha (Ellison 2003), which is equivalent to productivity levels in open coastal mangrove systems in subtropical eastern Australia. **Area:** Approximately 22.5 ha. **Typical range of variability:** Knowledge gap

3.3.2 Significant biological asset: Unique combination of mangroves, mudflats, sedges and saltmarshes in an arid region

Plate 3 below shows some of the wetland types that characterise Lake MacLeod while Table 5 considers the key ecological and hydrological processes sustaining the unique combination of wetland types. Table 6 further details the extent and condition of these habitats.

Plate 3: Major wetland types at Lake MacLeod (see also Plate 2 in the preceding section). At left sinkhole with fringing mangrove and permanent lake, sinkhole and mudflat areas (all photos by Colin Davis)

Table 5: Key ecological and hydrological processes sustaining the unique combination of mangroves, mudflats, sedges and saltmarshes of Lake MacLeod

	Description
Tidal inputs	
Discharge through vents	The connection of the wetland system to the Indian Ocean and the discharge of marine water into the system is the principal driver of this ecosystem. Discharge maintains the water level and has a significant impact on water chemistry. This in turn influences the biological communities and ecological processes that occur at the site.
Salt deposition	See Table 3 in relation to the mangrove community.
Freshwater inputs	
Flow characteristics	Lake MacLeod is considered to be a saline coastal lake which is episodically inundated by freshwater. Little information is available regarding the role of overland flows in maintaining the various wetland types of the site. An assessment of the extent and types of wetland habitats in and around the main lake and tributary rivers is considered an important area for future work.
Nutrient cycling	See Table 3 in relation to the mangrove community. Increased nutrient availability can lead to algal blooms and physico-chemical changes to water quality – such as observed after the 2000 floods, where algal blooms and numerous fish deaths were noted towards December 2000. Nutrient cycling in the various wetland types is poorly understood for the Lake MacLeod site with the majority of data reported focusing on water column measurements for the permanent lakes.
Water quality	See Table 3 in relation to the mangrove community. **Salinity:** Salinity levels of the water appear to show a gradient from marine (35 ppt) through to hypersaline in the southern end of the permanent wetland systems with readings of up to 50 ppt being recorded in 2000. Seasonal influences and surface water inflows can affect the salinity gradients. Salinity has been shown to be a key determinant in the distribution of the mangrove community and salt marsh communities.

	Dissolved oxygen: Little is known about the oxygen levels of the water and soils in the Lake MacLeod site.
Sedimentation	This remains a knowledge gap
Groundwater exchanges	This remains a knowledge gap

Table 6: Extent and condition of the mangroves, mudflats, sedges and saltmarshes of Lake MacLeod

Significant biological asset: Unique combination of mangroves, mudflats, saltmarshes etc in an arid region
Qualitative description: Lake MacLeod has five different wetland types according to the Ramsar classification system (see Appendix A); namely (see Plate 3), R (seasonal**/intermittent** saline**/brackish/lakes** and flats) Q (permanent **saline**/brackish/alkaline **lakes**) Sp (permanent **saline**/brackish/alkaline marshes/pools) I (intertidal forested wetlands) but these mangroves are **<u>not</u> in an intertidal** situation; and Y (freshwater springs), but these are **saline** rather than freshwater. **Condition:** Knowledge gap. **Trend**: Knowledge gap. **Importance of the above for other Significant Biological Assets:** ***Grey mangroves*** (see section 3.3.1): ❖ The mangroves, in most instances, are found fringing the vents and their associated ponds (see Plate 2). ***Waterbirds*** (see section 3.3.3): ❖ Breeding waterbirds – breeding activities have been observed in the mangrove stands. ❖ Migratory shorebirds – these species, being species that mostly forage in shallow water mudflats and samphire habitats are mostly found in wetland types R, Q and Sp. ❖ 20,000+ aggregations of waterbirds (see Plate 4). These species include a variety that forage in the shallow water mudflats and samphire habitats, or deeper water habitats. Many of these species are piscivorous. Those that breed at the site seem reliant on the mangroves to provide nesting sites. ***Native fish*** (see section 3.3.4): ❖ The native fish recorded at the site are found within the ponds, and are offered protection among the roots and pneumatophores of the mangroves. They are also a vital food source for fish-eating bird species. ***Aquatic invertebrates and phytoplankton*** (see section 3.3.5) ❖ The aquatic invertebrates, while notable in their own right (see section 3.3.5), are also a keystone group of this ecosystem, providing a vital food source for many bird species. Together with the planktonic algae the aquatic invertebrates also support the native fish populations.
Quantitative description: **Areas of each type:** Knowledge gap **Typical range of variability:** Knowledge gap

3.3.3 Significant biological asset: Waterbirds

As indicated in Table 1, Lake Macleod is important for the waterbirds found there, usually in large numbers (20,000 +). Many of these are migratory shorebirds; seven of which occur there in numbers that regularly exceed the 1% population or sub-population level for that species. In addition, seven waterbird species have been recorded breeding at the site. Plates 1, 4 and 5 illustrate the importance of this site for waterbirds.

Plate 4: Migratory shorebirds at Lake MacLeod. At left, bird surveyors and at right shorebird foraging on the mudflats. (Both by Colin Davis). See also plates 1 and 5.

Table 7 below considers the key ecological and hydrological processes sustaining these waterbirds at Lake MacLeod, and Table 8 further details the populations and other aspects of the biology of these species at the site.

Table 7: Key ecological and hydrological processes sustaining the waterbirds.

	Description
Tidal inputs	
Discharge through vents	Knowledge gap.
Salt deposition	Knowledge gap.
Freshwater inputs	
Flow characteristics	The combination of the daily two-way exchange of water across the mudflat from the tidal fluxes, occasional overland freshwater flows, wind and wave actions, and evaporation can all play a role in determining the extent of inundation and the water depths. Flows and water depths are a key aspect of habitat connectivity, linking deeper water habitats with shallow areas, exposed mudflats and samphire, algal mats etc.
Nutrient cycling	Nutrient cycling and the nutrient requirements of aquatic plants in this system are not well understood.
Water quality	Water quality data are provided in Appendix B. **Salinity:** Ellison (2003) notes that all Streamtec water quality data for Lake MacLeod other than that for October 2000 shows a salinity gradient increasing from the vents southwards to outer edge of the lakes. She notes that "…this demonstrates the lake's function as an evaporation pond." These data can be found in Appendix B. Further investigations may reveal that this salinity gradient is a significant determining factor for aquatic plant growth, and the distribution of food sources of the waterbird species.

	Dissolved oxygen: As shallow water bodies it is likely that wind-induced mixing prevents stratification in the lakes for most of the time, this resulting in a well mixed, oxygenated water column. Dissolved oxygen recordings by various surveys are provided in Appendix B. **Turbidity:** See below under sedimentation also. Turbidity causes a reduction in light available for photosynthesis for submerged aquatic plants and changes the conditions to favour the growth of phytoplankton over aquatic macrophytes. High levels of turbidity can also reduce the success of visual feeders such as waterbirds and carnivorous fish that require adequate visibility to see prey. Notably, high turbidity levels restrict growth for *Ruppia spp* to shallower waters.
Sedimentation	Sedimentation needs to be balanced between the amounts needed to replenish the organic matter and nutrients for the sand and mud flats and the amounts that will not cause decline in aquatic plant growth due to light limitation and biofilm growth. Excess sedimentation may also change the topography of the floor of the lakes, filling in holes and covering sand, mud and stoney flats that may be important for fish feeding and spawning.
Groundwater exchanges	Knowledge gap.
Food sources	See also section 3.3.4 and 3.3.5 following. "Invertebrates are a key element of the food web at Lake MacLeod. Shorebirds feed on mudflat and shallow water benthic invertebrates (of both inland and marine origin) and these invertebrates, together with planktonic algae, are the food source for the Lake's abundant fish population. Many of the more resident bird species at the Lake, such as pelicans, cormorants, terns and gulls, feed on fish, as do some of the large wading birds present." (S. Halse, pers comm., 2005)

Table 8: Populations and other aspects of the biology of waterbird species at Lake MacLeod

Significant biological asset: Waterbirds
Qualitative description: ***Breeding at the site***: The following species of waterbirds have been observed breeding at Lake MacLeod: Darter, Pied Cormorant, Little Pied Cormorant, Great Egret, Little Egret, Nankeen Night Heron, Caspian Tern, Fairy Tern and Osprey (see Tables 9 and 10 below). ***Migratory shorebirds:*** Lake Macleod is a major migration stop-over and drought refuge area for shorebirds. A total of 28 migratory bird species listed under international bird agreements (JAMBA and/or CAMBA) have been observed at the site in surveys conducted since 1987 (see Tables 11 and 12 and Plate 4). Lake Macleod has supported significant proportions (>1%) of the population or sub-populations of six species of waterbird: Curlew Sandpiper, Banded Stilt, Red-necked Avocet, Red-capped Plover, Red-necked Stint and Red Knot (refer to Appendix A for further details of this determination). ***Large aggregations of waterbirds that regularly exceed 20,000:*** Lake MacLeod is important both regionally and nationally for waterbirds, with over 70 species having been recorded there since 1987.
Quantitative description: ***Breeding at the site***:

This remains a knowledge gap, although some observations bird the regular surveys have begun to provide some insights as follows:

Davis and Kirby from the Birds Western Australian Waders Study Group reported the following from the survey of September 2000. "One location best described as an exposed mud bank in the centre of the central basin with a stand of mature mangroves on the northern fringe, is an area of intense nest building activity with at least three species busy here. Pied Cormorants were fairly well established in taller trees. One hundred and fifty nests were counted with birds in attendance. Little Egrets and Great Egrets were nest building with a few birds sitting but most were competing for nesting spots or foraging for nesting material. A count revealed 60 Great Egret and 100 Little Egret. Sixty Little Black Cormorants were also counted flying into an area behind the Egrets.

At a junction of channels in the launch point vent area, a colony of 90 Nankeen Night Heron were residing amongst a large number of abandoned nests. Although no nesting behaviour was observed, some recent activity was evident as there were unbroken light blue eggs below some of the nests. This gathering comprised mostly of birds in immature plumage accompanied by a few birds in adult plumage." (cited in DSL, 2000).

Migratory shorebirds:
The following species have been recorded at the site in numbers exceeding 1% of their estimated flyway populations.
Curlew Sandpiper
Banded Stilt
Red Knot
Red-capped Plover
Red-necked Stint
Red-necked Avocet.
(see Tables 11 and 12 below).

Large aggregations of waterbirds that regularly exceed 20,000:
The total number of waterbirds counted at the site has exceeded 50 000 for the surveys since 2000, with the maximum number being nearly 175 000 in November 2004. See Table in Ramsar Information Sheet (Appendix A)

Typical range of variability:
Breeding at the site:
Knowledge gap.

