Ecological Character Description for the Forrestdale and Thomsons Lakes Ramsar Site

A report to the Department of Environment and Conservation

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Black-winged Stilts in flight over Thomsons Lake, 28th June 2008, during a deep-water phase (Figure E1) (J. Davis).

Cover photo: Black Swans at Thomsons Lake, 28th June 2008, during a deep-water phase (Figure E1) (J. Davis).

Table of Contents

List of Tables

List of Figures

Glossary

Acceptable change	The variation that is considered 'acceptable' in a particular measure or feature of the ecological character of a wetland. Acceptable variation is that variation that will sustain the component or process to which it refers (Phillips 2006).
Aeolian	Erosion and deposition of sediments by wind processes (Phillips & Muller 2006).
Assessment	The identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities (as defined by Ramsar Convention 2002, Resolution VIII.6).
Baseline	Condition at a starting point. For Ramsar wetlands it will usually be the time of listing of a Ramsar site.
Benchmark	A standard or point of reference (ANZECC and ARMCANZ 2000). A pre-determined state (based on the values which are sought to be protected) to be achieved or maintained.
Benefits	Benefits/services are defined in accordance with the Millennium Ecosystem Assessment definition of ecosystem services as "the benefits that people receive from ecosystems" (Ramsar Convention 2005, Resolution IX.1 Annex A). See also "Ecosystem Services".
Benthic	Species that thrive on the bottom of a water body, *i.e.* benthic algae can thrive on the bottom of lakes (Phillips & Muller 2006).
Biogeographic region	A scientifically rigorous determination of regions as established using biological and physical parameters such as climate, soil type, vegetation cover, etc. (Ramsar Convention 2009).
Biological diversity	The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species (genetic diversity), between species (species diversity), of ecosystems (ecosystem diversity), and of ecological processes. (This definition is largely based on the one contained in Article 2 of the Convention on Biological Diversity.) (Ramsar Convention 2009).
Biomass	The amount of living material in a unit area or volume, usually expressed as mass or weight (Phillips & Muller 2006).
Brackish	Water with a salinity of between 1,000 mg/L and 3,000 mg/L (or 200 - 880 mS/m) (ANZECC and ARMCANZ 2000).
Catchment	The total area draining into a river, reservoir, or other body of water (ANZECC and ARMCANZ 2000).
Change in ecological character	Defined as the human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service (Ramsar Convention 2005, Resolution IX.1 Annex A).
Community	An assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another (ANZECC and ARMCANZ 2000).
Community composition	All the types of taxa present in a community (ANZECC and ARMCANZ 2000).
Community Structure	All the types of taxa present in a community and their relative abundances (ANZECC and ARMCANZ 2000).
Conceptual model	Wetland conceptual models (or diagrams) illustrate our understanding of ecosystem components and processes and the interactions between them.
Contracting Parties	Countries that are Member States to the Ramsar Convention on Wetlands; 159 as at June 2009. Membership in the Convention is open to all states that are members of the United Nations, one of the UN specialized agencies, or the International Atomic Energy Agency, or is a Party to the Statute of the International Court of Justice.
Critical stage	Meaning stage of the life cycle of wetland-dependent species. Critical stages being those activities (breeding, migration stopovers etc.) which if interrupted or prevented from occurring may threaten long-term conservation of the species. For some species (Anatidae for example), areas where moulting occurs are vitally important (Ramsar Convention 2009).
Cyanobacteria	Aquatic bacteria that can photosynthesise (Phillips & Muller 2006) and typically appear blue green in colour.