Migratory shorebirds:
Range of numbers observed in surveys between 1987 and 2004 (with mean) for each species;

Curlew Sandpiper:	70 – 45 000	(21 836)
Banded Stilt:	1- 100 000	(22 454)
Red Knot:	0 – 2 566	(497)
Red-capped Plover:	70 – 3 125	(835)
Red-necked Stint:	250 – 8 312	(5 161)
Red-necked Avocet:	0 – 2 401	(728)

Large aggregations of waterbirds that regularly exceed 20,000:
Species present: Up to 70 species have been recorded, but highly variable. Waterbirds respond to drivers at different scales to that of the site at which they are being assessed.
Numbers of waterbirds recorded: 20,000-175,000

Table 9 - Waterbirds observed breeding at Lake Macleod

Waterbird species (organised by Family[#])	October 1987	November 1999	September 2000	January 2002	September 2002	March 2003	October 2003	March 2004	November 2004
Anhingas (Darters) - Family *Anhingidae*									
1. Darter	37 [B]	5	8	2	20	20	40	12	50[B]
Cormorants – Family *Phalacrocoracidae*									
2. Pied cormorant	504	502	650[B]	150	450	321	321	350	350
3. Little Pied Cormorant	28 [B]	0	3	8	30	0	1	1	27
Herons, Egrets, Bitterns – Family *Ardeidae*									
4. Great Egret *[J/CAMBA]	25	13	150 [B]	16	30	4	15	10	6
5. Little Egret	96	22	170 [B]	20	70	229	69	112	80
6. Nankeen Night Heron [+B]	3	0	110	0	50[B]	2	0	0	0
Gulls, Terns etc – Family *Laridae*									
7. Caspian Tern *[CAMBA] [+B]	213 [B]	346	40	20	45	9	46	50	20
8. Fairy Tern [+B]	265 [B]	92	5	57	40	422	63	110	400
Ospreys,Kites etc – Family *Accipitridae*									
9. Osprey	0	2	2	ND	1[B]	2	3	ND	ND

[#] The order used follows that of *Field Guide to the Birds of Australia*, 6th Edition by Simpson and Day, 1999

[B] observed nesting, breeding (Note – survey data sourced from Hassell, 2004 does not consider breeding species)

[+B] recorded breeding – see DSL citation under 31.

* 27 species listed under either the Japan-Australia or China-Australia Migratory Bird Agreements, and therefore also under the Commonwealth Governments' *Environment Protection and Biodiversity Conservation Act 1999*.

ND = no data for these species included in the survey report.

Sources:

October 1987 data: Jaensch and Vervest, 1990
November 1999 and September 2000 data: Davis, Kirkby and Singor, 2001
September 2002 and March 2003 data: Davis, 2003
October 2003 data: Davis and Kirkby (unpublished)
January 2002, March and November 2004, cited in Hassell, 2004

Table 10: Waterbirds that breed within the Ramsar site and summary life history information

Common name	Scientific name	Source: Earthtech, 2003, cited as P.A.Paton based on Jaensch, 1982 and personal observations, and HANZAB, 1990, 1993 and 1996 (unless otherwise indicated).		
		Preferred breeding habitat*	**Preferred feeding habitat***	**Preferred food***
Darters - Family Anhingidae				
Darter	*Anhinga melanogaster*	Nest in trees or shrubs over water (HANZAB)	Open water	Fish, aquatic invertebrates
Cormorants – Family Phalacrocoracidae				
Pied Cormorant	*Phalacrocorax varius*	Coastally on rocky or sandy islands, or in estuaries, in trees (HANZAB)	Open water	Fish
Little Pied Cormorant	*Phalacrocorax melanoleucos*	Shrubland, mainly freshwater wetlands (HANZAB)	Open water	Aquatic invertebrates, fish
Herons, Egrets, Bitterns – Family Ardeidae				
Great Egret	*Ardea alba*	Shrubland or flooded trees (HANZAB)	Rushes, floating vegetation, grass and weeds, bare margins	Fish, aquatic invertebrates and vertebrates
Little Egret	*Ardea garzetta*	Nest in trees near vegetated wetlands; fresh, brackish, marine or saline (HANZAB)	Shrubland, grass and weeds, bare margins	Fish, aquatic invertebrates and vertebrates
Nankeen (Rufous) Night Heron	*Nyctocorax caledonicus*	Nest in various locations; trees, off-shore islands on the ground etc (HANZAB)	Littoral, estuarine or inland wetlands; mainly nocturnal foraging in still or slow-moving shallow water (HANZAB)	Carnivore, mostly fish also insects and crustaceans (Scholz, 2001)
Gulls, Terns etc – Family Laridae				
Caspian Tern	*Hydropogne tschegrava* (*Hydroprogne caspia*)	Breed on islands, sandy cays and banks (HANZAB)	Forages in open wetlands, often in sheltered water areas near the margins (HANZAB)	Fish, crustaceans
Fairy Tern	*Sterna nereis*	Nest above high water on sheltered beaches, spits or sand bars often in estuaries and on islands (HANZAB)	Sheltered coasts and estuaries; fresh or saline near-coastal wetlands (HANZAB)	Small fish

The order used above follows that of *Field Guide to the Birds of Australia*, 6th Edition by Simpson and Day, 1999

 # = for these species there is some uncertainty about whether they breed in the system or not. They have been included for now in the hope that during the public comment phase on this document confirmation or otherwise will be provided.

* = information (mostly) from Earthtech, 2003, cited as P.A.Paton based on Jaensch, 1982 and personal observations, and HANZAB, 1990, 1993 and 1996.

Key = Shrubland = *Melaleauca halmaturom*; Reedbeds = stands of *Typha spp* and *Phragmites australis*; Rushes = Diverse beds; Tussock = mainly Gahnia filum; Floating vegetation = *Triglochin procerum* and other plants in freshwater; Bare margins = subject to inundation or dry; Open water = area of water with no emergent or overhanging vegetation.

Table 11 - Waterbirds recorded at Lake Macleod: JAMBA and/or CAMBA listed and those present in numbers exceeding the 1% population or sub-population levels

Waterbird species (organised by Family#)	October 1987	November 1999	September 2000	January 2002	September 2002	March 2003	October 2003	March 2004	November 2004
Herons, Egrets, Bitterns – Family *Ardeidae*									
1. Great Egret * J/CAMBA	25	13	150 B	16	30	4	15	10	6
Curlews, Sandpipers, Snipes, Godwits, Phalaropes – Family *Scolopacidae*									
2. Ruddy Turnstone * J/CAMBA	18	37	10	2	25	2	3	6	38
3. Eastern Curlew * CAMBA	0	0	1	0	0	0	0	0	0
4. Little Curlew * CAMBA	1	0	0	0	0	0	0	0	0
5. Wood Sandpiper * J/CAMBA	0	3	0	0	0	0	0	0	2
6. Grey-tailed Tattler* J/CAMBA	0	2	0	0	0	0	0	0	13
7. Common Sandpiper * J/CAMBA	5	6	2	2	2	7	20	2	11
8. Common Greenshank * J/CAMBA	92	235	300	30	40	72	70	62	270
9. Marsh Sandpiper * CAMBA	66	3	0	0	10	2	1	0	3
10. Terek Sandpiper * J/CAMBA	1	0	0	0	0	0	0	0	4
11. Asian Dowitcher * CAMBA	1	0	0	0	0	0	0	0	0
12. Black-tailed Godwit * J/CAMBA	25	14	0	0	0	0	0	66	1
13. Bar-tailed Godwit * J/CAMBA	111	386	18	54	160	3	26	65	50
14. Red Knot * J/CAMBA (>1%)	2 566	137	8	0	515	187	668	150	250
15. Great Knot * J/CAMBA	135	211	39	0	75	7	60	83	260
16. Sharp-tailed Sandpiper * J/CAMBA	602	214	10	3	50	23	205	8	850
17. Red-necked Stint * J/CAMBA (>1%)	8 312	2 350	6 000	250	3 340	6 206	6 440	6 000	7 550
18. Long-toed Stint * J/CAMBA	2	0	0	0	0	0	0	1	1
19. Curlew Sandpiper * J/CAMBA (>1%)	41 606	18 392	40 000	70	8 000	16 690	26 283	485	45 000
20. Pectoral Sandpiper * JAMBA	0	0	0	0	0	0	0	1	0
21. Sanderling * J/CAMBA	1	1	0	0	0	0	0	0	5
22. Broad-billed Sandpiper * J/CAMBA	1	1	0	0	3	0	0	30	0
23. Grey Plover * J/CAMBA	34	31	2	0	14	18	5	60	21
24. Pacific (Lesser) Golden Plover * J/CAMBA	7	3	0	0	1	0	0	0	4
25. Mongolian (Lesser Sand) Plover * J/CAMBA	1	3	0	0	17	1	4	0	0
26. Greater Sand Plover * J/CAMBA	75	12	0	0	35	3	6	0	515
27. Red-capped Plover (>1%)	2 110	114	500	70	300	457	442	400	3 125
Stilts, Avocets – Family *Recurvirostridae*									
28. Banded Stilt (>1%)	53 098	2 042	8 500	600	6 000	15 645	16 204	1	100 000
29. Red-necked Avocet (>1%)	2 401	0	70	402	346	778	214	28	2 315

Waterbird species (organised by Family[#])	October 1987	November 1999	September 2000	January 2002	September 2002	March 2003	October 2003	March 2004	November 2004
Gulls, Terns etc – Family *Laridae*									
30. White-winged Black Tern * J/CAMBA	5	0	0	0	3	1	0	44	10
31. Caspian Tern * CAMBA +B	213 B	346	40	20	45	9	46	50	20

The order used follows that of *Field Guide to the Birds of Australia*, 6th Edition by Simpson and Day, 1999

B Observed nesting, breeding (Note – survey data sourced from Hassell, 2004 does not consider breeding species)

+B Recorded breeding

* 28 species listed under either the Japan-Australia or China-Australia Migratory Bird Agreements, and therefore also under the Commonwealth Governments' *Environment Protection and Biodiversity Conservation Act 1999*.