Ecological character	The combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time. Within this context, ecosystem benefits are defined in accordance with the Millennium Ecosystem Assessment (2005) definition of ecosystem services as “the benefits that people receive from ecosystems” (Ramsar Convention 2005, Resolution IX.1 Annex A). The phrase “at a given point in time” refers to Resolution VI.1 paragraph 2.1, which states that “it is essential that the ecological character of a site be described by the Contracting Party concerned at the time of designation for the Ramsar List, by completion of the Information Sheet on Ramsar Wetlands” (as adopted by Recommendation IV. 7).
Ecological communities	Any naturally occurring group of species inhabiting a common environment, interacting with each other especially through food relationships and relatively independent of other groups. Ecological communities may be of varying sizes, and larger ones may contain smaller ones (Ramsar Convention 2009).
Ecosystem components	The physical, chemical and biological parts of a wetland (from large scale to very small scale, e.g. habitat, species and genes) (Millennium Ecosystem Assessment 2005).
Ecosystem processes	The changes or reactions which occur naturally within wetland systems. They may be physical, chemical or biological (Ramsar Convention 1996, Resolution VI.1 Annex A).
Ecosystem services	The benefits that people receive or obtain from an ecosystem. The components of ecosystem services are provisioning (e.g. food & water), regulating (e.g. flood control), cultural (e.g. spiritual, recreational), and supporting (e.g. nutrient cycling, ecological value). (Millennium Ecosystem Assessment 2005). See also “Benefits”.
Ecosystems	The complex of living communities (including human communities) and non-living environment (Ecosystem Components) interacting (through Ecological Processes) as a functional unit which provides inter alia a variety of benefits to people (Ecosystem Services). (Millennium Ecosystem Assessment 2005).
Fresh (water)	With a salinity of less than 500 mg/L (or < 90 mS/m) (ANZECC and ARMCANZ 2000).
Geomorphology	The study of water-shaped landforms (Gordon *et al.* 1999)
Hypersaline	Water with a salinity of greater than 35,000 mg/L (or > 5,000 mS/m). Seawater has a salinity of 35,000 mg/L (ANZECC and ARMCANZ 2000).
Indicator species	Species whose status provides information on the overall condition of the ecosystem and of other species in that ecosystem; taxa that are sensitive to environmental conditions and which can therefore be used to assess environmental quality (Ramsar Convention 2009).
Indigenous species	A species that originates and occurs naturally in a particular country (Ramsar Convention 2009).
Introduced (non-native) species	A species that does not originate or occur naturally in a particular country (Ramsar Convention 2009).
Key components, processes or benefits/services	Components, processes and benefits/services which have the potential to cause a fundamental shift in ecological character of the whole site; *sensu* Phillips and Muller (2006) “keystone species”. They include but are not restricted to the values for which the Site was Ramsar listed.
Limits of Acceptable Change	The variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland without indicating change in ecological character which may lead to a reduction or loss of the values for which the site was Ramsar listed (Phillips 2006).
List of Wetlands of International Importance (“the Ramsar List”)	The list of wetlands which have been designated by the Ramsar Contracting Party in which they reside as internationally important, according to one or more of the criteria that have been adopted by the Conference of the Parties.
Macroinvertebrate	Animals which do not have a back bone and are visible to the naked eye (typically larger than 250 microns), such as beetles, snails, dragonfly, mayfly, caddis-fly and mosquito larvae.
Macrophyte	Macroalgae (*e.g.* seaweed, sea lettuce, filamentous greens) and aquatic and fringing vascular plants. Vascular plants fall into three categories: submerged (*e.g.* seagrass, ribbonweed), floating (*e.g.* pondweed, duckweed) and fringing emergent (*e.g*. sedges, rushes).

Maintain	To keep the condition of the asset (or feature) in its current state, this is used if the condition is healthy, but may be appropriate if the condition is declining and there is no way of improving it (Phillips & Muller 2006).
Monitoring	The collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management (Ramsar Convention 2002, Resolution VIII.6).
Phytoplankton	All microscopic plants, usually dominated by microalgae and including chlorophytes (green algae), diatoms (*e.g*. bacillariophytes), dinoflagellates (*e.g.* dinophytes) and cyanophytes (*i.e.* blue-greens = cyanobacteria).
Ramsar	City in Iran, on the shores of the Caspian Sea, where the Convention on Wetlands was signed on 2 February 1971; thus the Convention's short title, "Ramsar Convention on Wetlands".
Ramsar Convention	Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar (Iran), 2 February 1971. UN Treaty Series No. 14583. As amended by the Paris Protocol, 3 December 1982, and Regina Amendments, 28 May 1987. The abbreviated names "Convention on Wetlands (Ramsar, Iran, 1971)" or "Ramsar Convention" are more commonly used.
Ramsar Criteria	Criteria for Identifying Wetlands of International Importance, used by Contracting Parties and advisory bodies to identify wetlands as qualifying for the Ramsar List on the basis of representativeness or uniqueness or of biodiversity values.
Ramsar Information Sheet (RIS)	The form upon which Contracting Parties record relevant data on proposed Wetlands of International Importance for inclusion in the Ramsar Database; covers identifying details like geographical coordinates and surface area, criteria for inclusion in the Ramsar List and wetland types present, hydrological, ecological, and socioeconomic issues among others, ownership and jurisdictions, and conservation measures taken and needed.
Ramsar List	The List of Wetlands of International Importance.
Ramsar Sites	Wetlands designated by the Contracting Parties for inclusion in the List of Wetlands of International Importance because they meet one or more of the Ramsar Criteria.
Restore	To change the condition of the feature back to (or close to) its natural condition (Phillips & Muller 2006).
Riparian	Any land which adjoins, directly influences, or is influenced by a body of water (LWRRDC 1998).
Risk Assessment	A quantitative or qualitative evaluation of the actual or potential adverse effects of stressors on a wetland ecosystem (US EPA 1989).
Saline	Water with a salinity of between 3,000 mg/L and 35,000 mg/L (or 880 - 5,000 mS/m). Seawater has a salinity of 35,000 mg/L (ANZECC and ARMCANZ 2000).
Stratification	A natural feature of water bodies characterised by a vertical gradient in density, caused by a differential heating of the water surface and/or differences in salinity (Phillips & Muller 2006).
Taxa	A grouping of organisms given a formal taxonomic name such as species, genus, family etc (Phillips & Muller 2006).
Turbidity	The muddy appearance of water resulting from suspended sediment.
Wetland types	As defined by the Ramsar Convention's wetland classification system.
Wetlands	Are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Ramsar Convention 1987).