>1% numbers exceed the estimate 1% of the population within the East Asian-Australasian flyway. The data used to establish the 1% flyway population level are as given by Wetlands International (http://www.wetlands.org/IWC/WPEnote.htm) in the publication Waterbird Population Estimates, Third Edition, 2002. For these six species these 1% levels at present are as follows (

- Red Knot = 2 200
- Red-necked Stint = 3 200
- Curlew Sandpiper = 1 800
- Red-capped Plover = 950
- Banded Stilt = 2 100
- Red-necked Avocet = 1 100

Sources (see section 32 for full citations):

October 1987 data: Jaensch and Vervest, 1990
November 1999 and September 2000 data: Davis, Kirkby and Singor, 2001
September 2002 and March 2003 data: Davis, 2003
October 2003 data: Davis and Kirkby (unpublished)
January 2002, March and November 2004, cited in Hassell, 2004

Table 12: Significant migratory waterbirds found within the Ramsar site and summary life history information

Common name	Scientific name	J/CAMBA or CMS	Habitat and other life history information (Based on species accounts in the HANZAB)
Curlews, Sandpipers, Snipes, Godwits, Phalaropes – Family *Scolopacidae*			
Sharp-tailed Sandpiper	*Calidris acuminata*	J/CAMBA, CMS	Forage mainly in shallow water up to 5cm deepon bare, wet mud or sand in intertidal areas. Also use areas with saltmarsh, grasses or sedges.
Little Curlew	*Numenius minutus*		Found mainly in small flocks of up to 24 individuals on samphire and grass flats.
Curlew Sandpiper	*Calidris ferruginea*	J/CAMBA, CMS	Feed mainly in shallow water on mudflats or sandflats.
Common Sandpiper	*Tringa hypoleucos*	J/CAMBA, CMS	Uses both coastal and inland wetlands. Generally forage in shallow water with bare mud and near protruding obstacles such as rocks or roots.
Marsh Sandpiper	*Tringa stagnatilis*	CAMBA, CMS	Prefers intertidal mudflats although does also use a range of habitat types including shallow freshwater areas. Feeds among mud and vegetation.
Terek Sandpiper	*Xenus cinereus* (*Tringa terek*)	J/CAMBA, CMS	Forages in saline intertidal mudflats in sheltered estuaries. Usually feeds in the open on soft intertidal mudflats, near mangroves and at times in samphire.
Asian Dowitcher	*Limnodromus semipalmatus*		Rare visitor to Lake MacLeod – recorded once (Johnstone et al. (2000)
Red-necked Stint	*Calidris ruficollis*	J/CAMBA, CMS	Forage mainly in shallow water up to 2cm deep over sand and mud flats
Long-toed Stint	*Calidris subminuta*		Recorded on the shores of Lake MacLeod, rare visitor (Johnstone et al. 2000).
Sanderling	*Crocethia alba*	J/CAMBA, CMS	Forage on sandy beaches, exposed sand bars in the wave- wash zone. At times also use the edges of shallow pools on sandspits and near to mudflats.
Broad-billed Sandpiper	*Limicola falcinellus*		Recorded at Lake MacLeod in 1987 (Johnstone et al. 2000). Records from elsewhere in Australia suggests they typically feeds on wet mudflats, but will also feed whilst wading. Favour estuarine mudflats, saltmarshes and reefs as feeding and roosting habitat. Feeds on insects, crustaceans, worms, molluscs, and seeds. Large flocks are seldom recorded and birds are often encountered alone.
Common Greenshank	*Tringa nebularia*	J/CAMBA, CMS	Uses both inland and coastal wetlands, foraging in the soft mud near the waters edge and also around emerging vegetation such salt marshes. Often found in deeper water (10-20cm deep in Coorong region) (D. Paton pers. comm.)
Bar-tailed Godwit	*Limosa lapponica*	J/CAMBA, CMS	Feed near waters edge or shallow water, preferring exposed sandy substrates on intertidal flats. Also feed in soft mud, often with beds of eelgrass or other seagrasses.
Black-tailed Godwit	*Limosa limosa*	J/CAMBA, CMS	Feed on wide intertidal mudflats or sandflats, and occasionally in shallow estuaries, salt marshes, saltflats or river flats.
Great Knot	*Calidris tenuirostris*	J/CAMBA, CMS	Forage on intertidal flats, in soft sand and mud, usually at the edge of shallow water as the tide falls.
Red Knot	*Calidris canutus*	J/CAMBA, CMS	Feed on soft sand and mudflats, and occasionally on sand beaches, rock platform, reefs.
Ruddy turnstone	*Arenaria interpres*	J/CAMBA, CMS	Tend to be found on exposed rock or reef, often in shallow tidal water, and on shingle or sand beaches. Only occasionally in forage in saltmarsh or exposed seagrass areas.
Lapwings, Plovers, Dotterels – Family *Charadriidae*			
Grey Plover	*Pluvialis squatarola*	J/CAMBA ,CMS	Mostly a coastal species found foraging on tidal mud and sandflats. Inland it uses the edges of salt lakes and pans.
Lesser Sand Plover	*Charadrius mongolus*	CMS	Mostly a coastal species, preferring beaches, wide intertidal flats, and sometimes salt marshes or

			mangroves.
Greater Sand Plover	*Charadrius leschenaultii*		Forages on wet ground usually away from the waters edge, tidal flats saltlakes, and sandy beaches.
Red-capped Plover	*Charadrius ruficapillus*	CMS	Feeds on sand and mudflats along the edges of estuaries, lagoons and lakes, and even at times gravel or shell grit.
Stilts, Avocets – Family *Recurvirostridae*			
Banded Stilt	*Cladorhynchus leucocephalus*	CMS	Feed in shallow saline or hyper-saline water or by wading or swimming into deeper water.
Red-necked Avocet	*Recurvirostra novaehollandiae*	CMS	Found in ephemeral inland, fresh, saline and hyper-saline wetlands, especially drying salt lakes. Feed in soft mud areas, wading to their belly.
Gulls, Terns etc – Family Laridae			
Caspian Tern	*Hydropogne tschegrava* (*Hydroprogne caspia*)		Forages in open wetlands, often in sheltered water areas near the margins (HANZAB). Prefers fish and crustaceans.
White-winged Black Tern	*Sterna leucoptera*		

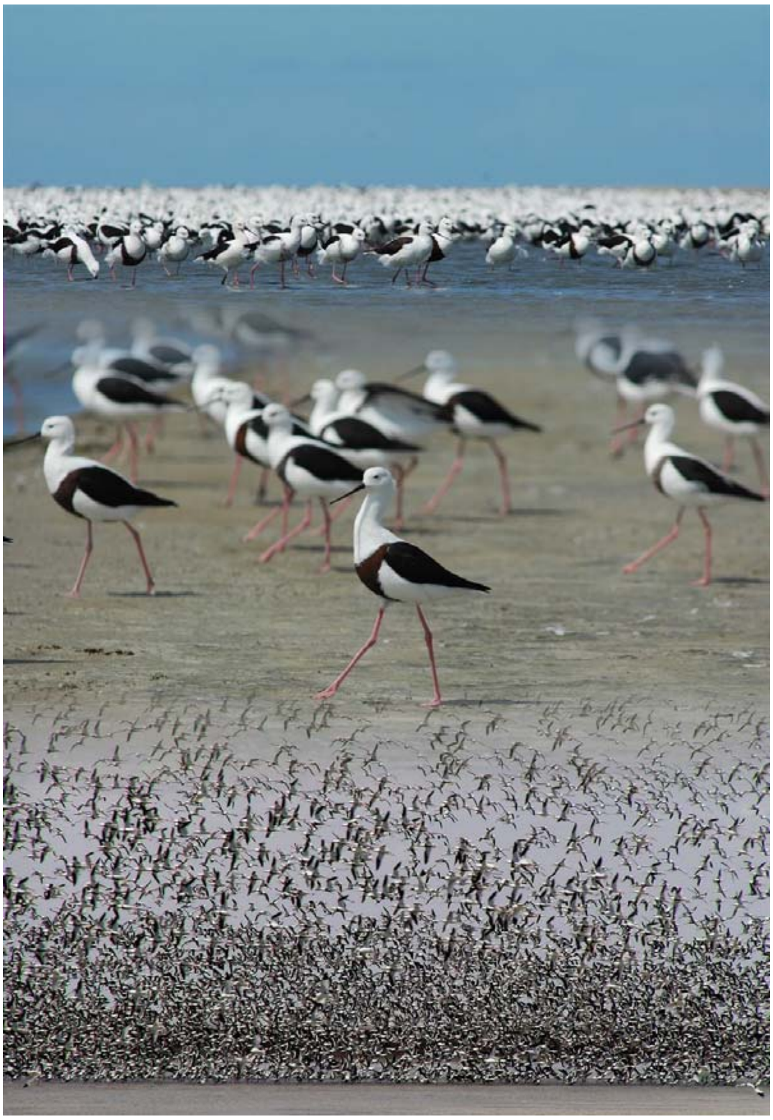

Plate 5: Banded Stilts at Lake MacLeod. In the survey of November 2004 (Hassell, 2004) 100,000 of this species were recorded (see Plate 1 also).

3.3.4 Significant biological asset: Native fish

Table 13 below considers the key ecological and hydrological processes sustaining the native fish populations at Lake MacLeod, and Table 14 further details the populations and other aspects of the biology of these species at the site.

Table 13: Key ecological and hydrological processes sustaining the native fish

	Description
Tidal inputs	
Discharge through vents	Knowledge gap.
Salt deposition	Knowledge gap.
Freshwater inputs	
Flow characteristics	Knowledge gap. Flows and water depths are a key aspect of habitat connectivity, linking deeper water habitats with shallow areas, exposed mudflats and samphire, algal mats etc. The degree to which these habitats away from the actual vents are exploited by native fish is not known.
Nutrient cycling	Knowledge gap.
Water quality	Knowledge gap. These species are not likely to be tolerant of highly saline waters. Highly turbid waters will reduce photosynthesis for submerged aquatic plants and change the conditions to favour the growth of phytoplankton over aquatic macrophytes. High levels of turbidity can also impact on the foraging success of certain visual feeding fish species. High turbidity levels restrict growth for *Ruppia spp* to shallower waters and this may be significant for species such as the Estuarine hardyhead.
Sedimentation	Knowledge gap.
Groundwater exchanges	Knowledge gap.
Food sources	See also section 3.3.3. "Invertebrates are a key element of the food web at Lake MacLeod. Shorebirds feed on mudflat and shallow water benthic invertebrates (of both inland and marine origin) and these invertebrates, together with planktonic algae, are the food source for the Lake's abundant fish population. Many of the more resident bird species at the Lake, such as pelicans, cormorants, terns and gulls, feed on fish, as do some of the large wading birds present." (S. Halse, pers comm., 2005)

Table 14: Populations and other aspects of the biology of native fish species at Lake MacLeod

Significant biological asset: Native fish
Qualitative description: Four species of native fish have been recorded. The Flag-tailed grunter (*Amniataba caudavittus)* and the Estuarine hardyhead (*Craterocephalus pauciradiatus*) exist in large schools near the vents. Dead specimens of the Sea-mullet (*Mugil cephalus*) have been found on the exposed mud banks and were possibly brought there by birds. The Spangled perch (*Leiopotherapon unicolour*) was not found in the lake until after the flooding of 2000, and it is believed the fish may have been flushed out of tributary rivers during high flows. The fish reside predominantly in the areas around the vents where salinities of marine water upwelling are close to that of sea water. The numerous small gullies and fringing mangrove roots offer protection from predators (mainly birds) and act as nurseries for young fry. Also, since 2000, the introduced fish, the Mozambique mouthbrooder *(Tilapia mossambicus)* has been provisionally identified in some of the smaller, isolated ponds.

Quantitative description: Knowledge gap. No population estimates have been made at this time.
Typical range of variability: Knowledge gap. **Species present:** Flag-tailed grunter (*Amniataba caudavittus)* and the Estuarine hardyhead (*Craterocephalus pauciradiatus*). See above regarding records of Sea-mullet (*Mugil cephalus*), Spangled perch (*Leiopotherapon unicolour*) and Mozambique mouthbrooder *(Tilapia mossambicus).* **Numbers of native fish:** 20,000-175,000 Knowledge gap

3.3.5 Aquatic invertebrates and phytoplankton

Table 15 below considers the key ecological and hydrological processes sustaining the aquatic invertebrates and phytoplankton at Lake MacLeod, and Table 14 further details the populations and other aspects of the biology of these species at the site.

Table 15: Key ecological and hydrological processes sustaining the aquatic invertebrates and phytoplankton

	Description
Tidal inputs	
Discharge through vents	Knowledge gap.
Salt deposition	Knowledge gap.
Freshwater inputs	
Flow characteristics	Flow patterns and water quality (see below) may be primary determinants of the aquatic invertebrate and phytoplankton communities, however, this remains a knowledge gap.
Nutrient cycling	Nutrient cycling and the nutrient requirements of the aquatic invertebrates and phytoplankton in this system are not well understood.
Water quality	Knowledge gap. Further investigations may reveal that the salinity gradient apparent across the inundated areas (see Table 7) may be a significant determining factor for aquatic plant growth, and the distribution of food sources (including aquatic invertebrates) of the waterbird species. High levels of turbidity can also reduce the success of visual feeders such as waterbirds that require adequate visibility to see prey. Notably, high turbidity levels restrict growth for *Ruppia spp* to shallower waters.
Sedimentation	Knowledge gap.
Groundwater exchanges	Knowledge gap.
Food sources	See also section 3.3.3. "Invertebrates are a key element of the food web at Lake MacLeod. Shorebirds feed on mudflat and shallow water benthic invertebrates (of both inland and marine origin) and these invertebrates, together with planktonic algae, are the food source for the Lake's abundant fish population. Many of the more resident bird species at the Lake, such as pelicans, cormorants, terns and gulls, feed on fish, as do some of the large wading birds present." (S. Halse, pers comm., 2005)

Table 16: Populations and other aspects of the biology of the aquatic invertebrates and phytoplankton

Significant biological asset: Aquatic invertebrates and phytoplankton
Qualitative description: As advised in the RIS (See Appendix A), Dampier Salt has been conducting monitoring surveys since 1997 to establish an understanding of baseline conditions in the naturally fluctuating environment of the lake. Fresh water inundation and subsequent changes in water chemistry of the ponds has a significant impact on the macro-invertebrate fauna, which is dominated by salt tolerant freshwater species. Some are of freshwater origin, adapted to live in hypersaline environments, while others are typically marine species. Macro-invertebrates collected so far have included species of insects, crustaceans, molluscs, nematodes, annelids and arachnids. The biodiversity of aquatic fauna in Lake MacLeod is quite low, however it is comparable to other inland saline lakes in Western Australia.
Quantitative description: Initial surveys found the lake to be dominated primarily by gastropods and crustaceans, with an increased presence of insects during the 'dry' season. Following the flood in 2000, there was a reduction in biodiversity and abundance of certain species. Five species of mollusc were notably absent (present in previous surveys) and the abundance of amphipods and molluscs was greatly reduced. By November 2001 the community structure was similar to pre-flood conditions. Surveys to date have not provided sufficient data to allow any quantitative descriptions to be provided.
Typical range of variability: Knowledge gap. **Species present:** Knowledge gap.

3.4 Ecological character management benchmarks (Step 5)

The simplified conceptual model presented in section 3.2 (Figure 4), along with the information relating to the significant biological assets (section 3.3) allows for a systematic documentation of the key features of the Lake MacLeod wetland ecosystem, along with limits of acceptable change, both short-term and longer-term.

The setting of limits of acceptable change for the management of wetland ecosystems in general (see Section 2), and Lake MacLeod in particular, is very challenging. As shown by the preceding section, for Lake McLeod many of the key drivers and ecological processes remain poorly understood at present. Additionally, this system is a highly variable one, and several key processes and variables can be expected to change by orders of magnitude during major climatic events such as cyclones or freshwater floods.

Therefore, the guidance given below regarding limits of acceptable change is provided while also acknowledging the inherent problems in doing this without long-term data to demonstrate natural variability of the key system attributes. These values should not be seen as threshold values. Rather, they are interim values which will be further refined and developed as more information about the system becomes available.

In the event that monitoring detects changes to species abundance/presence, area occupied or condition approaching or exceeding the specified limit of acceptable change indicated below, then it is recommended that Dampier Salt Limited draw this to the attention of the Management Advisory Group (MAG) for the site as soon as feasible and seek guidance on the appropriate further investigations or more detailed monitoring to undertake. The Commonwealth Government representative on the MAG should provide advice with respect to appropriate actions pursuant to the EPBC Act 1999, if required.

Table 17: '*Ecological character*' management benchmarks for Lake MacLeod

'*Ecological character'* key ecological features	Baseline condition* and range of natural variation where known	Interim limits of acceptable change^	
		Short-term (1-2 years)	**Long-term (10 - 20 years)**
System drivers, features and processes			
Geomorphology			
Tidal inputs, seawater discharge – hydraulic head through vents	3-4 metres of head.	Knowledge gap	Knowledge gap
Sedimentation	Rates of sedimentation are not known at present. Turbidity suggests some re-suspension is occurring, possibly due to wind and wave action and associated shoreline erosion. Increased turbidity caused by disturbance in the overland flow catchments could be a concern.	Knowledge gap	Knowledge gap
Soil chemistry	This remains a knowledge gap, although soil salinity may be important in determining mangrove distribution (see section addressing SBA 1(a) above	Knowledge gap	Knowledge gap
Climate			
Evaporation rates - Seasonal drying Area of open water	6000 ha of open water in summer with substantial seasonal fluctuations. Need to determine range of acceptable change using aerial mapping.	Knowledge gap	No net change in area of open water.
Cyclones	Cannot predict frequency or severity of impacts.	Not applicable	Not applicable
Flooding and associated freshwater inputs	Cannot predict frequency of natural flooding events or their extent.	Not applicable	Not applicable
Hydrology			
Tidal inputs – see above			
Seasonal drying – see above			
Freshwater inputs	Any changes in delivery of water from the inland catchments, via reduction of flows, could have significant impacts on the ecology of the system. Diversions of water upstream, or dam construction could have significant detrimental impacts.	No net change in the timing, duration, and frequency of inundation events and freshwater inputs.	No net change in the timing, duration, and frequency of inundation events and freshwater inputs.

Water chemistry Dissolved nitrogen (nitrate-nitrite + ammonium)	There is little information available on the nitrogen concentrations of Lake McLeod, with the exception of high levels (> 1000 ug / L) during surface water inflow. Many of the biological processes are driven by inorganic, bio-available forms of nitrogen and information is required for these. Generic levels have been provided for tropical wetlands by ANZECC (2000)	Interim ANZECC (2000) recommendations: Total nitrogen of < 350 – 1200 ug / L (higher level an indicator for freshwater flushes). Nitrate-nitrite of < 10 ug / L Ammonium of < 10 ug / L Once sufficient data has been collected, site specific trigger values based on 80^{th} percentile of the median should be calculated and adopted.	No significant change in median concentrations from baseline.
Dissolved phosphorus (filterable reactive phosphorus)	Mesotrophic as defined by the OECD, is based on a measure of mean total phosphorus being 10 – 35 ug /L As with nitrogen, concentrations of bioavailable phosphorus (filterable reactive phosphorus) are a more useful indicator than total amounts. There is little information, other than the mesotrophic status of Lake McLeod available. ANZECC (2000) provides generic values for tropical wetlands.	Interim ANZECC (2000) recommendations: Total Phosphorus of < 10 – 50 ug / L (higher level an indicator for freshwater flushes). Filterable reactive phosphorus of 5 – 25 ug / L Once sufficient data has been collected, site specific trigger values based on 80^{th} percentile of the median should be calculated and adopted.	No significant change in median concentrations from baseline.
Sedimentation – see above			
Turbidity – see comment above under Geomorphology – sedimentation.	Turbidity can be expected to vary with freshwater inflows, wind and tidal actions < 50 NTU pre-flood < 200 NTU post-flood (need to check, these seem high)	ANZECC (2000) trigger values 2 – 200 NTU Once sufficient data has been collected, site specific trigger values based on 80^{th} percentile of the median should be calculated and adopted.	No significant change in median concentrations from baseline.

Salinity	Hypersaline range = 40-100 g/l Measured as saline to hypersaline in October 2000. 38.4 – 49.5 ppt Insufficient data at this stage. Salinity may vary dramatically over seasonal cycles.	Trigger value based on site specific data and the salinity tolerance of significant biota.	No significant change in median concentrations from baseline.
Soil chemistry Salinity	Data insufficient. Soil salinity is closely linked to the vegetation zonation of mangrove and saltmarsh systems. Saltmarsh communities can tolerate higher concentrations of salinity in the sediment – the role of freshwater and tidal flushing is important in open systems, but there is insufficient data to establish baseline conditions.	Insufficient data	No significant change in median concentrations from baseline.
Redox potential	Data insufficient	Knowledge gap	Knowledge gap
Nutrients	Data insufficient	Knowledge gap	No significant change in median concentrations from baseline.
Groundwater exchanges	Under investigation by DSL at present in relation to its operations further to the south in Lake MacLeod	Knowledge gap	Knowledge gap
Significant biological assets			
Grey mangrove community	Approximately 22.5 ha in generally good condition, although significant dieback suffered after cyclone in 2000. Trend in recruiting success after the 2000 dieback is unknown.	4% mortality rate under stable climatic conditions Loss of up to 90% due to flooding or cyclone.	No net change to population or reduction in recruitment rate.
Wetland/habitat types including the sedges, saltmarshes and mudflats	Areas of each type and typical range of variability remains a knowledge gap.	Knowledge gap	Knowledge gap
Waterbirds Number of waterbirds species breeding at the site.	Nine species have been recorded breeding at the site, although this hasn't occurred every year (see Tables 9 and 10)	Knowledge gap	Knowledge gap