Wise use of wetlands	Is the maintenance of their ecological character, achieved through the implementation of ecosystem approaches[1], within the context of sustainable development[2]" (Ramsar Convention 2005 Resolution IX.1 Annex A).
	1. Including inter alia the Convention on Biological Diversity's "Ecosystem Approach" (CBD COP5 Decision V/6) and that applied by HELCOM and OSPAR (Declaration of the First Joint Ministerial Meeting of the Helsinki and OSPAR Commissions, Bremen, 25-26 June 2003).
	2. The phrase "in the context of sustainable development" is intended to recognize that whilst some wetland development is inevitable and that many developments have important benefits to society, developments can be facilitated in sustainable ways by approaches elaborated under the Convention, and it is not appropriate to imply that 'development' is an objective for every wetland.

List of Abbreviations

AHD	Australian Height Datum - a geodetic datum for altitude measurement in Australia
ANCA	Australian Nature Conservation Agency
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
CALM	Department of Conservation and Land Management (Western Australia); now Department of Environment and Conservation (DEC)
CAMBA	The Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment, 1986
CEPA	Communication, Education and Public Awareness
COP	Conference of the Contracting Parties
DEC	Department of Environment and Conservation (Western Australia)
DEW	Australian Government Department of the Environment and Water Resources; now Department of the Environment, Water, Heritage and the Arts (DEWHA)
DEWHA	The Australian Government Department of the Environment, Water, Heritage and the Arts
DoE	Department of Environment (Western Australia); now Department of Environment and Conservation (DEC)
DoW	Department of Water (Western Australia)
ECD	Ecological character description
EPA	Environment Protection Authority (Western Australia)
EPBC Act	Environment Protection and Biodiversity Conservation Act, 1999
EWPs	Environmental Water Provisions
IOCI	Indian Ocean Climate Initiative
IUCN	The International Union for the Conservation of Nature and Natural Resources
JAMBA	The Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment, 1974
JGM	Jandakot Groundwater Mound
NTU	Nephelometric Turbidity Units
RIS	Ramsar Information Sheet
ROKAMBA	The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds and their Environment, 2006

Executive Summary

The Forrestdale and Thomsons Lakes Ramsar site is located within the southern Perth metropolitan area, in southwestern Australia. The lakes are the best remaining examples of brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain bioregion. The Ramsar site includes 246 ha at Forrestdale Lake and 538 ha at Thomsons Lake. The lakes are shallow (< 2m) and circular to oval in shape and when full, Forrestdale Lake has an area of open water covering approximately 221 ha and Thomsons Lake covers approximately 151 ha.

Forrestdale and Thomsons Lakes are interdunal groundwater wetlands with little natural surface drainage. Wind-mixing processes dominate the physical structure of the lakes, preventing the formation of thermally stratified layers for prolonged periods of time. This general low stability indicates that these lakes can be classified as continuous or discontinuous warm polymictic lakes (Davis *et al.* 1993).