Number of waterbird <u>species</u> recorded at site annually	Up to 70 species have been recorded, but this is highly variable based on annual surveys (See Appendix A).	Wetland species show marked variation between years, and observed differences between years are difficult to interpret. There is insufficient data available to do this as yet.	No net reduction in the number of waterbird species recorded. An observed, estimated, inferred or suspected reduction of at least 10% within 10 years
Numbers of <u>waterbirds</u> recorded in annual/bi-annual surveys	20,000-175,000	Less than 30,000 birds recorded for two consecutive years, based on consideration of previous 24 months data.	No net reduction in total waterbird numbers over 10 years.
Species observed present in numbers exceeding 1% of flyway population (= notable species) Curlew Sandpiper Banded Stilt Red Knot Red-capped Plover Red-necked Stint Red-necked Avocet	Range of numbers observed between 1987 and 2003 (with mean) for each species: 70 – 45 000 (21 836) 1 – 100 000 (22 454) 0 – 2 566 (497) 70 – 3 125 (835) 250 – 8 312 (5 161) 0 – 2 401 (728)	No recording of these notable species for two consecutive years.	No net reduction in the number of waterbird species recorded. Counts of notable species >1% levels one in every five years.
Native fish	Two species Flag-tailed grunter and the Estuarine hardyhead are regularly reported. Two others may be 'accidental occurrences (see section 3.3.4). Unconfirmed report of introduced Mozambique mouthbrooder *(Tilapia mossambicus*) is a major concern.	Data insufficient at this time	No net reduction in fish populations

Macroinvertebrates and phytoplankton	The site has low numbers of insects, dominated by air breathers and dipterans; may have some molluscs, but salt tolerant crustacean species expected to be the dominant fauna. Phytoplankton driven system – plankton may be important food for waterbirds and fish. Data insufficient at this time	>20% change in number of species of any of the classes of invertebrates present sustained for longer than two years. Significant changes in abundances of common species may indicate altered conditions – should be short term associated with seasonal physico-chemical water quality gradient. Significant and sustained shifts in functional feeding groups may also indicate an impact or change to ecological character. Could be large seasonal fluctuations. Algal blooms are normal occurring events in natural systems and can be important to ecological function ANZECC (2000) interim trigger value for tropical wetlands is < 10 ug / L chlorophyll a	Sustained changes in community composition – abundances of common groups. No net loss of species. No net change in the occurrence or dominant species of algal blooms

Explanations:

* Baseline condition = the quantitative measures used to gauge whether or not management is acting to retain this ecological attribute.

^ Limits of acceptable change = the tolerance that is considered acceptable without indicating a change of 'ecological character' is occurring. For example – if the mortality rate within the mangrove community doubled, or the area of permanent water was reduced by more than 5%, then these would require careful examination to establish the causes, and to respond through adaptive management. 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 then the precautionary principle will be applied.

Due to the variable nature of the physical, chemical and biological indicators in natural systems, ANZECC (2000) recommends the use of medians and percentiles rather than averages to set trigger values or targets

3.5 Ecosystem services of Lake MacLeod Ramsar site (Step 6)

The Lake MacLeod Ramsar site and its surrounding management zone provides the following ecosystem services. Those that relate to activities outside the Ramsar-listed portion of the site are indicated with a #.

Table 18: Ecosystem services of Lake MacLeod Ramsar site

Ecosystem service	Source
Provisioning services	
Salt for commercial production (DSL)#	1, 2
Gypsum mining (DSL) #	1, 2
Cattle grazing#	1, 2
Beta Nutrition Limited operations#	1, 2
Regulating services	
Flood control for distributaries of the Gascoyne River	Ex
Local climate regulation	Ex
Cultural services	
Nature observation (bird watching)	1
Scenic-aesthetic values	1
Significance for indigenous people – to be investigated further	1, 2
Supporting services	
Nutrient cycling	Ex
Primary production (phytoplankton)	Ex
Biodiversity conservation: Supporting the largest inland community of Grey Mangrove in the world; Bioregionally unique wetland ecosystem; Waterbird breeding and stop-over for migratory birds; Supports large aggregations of waterbirds (20,000+); Supports six waterbird species that occur there in numbers exceeding the 1% population or sub-populations levels of their species.	1

Sources:
1= Ramsar information sheet (Appendix A).
2 = Plan of Management
Ex = Expert opinion

3.6 Key knowledge gaps (Step 7)

The preceding sections have identified a range of knowledge gaps that warrant attention in gaining a better understanding of the ecological character of the Lake MacLeod Ramsar site. Below, the priority knowledge gaps are listed.

Drivers (See section 3.2, Table 2):

- Soil chemistry in relation to the geomorphology driver;
- The interaction between Lake MacLeod and the marine environment with which it has underground tidal exchange;
- Rate of salt deposition from seawater influxes;
- Detailed bathymetry across the lake areas regularly inundated;
- Seasonal drying patterns of the inundated areas and how this effects food sources for waterbirds;
- Detailed seasonal water quality profiles across the inundated areas, including of salinity, dissolve oxygen and turbidity;
- Measurement of total phosphorus in incoming water and soil phosphorus mechanics;
- The surface-groundwater interaction at Lake MacLeod

Ecological, hydrological and other processes (See section 3.3, Tables 3, 5, 7, 13 and 15)

- Many of those given above are also relevant in terms of the processes;
- Ecological and hydrological role of the discharge through the vents;
- Sedimentation rates within the various habitats;
- Ecological and hydrological roles of overland flows;
- Nutrient cycling;

Significant biological assets (See section 3.3, Tables 4, 6, 8, 14 and 16)

- Complete flora and fauna species lists, in particular native fish and aquatic invertebrates;
- Aerial extent of mangrove, mudflat, salt marsh and sedge communities to allow for repeatable monitoring and improved understanding of natural variabilities;
- Improved understanding of water bird breeding effort: species, frequency, numbers and preferred habitats;
- Habitat partitioning among the foraging waders and other waterbirds;

Limits of acceptable change:

- See Table 17.

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Appendix A: Information Sheet on Ramsar Wetlands (RIS)

1. Name and address of the compiler(s) of this form:	Dr Bill Phillips (MainStream Environmental Consulting) – mainstream@mainstream.com.au, based on that prepared by Roger Jaensch and Doug Watkins, March 1999. Additional input was provided by the late Colin Davis, Wader Study Group of Birds Australia, WA and Streamtec Ecological Consultants and Michael Coote from the Department of Conservation and Land Management. (see 32. below, Bibliographical references for full citations).
2. Date this sheet was completed/updated:	October 2004
3. Country:	Australia
4. Name of Ramsar site:	Lake MacLeod
5. Map of the site included ?	
5a) hardcopy	a) Yes, as attached.
5b) digital (electronic) format	b) Yes, provided separately.
6. Geographical coordinates and boundary description:	About 38,200 ha, Lake Macleod, Carnarvon, comprising all that part of Lake Macleod, bounded by a line starting at a point on the eastern boundary of Pastoral Lease number 3114 560 (Quobba) and approximate Zone 49 MGA coordinates 759701 metres East and 7329123 metres North and extending generally northerly along the eastern boundaries of that lease and Pastoral Lease number 3114 1184 (Gnaraloo) to a point with approximate MGA coordinates 782086 metres East and 7370914 metres North and thence south, south easterly about 16,400 metres to a point on the western boundary of Pastoral Lease number 3114 420 (Minilya) with approximate MGA coordinates 785661 metres East and 7354830 metres North and then generally southerly along the western boundary of that lease to a point with approximate MGA coordinates 780732 metres East and 7346381 metres North and thence south westerly about 27,200 metres to the starting point. [To be finalised once boundaries confirmed.]
7. General location:	Lake MacLeod is in the Shire of Carnarvon (local authority) in the State of Western Australia. The Ramsar site is 105 kilometres north of the town of Carnarvon.
8. Elevation:	From sea level to 3 - 4 metres below sea level (Australian Height Datum).
9. Area:	38,200 ha. [To be confirmed when boundaries endorsed.]
10. Overview:	The northern ponds area at Lake MacLeod is one of the most remarkable wetlands in Australia, with a unique combination of features. It comprises intermittently inundated, brackish-saline flats surrounding a series of saline springs and associated permanent saline channels and permanent lagoons. It supports a rare inland occurrence of Grey Mangrove *Avicennia marina* which is sustained by up-welling of subterranean seawater because much of the site is below sea-level. It is internationally important for both migratory and non-migratory shorebirds, with total numbers at times exceeding 100,000. It supports more than 1% of the flyway populations of six shorebird species; among them most notably Curlew Sandpiper *Calidris ferruginea* and Banded Stilt *Cladorhynchus leucocephalus* (Jaensch and Watkins, 1999). See Table 1 for full details.

11.Ramsar site criteria met by the site:

The site qualifies as a Ramsar site against the following criteria (as provided in full below):

1	2	3	4	5	6	7	8

Criteria for designating Wetlands of International Importance under the Ramsar Convention on Wetlands

As last amended by the 7th Ramsar Convention Conference of the Contracting Parties (San Jose, Costa Rica, 1999), the criteria for designating wetlands as internationally important are as follows:

Criterion 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.

Criterion 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.

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.

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

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.

12. Justification of the criteria selected under 11 above:	Criterion l. The site includes an unusual occurrence of Grey Mangroves *Avicennia marina*, more than fifteen kilometres inland and with no surface water connection. They are sustained by up-welling of seawater delivered by subterranean waterways to springs (sinkholes) in the lake bed. The site is also representative of a unique wetland ecosystem at the bioregional scale as well as internationally; with the combination of mangroves, mudflats and saltmarshes in an arid environment. Criterion 3. See below regarding qualification of the site against criteria 5 and 6. This means the site also qualifies under Criterion 3 for the role it plays in conserving biodiversity within the bioregion. Criterion 4. The site is an internationally important migration stopover area for shorebirds and one of the most important such areas in Western Australia. Seven waterbird species have been recorded breeding at the site also. – see item 20 and Table 1. Criterion 5. More than 114,000 waterbirds were counted at the site in October 1987, 31,000 in November 1999, more than 50,000 in September 2000, 2002, March 2003 and October 2003. In November 2004 174,764 waterbirds were recorded, 100,000 of these being Banded Stilt - see item 20 and Table 1. Criterion 6. The site regularly supports at least 1% of the flyway populations of Curlew Sandpiper, Banded Stilt, Red Knot, Red-capped Plover, Red-necked Stint and Red-necked Avocet - see item 20 and Table 1.
13. Biogeography:	
13a) Biogeographic region:	Carnarvon
13b) Biogeographic regionalisation	Interim Biogeographic Regionalisation of Australia (IBRA), version 5.1

scheme:	
14. Physical features of the site:	Lake MacLeod lies approximately parallel to the coast, is about 120 kilometres long and for most of its length is around 10 kilometres (exceptionally 40 kilometres) wide. The lake surface is at an elevation of three to four metres below sea level. The surface of the lake is normally dry from September to June, though winter or summer rains can result in the lake being wholly or partially covered by water. The Ramsar site (see map) is located at the northern end of the lake. It encompasses a series of sinkholes or vents, typically tens of metres wide. The sinkholes are connected by channels, between a few metres and hundreds of metres wide, to a system of permanent lagoons, marshes and mudflats. The pond areas can vary substantially, depending on evaporation, rainfall and prevailing winds, and during summer might occupy approximately 5000 hectares. Dampier Salt Limited (2000) provided the following advice regarding the baseline aquatic surveys of Lake MacLeod that have been conducted annually by Streamtec Ecological Consultants in conjunction with DSL staff since 1997. "The study includes analysis of water chemistry at a number of different sites. Aquatic invertebrates and fish are also sampled and identified in a range of habitats (eg. littoral margins, sedges, mangroves, benthos and open water). Water in the lake is hypersaline, in October 2000 being measured between 38.4 and 49.5 ppt (compared with 35 ppt for seawater). There appears to be little change in water quality parameters seasonally (wet versus dry seasons). Evaporation rates, coupled with marine water discharge through the vents, appear to be the main determinants of water chemistry. However, superimposed on this is the seasonal influence of freshwater discharge which sets up a short-term gradient in pH, salinity, dissolved oxygen and nutrients in surface water. This gradient has been found to all but disappear by the end of the wet season. Nutrient levels in the lake were found to be low (classified as meso-eutrophic) however, after the flood in 2000, total nitrogen concentrations increased up to ten fold. Nitrogen was determined to be 0.9-1.1mg/L in October 2000, expected to be a result of nutrient enriched surface water inflow. The influx of nutrients was observed to have a significant impact on the lake, with severe algal blooms forming and numerous fish deaths towards December 2000."
15. Physical features of the catchment:	Lake MacLeod is situated in the Carnarvon Basin, in calcareous marine deposits. It is a former Pleistocene sea embayment that was isolated from the sea at both its northern and southern ends by falling sea level and development of sand dunes. It is underlain by sand, silt, clay and evaporate beds of gypsum and halite. To the west is limestone upland, forming high cliffs at the sea-front, overlain with red quartzite sand. Alluvial lowlands lie to the south-east and north and Gnargoo Range (of marine origin) is at the north-east side. The greater part of Lake MacLeod periodically receives freshwater from the Lyndon and Minilya Rivers and Cardabia and Boolathana Creeks; the latter being a distributary of the Gascoyne River which originates 620 kilometres to the east south-east (surface catchment 73,000 square kilometres). Surface inflow from the smaller rivers is intermittent and may affect only the vicinity of the river mouths, not spreading as far as the Ramsar site. Major flooding from the Gascoyne River occurs infrequently, with significant flow to the lake occurring in 1960, 1961, 1980, 1995 and 2000. The 2000 flood was the largest recorded over this period with water contributed by all rivers and local rainfall. Most floods occur during the cyclone season (February-March) and in mid-winter

	(May-June). (Logan 2001). All surface catchments are highly disturbed by grazing.
16. Hydrological values:	Water from the Indian Ocean passes underground 18 kilometres through coastal limestone and under hydrostatic pressure rises up in the site's sinkholes, which are slightly below sea level. Water flows southwards from several principal points of discharge within the sinkhole network, through the channel system to the main permanent lagoon. It periodically overflows across a broad mudflat to the terminal lagoon. Daily two-way exchange of water across the mudflat occurs in spring, and possibly also in other seasons, when prevailing winds have an easterly component in the morning and a westerly component in the afternoon. Water discharging from minor sinkholes terminates in adjacent saline marshes. The up-welling of seawater is continuous and the discharge rate varies during the day, apparently under the influence of twice-daily tides. Water in the sinkholes may be several metres deep; water in the lagoons and marshes can be in the order of one metre in depth. Average water depth is estimated to have been 1.4 metres during the 2000 flood. Water emerging from the sinkholes is at sea salinity but is hypersaline to brine when it reaches the terminal lagoon. River floodwaters are initially fresh, but become brackish or saline. Median and mean annual rainfall at Gnaraloo (15 kilometres west-north-west of the site) are 203 mm and 230 mm respectively, mostly falling in May-July. Annual evaporation across the site is about 2800-3000 mm.

17. Wetland types:

a) presence:

As per the Ramsar Convention type listing shown below, the shaded types are those found at Lake MacLeod (see explanatory notes below):

marine-coastal:	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**Zk(a)**
inland:	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**Sp**	**Ss**	**Tp**	**Ts**	
	U	**Va**	**Vt**	**W**	**Xf**	**Xp**	**Y**	**Zg**	**Zk(b)**			
human-made:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Zk(c)**		

In relation to the types shown above, more specific type information is given in **bold** below:

I (intertidal forested wetlands) but note these mangroves are not in an intertidal situation;
Q (permanent **saline**/brackish/alkaline **lakes**);
R **(**seasonal**/intermittent** saline**/brackish/lakes** and flats);
Sp (permanent **saline**/brackish/alkaline marshes/pools); and
Y (freshwater springs), although note that these are saline rather than freshwater.

b) dominance:

The ranking of these types beginning with most dominant is as follows: R, Q, Sp, I and Y.

18. General ecological features:	Grey Mangroves *Avicennia marina* occur within the site in low closed-forest to open-scrub/shrubland formations, mainly fringing the sinkholes, channels and permanent lagoon although small patches of mangrove are also scattered across the surrounding lake bed. The mangrove community is the largest (covering 22.5 ha) of only two inland occurrences in Western Australia (Johnstone 1990); the other is at Mandora Salt Marshes which is within the Eighty Mile Beach Ramsar Site. Low shrubland of samphire (*Halosarcia sp.*) occurs near the high water mark of the (greater) lake. The alga *Dunaliella salina* occurs. Algal mats cover parts of the mudflats within the lagoon complex. The surrounding areas support low and open-shrubland.
19. Noteworthy flora:	See above regarding the Grey Mangrove *Avicennia marina* community.
20. Noteworthy fauna:	**Waterbirds**. Lake MacLeod is one of the most important non-tidal sites for migratory shorebirds in Australia. Large aggregations of migratory shorebirds have been counted at the Ramsar site (see Table 1 for details over the years 1987 to 2004), mainly on the shallows and mudflats associated with the permanent lagoons. It is probable that many of the shorebirds may be using the lake as a stop-over site during their journey from north-western to south-western and perhaps south-eastern Australia. The discovery of large flocks of adult birds in full or partial breeding plumage in March 2003 indicates Lake MacLeod to be an important staging area for northern migration also. The most abundant migratory shorebird at the Ramsar site is the Curlew Sandpiper: highest numbers counted are 45,000 (November 2004) and 41,606 in October 1987. 1% level for in the East Asian-Australasian Flyway is 1,800. Other migratory species occurring in numbers exceeding 1% of the estimated flyway population are Red-necked Stint and Red Knot (see Table 1). The site is also internationally important for non-migratory shorebirds. The 2004 record of 100,000 Banded Stilt represents nearly 50% of the estimated population of this endemic species, and the site also supports more than 1% of the flyway populations of Red-necked Avocet and Red-capped Plover. The total number of waterbirds counted at the site has exceeded 50,000 for the surveys since 2000 presented in Table 1, with the maximum number being nearly 175 000 in November 2004. It is likely that conditions may be suitable for similar numbers to occur on a regular basis. Surveys have recorded 70 waterbird species at Lake MacLeod: 28 of these are listed under one or both of Australia's bilateral treaties on migratory birds with Japan and China. Uncommon species recorded at the Lake include the globally threatened (Collar *et al*. 1994) Asian Dowitcher *Limnodromus semipalmatus*. Seven species of waterbirds have been recorded breeding at Lake MacLeod, mostly in the mangroves. **Other noteworthy fauna.** Dampier Salt has been conducting monitoring surveys since 1997 to establish an understanding of baseline conditions in the naturally fluctuating environment of the lake. Fresh water inundation and subsequent changes in water chemistry of the ponds has a significant impact on the macro-invertebrate fauna, which is dominated by salt tolerant freshwater species. Some are of freshwater origin, adapted to live in hypersaline environments, while others are typically marine species. Macro-invertebrates collected so far have included species of insects, crustaceans, molluscs, nematodes, annelids and arachnids. The biodiversity of aquatic fauna in Lake MacLeod is quite low, however it is

	comparable to other inland saline lakes in Western Australia. Initial surveys found the lake to be dominated primarily by gastropods and crustaceans, with an increased presence of insects during the 'dry' season. Following the flood in 2000, there was a reduction in biodiversity and abundance of certain species. Five species of mollusc were notably absent (present in previous surveys) and the abundance of amphipods and molluscs was greatly reduced. By November 2001 the community structure was similar to pre-flood conditions. In addition to macro-invertebrates, four species of fish have been recorded. The flag-tailed grunter (*Amniataba caudavittus)* and the estuarine hardyhead (*Craterocephalus pauciradiatus*) exist in large schools near the vents. Dead specimens of the sea-mullet (*Mugil cephalus*) have been found on the exposed mud banks and were possibly brought there by birds. The spangled perch (*Leiopotherapon unicolour*) was not found in the lake until after the flooding of 2000, and it is believed the fish may have been flushed out of tributary rivers during high flows. The fish reside predominantly in the areas around the vents where salinities of marine water upwelling are close to that of sea water. The numerous small gullies and fringing mangrove roots offer protection from predators (mainly birds) and act as nurseries for young fry. Also, since 2000, the introduced fish, the Mozambique mouthbrooder *(Tilapia mossambicus)* has been provisionally identified in some of the smaller, isolated ponds. Table 2 summarises the macroinvertebrate and fish taxa found at Lake MacLeod by the DSL/Streamtec Ecological Consultants. Data are from Smith and Johnstone 1985, Jaensch and Vervest 1990, Lane et al. 1996, Dampier Salt Limited (2000)and data sets held by the Western Australian Department of Conservation and Land Management.
21. Social & cultural values	Lake MacLeod is a remote location and attracts only minor tourism activity at present. The cultural significance of the site for the Indigenous Australians of the region is yet to be fully investigated and documented.
22. Land tenure/ownership	
22a) site:	The Ramsar site is unallocated Crown Land. Dampier Salt Limited has a mining lease over the entire lake. There are some overlaps with pastoral leases which surround the lake.
22b) surrounding area:	Areas surrounding Lake MacLeod are covered by a number of pastoral leases. On the eastern side there is small area vested in the WA Department of Conservation and Land Management.
23. Current land (including water) use	
23a) within the Ramsar site:	Within the designated area there are no on-going land uses. See 24(b) below in relation to the operations of Dampier Salt Limited and possible hydrological links with the Ramsar-listed area.
23b) surrounding area or catchment:	Sheep and/or cattle grazing occur on the surrounding lands. Human population in the catchment of Lake MacLeod is in the order of hundreds of people.
24. Factors (past, present or potential) adversely affecting the site's ecological character	
24(a) at the site:	At present, there is low level visitation to the site by members of the public, however, it can be expected that visitor numbers will increase with an expected increase in visitor numbers to the region. Human disturbance impacts can include disturbance of vegetation and mud surfaces by four wheel-drive vehicles (including bikes), erosion of lake shoreline due to boat wakes and introduction of pollution due to fuels and/or litter. Introduced species, such as foxes, rabbits, goats, are also considered to have the potential to affect the biological values of the site.

24(b) around the site:	In the southern part of Lake MacLeod, Dampier Salt pump a brine solution from beneath the lake bed as the feed source for their salt production. The possible hydrological links between this water extraction and the ponds to the north is under investigation. Gypsum is also mined from the surface of the lake. These activities are managed under the *Evaporities (Lake MacLeod) Agreement Act 1967 – 1979*, with an appropriate licence to operate issued by the WA Department of Environment Protection. The DSL environmental management system has ISO14001 accreditation and monitoring programmes that have been in place since 1997 to detect any impacts. To date, evidence of any impact of DSL activities has not been identified. Commercial activities undertaken by people around the site have the potential to affect both the river catchments and the inflow of seawater through the coastal limestone. Activities of particular interest are grazing and tourism developments. Local pastoral lease holders have a small number of coastal chalets which serve as accommodation nodes for visitors to the region. Seepage from development has the potential to deleteriously affect the quality of the water up-welling into the pond system. If nature-based or ecotourism ventures are further developed this must be carefully done as the area is vulnerable to impact. For example, mangroves are slow to regenerate following impact. Such issues are considered in the management plan. Natural events, such as cyclones and flooding, have been demonstrated to have a significant impact on the mangroves that fringe the permanent vents. Climate change and sea level changes can be expected to impact the ecological communities of the ponds.
25. Conservation measures taken:	No part of Lake MacLeod is within a protected area. The lake is however listed on the Register of the National Estate. Dampier Salt has a clearly stated environment policy which includes commitments to prevent pollution and minimise the impact of its operations on the surrounding environment and neighbouring communities. Monitoring of the ponds was initiated in 1997 and development of a management plan is underway. (see Sec 26) Rio Tinto (the major shareholder in DSL) has also committed to a five year partnership with BirdLife International to advance opportunities for improved bird conservation at or near its facilities. Among the activities which support this partnership has been assistance to the Wader Study Group of Birds Australia WA for regular bird surveys at Lake MacLeod.
26. Conservation measures proposed but not yet implemented:	A management plan has been prepared for the site which provides a conservation and sustainable use (wise use) framework for the site and the immediate surrounds, the so-called Lake MacLeod Ramsar Management Zone.
27. Current scientific research and facilities:	Surveys of the wetlands and waterbirds within the proposed Ramsar site have been conducted by J. Lane *et al* of the Western Australian Department of Conservation and Land Management (1970s), L. Smith and R. Johnstone of the Western Australian Museum (Smith & Johnstone 1985), R. Jaensch *et al* of the Royal Australasian Ornithologists Union (Jaensch & Vervest 1990). Davis and Kirkby of the Wader Study Group of Birds Australia WA have conducted surveys each year since 1999. Waterbird survey data for 2004 comes from the DSL-commissioned surveys by Hassell. Dampier Salt is undertaking monitoring of the condition of the site. This involves bird life surveys, mangrove monitoring and studies into the aquatic ecology and water chemistry.
28. Current conservation education:	During 2001 Dampier Salt established a sponsorship and participative programme with the Carnarvon Primary School. This focused on learning about local native plant species and their uses. Students have

	visited the DSL site and have collected and identified local native plants to be used in the rehabilitation of disturbed lands. Students returned for subsequent plantings following suitable rainfall in 2003 and will continue to participate in monitoring the progress of revegetation.
29. Current recreation and tourism:	Low level visitation at present. See also Sec 24.
30. Jurisdiction:	<u>Territorial</u>: The State Government of Western Australia. <u>Functional</u>: The Western Australian Department of Planning and Infrastructure (in regard to Unallocated Crown Land) and the Western Australian Department of Industry and Resources (in regard to the mining lease). The Department of Conservation and Land Management, WA's Ramsar focal point agency, also has an ongoing responsibility to ensure site activities are in accordance with the management plan.
31. Management authority:	Dampier Salt has management responsibility for its operations situated within the mining lease and for implementation of the management plan. DSL has established a Management Advisory Group to provide ongoing consultation on management of the site.
32. Bibliographical references:	Collar, N.J., Crosby, M. J. and Stattersfield, A.J. 1994. Birds to watch 2. The world list of threatened birds. BirdLife Conservation series No. 4. BirdLife International, Cambridge, UK. 407 pp. Dampier Salt Limited (Leon Staude and Stuart Simmonds), date unknown. *Increasing our understanding of a wetland of national importance*. Dampier Salt Limited, 2000. Nomination for Golden Gecko Award for Environmental Excellence; Lake MacLeod Northern Ponds Project. Dampier Salt Limited, 2001. *Social and Environment Review* Davis, C., Kirkby T. and Singor, M. 2001. Wader study group surveys at Lake MacLeod. *Westem Australian Bird Notes Vol 98 June 200.* Davis, C., 2003. Lake MacLeod Surveys 2002 - 2003. *Westem Australian Bird Notes Vol 107 September 2003.* Hassell, C, 2004. Bird survey reports for Dampier Salt Limited. Jaensch, R.P. and Vervest, R.M. 1990. Waterbirds at remote wetlands in Western Australia, 1986-8. Part 2: Lake MacLeod, Shark Say, Camballin Floodplain and Parry Floodplain. Royal Australasian Ornithologists Union Report 69. Jaensch, R. and Watkins, D. 1998 Nomination of additional Ramsar wetlands in Western Australia. Report by Wetlands International – Oceania to the Western Australian Department of Conservation and Land Management. Johnstone, R.E. 1990. Mangroves and mangrove birds of Western Australia. Records of the Western Australian Museum Supplement 32. Lane, J., Jaensch, R. and Lynch, R. 1996. Western Australia. In, ANCA. A directory of important wetlands in Australia. Second edition. Australian Nature Conservation Agency, Canberra. Logan, B.W. 1993. Gypsum mine feasibility study. Report to Dampier Salt Limited by Logiden Geoscience and Environmental Services. Logan, B.W. 2001. Lake MacLeod Floods 1960 to 2000. Report to Dampier Salt Limited by Logiden Pty Ltd. Smith, L.A. and Johnstone, R.E. 1985. The birds of Lake MacLeod,

	upper west coast, Western Australia. Western Australian Naturalist 16, 83-7. Watkins, D. 1993. *A National Plan for Shorebird Conservation in Australia*. RAOU Report No.90. Wetlands International, 2002, Waterbird Population Estimates, Third Edition

Table 1 - Waterbirds and other wetland-dependent birds recorded at Lake Macleod

Sources (see section 32 for full citations):

October 1987 data: Jaensch and Vervest, 1990
November 1999 and September 2000 data: Davis, Kirkby and Singor, 2001
September 2002 and March 2003 data: Davis, 2003
October 2003 data: Davis and Kirkby (unpublished)
January 2002, March and November 2004, cited in Hassell, 2004

Waterbird species (organised by Family[#])	October 1987	November 1999	September 2000	January 2002	September 2002	March 2003	October 2003	March 2004	November 2004
Pelicans - Family *Pelecanidae*									
1. Australian Pelican	376	338	1 600	100	600	551	402	180	300
Anhingas (Darters) - Family *Anhingidae*									
2. Darter	37 [B]	5	8	2	20	20	40	12	50[B]
Cormorants – Family *Phalacrocoracidae*									
3. Pied cormorant	504	502	650[B]	150	450	321	321	350	350
4. Little Pied Cormorant	28 [B]	0	3	8	30	0	1	1	27
5. Great cormorant	6	0	0	0	3	0	0	1	0
6. Little Black Cormorant	134	85	200	122	300	448	2488	757	550
Grebes – Family *Podicipedidae*									
7. Great Crested Grebe	0	0	0	0	5	0	1	1	0
8. Hoary-headed Grebe	50	0	3	0	60	96	47	0	60
9. Australasian Grebe	0	0	0	0	50	0	0	0	0
Geese, Swans and Ducks – Family *Anatidae*									
10. Black Swan	823	15	1	178	400	572	584	350	550
11. Australian Shelduck	2	0	5	0	12	0	3	0	5
12. Pacific Black Duck	0	1	0	1	0	0	0	0	21
13. Grey Teal	313	6	31	0	350	504	77	2	500
14. Chestnut Teal	0	0	0	0	0	1	0	0	0
15. Pink-eared Duck	5	0	0	1	0	0	0	0	0
16. Hardhead	0	0	0	0	4	0	0	0	8
Rails, Crakes, Swamphens, Coot – Family *Rallidae*									
17. Buff-banded Rail	0	0	1	0	0	0	0	2	10
18. Crake (unidentified)	1								
19. Eurasian Coot	0	5	2	0	0	0	1	3	4
Herons, Egrets, Bitterns – Family *Ardeidae*									
20. White-necked Heron	0	0	2	0	0	0	0	0	0
21. White-faced Heron	37	18	2	4	5	2	2	1	2
22. Great Egret *[J/CAMBA]	25	13	150 [B]	16	30	4	15	10	6
23. Little Egret	96	22	170 [B]	20	70	229	69	112	80
24. Striated Heron	5	21	25	0	1	0	0	2	2
25. Nankeen Night Heron [+B]	3	0	110	0	50[B]	2	0	0	0
Ibises, Spoonbills – Family *Threskiornidae*									
26. Straw-necked Ibis	0	0	0	0	28	0	0	0	0
Curlews, Sandpipers, Snipes, Godwits, Phalaropes – Family *Scolopacidae*									

Waterbird species (organised by Family#)	October 1987	November 1999	September 2000	January 2002	September 2002	March 2003	October 2003	March 2004	November 2004
27. Ruddy Turnstone * J/CAMBA	18	37	10	2	25	2	3	6	38
28. Eastern Curlew * CAMBA	0	0	1	0	0	0	0	0	0
29. Little Curlew * CAMBA	1	0	0	0	0	0	0	0	0
30. Wood Sandpiper* J/CAMBA	0	3	0	0	0	0	0	0	2
31. Grey-tailed Tattler* J/CAMBA	0	2	0	0	0	0	0	0	13
32. Common Sandpiper * J/CAMBA	5	6	2	2	2	7	20	2	11
33. Common Greenshank * J/CAMBA	92	235	300	30	40	72	70	62	270
34. Marsh Sandpiper * CAMBA	66	3	0	0	10	2	1	0	3
35. Terek Sandpiper * J/CAMBA	1	0	0	0	0	0	0	0	4
36. Asian Dowitcher * CAMBA	1	0	0	0	0	0	0	0	0
37. Black-tailed Godwit * J/CAMBA	25	14	0	0	0	0	0	66	1
38. Bar-tailed Godwit * J/CAMBA	111	386	18	54	160	3	26	65	50
39. Red Knot * J/CAMBA (>1%)	2 566	137	8	0	515	187	668	150	250
40. Great Knot * J/CAMBA	135	211	39	0	75	7	60	83	260
41. Sharp-tailed Sandpiper * J/CAMBA	602	214	10	3	50	23	205	8	850
42. Little Stint	0	2	0	0	0	0	1	1	0
43. Red-necked Stint * J/CAMBA (>1%)	8 312	2 350	6 000	250	3 340	6 206	6 440	6 000	7 550
44. Long-toed Stint * J/CAMBA	2	0	0	0	0	0	0	1	1
45. Curlew Sandpiper * J/CAMBA (>1%)	41 606	18 392	40 000	70	8 000	16 690	26 283	485	45 000
46. Pectoral Sandpiper * JAMBA	0	0	0	0	0	0	0	1	0
47. Sanderling * J/CAMBA	1	1	0	0	0	0	0	0	5
48. Broad-billed Sandpiper * J/CAMBA	1	1	0	0	3	0	0	30	0
49. Unidentified waders		5 500	2 500	34	50 000	7 700	8 000	0	10 000
Oystercatchers – Family *Haematopodidae*									
50. Pied Oystercatcher	19	2	2	1	6	3	6	6	8
Lapwings, Plovers, Dotterels – Family *Charadriidae*									
51. Banded Lapwing	0	0	4	0	3	0	0	0	0
52. Grey Plover * J/CAMBA	34	31	2	0	14	18	5	60	21
53. Pacific (Lesser) Golden Plover * J/CAMBA	7	3	0	0	1	0	0	0	4
54. Red-kneed Dotterel	0	0	0	0	14	2	5	0	0
55. Inland Dotterel	0	0	0	0	0	0	0	6	0
56. Mongolian (Lesser Sand) Plover * J/CAMBA	1	3	0	0	17	1	4	0	0
57. Greater Sand Plover * J/CAMBA	75	12	0	0	35	3	6	0	515
58. Oriental Plover	0	33	0	0	0	0	0	0	3
59. Red-capped Plover (>1%)	2 110	114	500	70	300	457	442	400	3 125
60. Black-fronted Plover	1	0	0		0	0	0	0	0
Stilts, Avocets – Family *Recurvirostridae*									
61. Black-winged Stilt	310	5	500	530	1 000	79	885	230	850
62. Banded Stilt (>1%)	53 098	2 042	8 500	600	6 000	15 645	16 204	1	100 000
63. Red-necked Avocet (>1%)	2 401	0	70	402	346	778	214	28	2 315
Gulls, Terns etc – Family *Laridae*									
64. Silver Gull	104	292	300	20	60	4	8	10	160

Waterbird species (organised by Family[#])	October 1987	November 1999	September 2000	January 2002	September 2002	March 2003	October 2003	March 2004	November 2004
65. Pacific Gull	1	0	0		0	0	0		
66. Whiskered Tern	300	75	50	13	90	230	66	10	500
67. White-winged Black Tern * J/CAMBA	5	0	0	0	3	1	0	44	10
68. Caspian Tern * CAMBA +B	213 B	346	40	20	45	9	46	50	20
69. Gull-billed Tern	1	14	30	0	30	0	0	0	0
70. Common Tern		0	5	0	0	0	0	0	0
71. Fairy Tern +B	265 B	92	5	57	40	422	63	110	400
72. Crested Tern	4	1	9	0	0	0	0	0	0
Ospreys,Kites etc – Family *Accipitridae*									
73. Osprey	0	2	2	ND	1B	2	3	ND	ND
74. Brahminy Kite	0	0	0	ND	0	0	1	ND	ND
75. White-bellied Sea-Eagle	2	4	3	ND	2	2	2	ND	ND
Warblers etc – Family *Sylviidae*									
76. Little Grassbird	15			ND				ND	ND
Number of species (for this survey)	**55**	**45**	**43**	**27**	**49**	**38**	**41**	**41**	**47**
Total individuals (for this survey)	**114 956**	**31 596**	**61 873**	**2 760**	**72 695**	**51 305**	**63 788**	**9 699**	**174 764**

The order used follows that of *Field Guide to the Birds of Australia*, 6th Edition by Simpson and Day, 1999

B observed nesting, breeding (Note – survey data sourced from Hassell, 2004 does not consider breeding species)

+B recorded breeding – see DSL citation under 31.

* 27 species listed under either the Japan-Australia or China-Australia Migratory Bird Agreements, and therefore also under the Commonwealth Governments' *Environment Protection and Biodiversity Conservation Act 1999*.

ND = no data for these species included in the survey report.

>1%numbers exceed the estimate 1% of the population within the East Asian-Australasian flyway. The data used to establish the 1% flyway population level are as given by Wetlands International (http://www.wetlands.org/IWC/WPEnote.htm) in the publication Waterbird Population Estimates, Third Edition, 2002. For these six species these 1% levels at present are as follows (

- Red Knot = 2 200
- Red-necked Stint = 3 200
- Curlew Sandpiper = 1 800
- Red-capped Plover = 950
- Banded Stilt = 2 100
- Red-necked Avocet = 1 100

Table 2 Systematic listing of macroinvertebrates and fish recorded between November 1997 and November 2001 (by Streamtec)

TAXA		SPECIES CODE	'97	'98	'99	'00	3/01	11/01
MCROINVERTEBRATES								
NEMATODA (Round worms)								
	Nematoda spp		✓	✓	✓	✓		✓
ANNELIDA								
OLIGOCHAETA (Worms)								
	Oligochaeta spp		✓	✓	✓	✓	✓	✓
POLYCHAETA								
	Polychaeta spp		✓	✓	✓		✓	✓
	Nereidae spp						✓	
MOLLUSCA								
BIVALVIA (Bivlaves)								
GALEOMMATIDAE								
	Mysella ? anomala	WAM S 12330 UWA LM Bivalvia v4	✓	✓	✓	✓	✓	✓
LATERNULIDAE								
	?Latermula spp	WAM S12329		✓	✓			✓
GASTROPODA (Snails)								
CYLICHNIDAE								
	Tomatina ?apiculata	WAM S12331 UWA LM Gastropoda V1	✓	✓	✓	✓	✓	✓
MARGINELLIDAE								
	Mesoginella australis	WAM S12332		✓	✓			✓
HYDROCOCCIDAE								
	?Hydrococcus brazieri	WAM S12333	✓	✓	✓			✓
PYRAMIDELLIDAE								
	Liostomia spp	WAM S12334		✓				✓
CRUSTACEA								
OSTRACODA (Seed shrimps)								
	Ostracoda spp		✓	✓	✓	✓	✓	✓
COPEPODA								
	Harpacticoida			✓			✓	✓
	Cyclopoida			✓			✓	✓
	Calanoida	UWA LM Copepoda V2	✓			✓	✓	
AMPHIPODA								
?COROPHIIDAE								
	?Corophidae sp	UWA LM Amphipoda V1	✓	✓	✓	✓	✓	✓
?CEINIDAE								
	?Ceinidae sp	UWA LM Amphipoda V3		✓	✓	✓	✓	✓
DECAPODA								
PENAEIDAE (Shrimps)								
	Penaeidae sp			✓				✓
ARACHNIDA								
HYDRACARINA								
	Unionocolidae sp.		✓					
INSECTA								
ODONATA								
CORDULIIDAE								
	Hermicordulia tau		✓					
DIPTERA								
CHIRONOMIDAE (Midges)								
	Tanytarsus barbitarsus	UWA LM Chironomidae V1	✓	✓		✓	✓	
	Chironomus sp	UWA LM Chironomidae V2				✓	✓	
	Procladius sp		✓					
EPHYDRIDAE								
	Ephydridae sp (Larva)		✓					
CERATOPOGONIDAE								
	Ceratopogonidae spp		✓			✓		
STRATIOMYIDAE								
	Stratiomyidae sp		✓					
ATHERICIDAE								
	Atherididae sp						✓	
TRICHOPTERA								
LEPTOCERIDAE								
	?Oecetis sp		✓					
COLEOPTERA								
DYTISCIDAE								
	Stemopriscus sp (Adult)		✓					
	Necterosoma sp (Adult)		✓					
HYDROPHILIDAE								
	Hydrophilidae sp		✓					
FISH								
OSTEICHTHYES								
TELEOSTEI								
TERAPONIDAE (Grunters)								
	Amniataba caudavittatus (Flag tailed grunter)		✓	✓	✓	✓	✓	
	Leiopotherapon unicolor (Spangled perch)					✓	✓	
MUGILIDAE (Mullets)								
	Mugil cephalus				✓		✓	
ATHERINIDAE								
	Craterocephalus pauciradiatus		✓	✓	✓			

Appendix B: Summary water quality measurements from Lake MacLeod (from Ellison, 2003)

Table 1: Summary of Water Quality measurements at Lake MacLeod.

Source or Streamtec Report	Sample date	Season as described	Temp °C	pH	DO % or (mg/L)	Conductivity mS/cm or (ppt)	Turbidity NTU	TN Mg/L	TP Mg/L
Halse et al. 2000	Oct 1994	winter		7.2-7.9	105-147	(40-53)	0.05-0.26	0.24-0.55	0-0.01
Halse et al. 2000	March 1995	summer		7.3-8.9	84-164	(40-46)	0.6-4.8	0.31-0.85	0.005-0.01
ST 5/98	Nov 1997	dry	24.8-27.4	6.88-7.04	(2.87-10.9)	(29-46)	(Secchi 0.4-5.0)	0.13-0.74	<0.01-0.02
ST 02/99	Sept 1998	wet	19.5-21.8	8.98-10.52	(12.2-14.0)	(31.0-61.0)	0.2-9.5	0.15-0.47	<0.01
ST 17/99	July 1999	dry	23.8-24.8 15.5-18.2	7.92-8.13	75-80 120-150	56.4-67.8 (37.3-46.2)	0-135.7	0.24-0.77	0.01-0.02
ST 01/01	Oct 2000	wet flood	15.6-23.1	6.1-8.9	74 69-192	(38.4-49.5)	0-177.9 variable	0.9-2.2	<0.01
ST 05/01	March 2001	dry, post flood	28.2-39.5 25.2	7.17-8.3	3-74 86	67.3-100.3 (46-68)	0.4-11.5	0.2 0.68-1.2	<0.01
ST 06/02	Nov 2001	before wet	19.3-26.4	7.9-8.6	79-84 122-161	52.7-75	0.4-42.8	0.16-2.1	<0.01-0.05
ST 05/03	Aug 2002		18.9-24.1	7.18-8.48	38 86-134	54-65.6 (36-44)	0.1-110.1	0.16-2.1	0.01-0.05

Legend
Yellow shading = a distinct North-South gradient occurred across Lake
Blue = Jack's Vent recording