The lakes are weakly coloured and are generally clear, probably because there is little inflow of surface water, and both have a neutral to alkaline pH. As basin wetlands with little to no flushing, Swan Coastal Plain wetlands have very long water residence times. Therefore, the nutrients that enter the wetlands tend to accumulate in the sediment. Both lakes have been moderately enriched since measurements began in the early 1970s and occasional algal blooms have been recorded. However, phosphorus levels have been lower since 2002–03 largely due to the more frequent and extended duration of complete drying at both lakes.

Forrestdale and Thomsons Lakes are dominated by submerged and floating macrophytes. Both lakes contain large areas of open water but are fringed by rushes and sedges, behind which are belts of trees tolerant of seasonal waterlogging. The higher ground around the lakes supports open woodland. The Ramsar site contains WA listed threatened ecological communities, declared rare flora and other priority flora species.

In a regional context, Forrestdale and Thomsons Lakes constitute an important breeding, migration stop-over and drought refuge area for waterbirds. Eighty five species of waterbird have been recorded at the two lakes and 27 species have been recorded breeding. The margins of both lakes support a large number of terrestrial birds, and other vertebrate species including the uncommon skink *Lerista lineata*. The Ramsar site supports 6 wetland frog species, and freshwater turtles *Chelodina oblonga* are also present in both lakes. Both lakes contain rich and diverse communities of aquatic invertebrates, which comprise much of the diet of many faunal species, including migratory waders and other waterbirds, and turtles.

Forrestdale and Thomsons Lakes were together designated as "Wetlands of International Importance" under the Ramsar Convention on Wetlands in 1990. As a Contracting Party to the Ramsar Convention, the Australian Government has accepted a number of obligations with regards to the management of listed wetlands in a manner that maintains their "ecological character" and to promote its conservation and wise use.

The Forrestdale and Thomsons Lakes Ramsar site meets the following two criteria for listing as a wetland of international importance:

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.

Forrestdale and Thomsons Lakes are the best remaining examples of large brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain, within the South-West Coast Drainage Division. While these types of wetland were formerly common, extensive development of the Swan Coastal Plain has resulted in the loss of many of these wetlands, and most of the remaining wetlands of this type have been degraded through drainage, eutrophication and the loss of fringing vegetation.

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.

Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain with 85 species of waterbird occurring at the two lakes, including 29 migratory species listed under the EPBC Act. In addition, 27 waterbird species have been recorded breeding at the lakes. The Ramsar site contains rich and diverse communities of aquatic invertebrates that are representative of relatively undisturbed, large, shallow Swan Coastal Plain wetlands dominated by submerged macrophytes. Macroinvertebrates are an important component of wetland food webs, comprising much of the diet of many faunal species, including migratory waders and other waterbirds, and turtles. There are two WA listed Threatened Ecological Communities at Forrestdale Lake Nature Reserve, two 'Declared Rare Flora' species listed under WA legislation and nine Priority taxa. Thomsons Lake Nature Reserve contains one 'Declared Rare Flora' species listed under WA legislation and three Priority taxa.

A summary of the ecological character of the Forrestdale and Thomsons Lakes Ramsar site (at the time of listing) is provided in Table E1.

Table E1: Summary of the ecological character of the Forrestdale and Thomsons Lakes Ramsar site at the time of listing.

Component/Process	Summary Description
Geomorphology and Geology	Located within interdunal depressions Soils considered infertile Underlain by pyritic peaty sediments (potentially acid sulfate soils)
Hydrology	Groundwater fed Little natural surface drainage Shallow (< 2 m), circular to oval in shape Seasonal drying
Physico-chemistry	Continuous or discontinuous warm polymictic lakes (wind-mixed) Weakly coloured with low turbidity Fresh to brackish Neutral to alkaline pH Moderately enriched; nutrients accumulate in the sediment Release of phosphorus is reduced with the current summer drying regime
Phytoplankton	Occasional cyanobacteria (blue-green algae) blooms
Aquatic Plants	Extensive stands of submerged and floating macrophytes
Littoral Vegetation	Edge of lakes: *Typha*, *Baumea*, *Juncus* and *Bolboschoenus* Beyond waters edge: *Melaleuca*, *Banksia*, *Eucalyptus* and *Acacia* Threatened ecological community 'shrublands on dry clay flats' and 'herb-rich shrublands in clay pans' at Forrestdale Lake (WA listed) *Typha orientalis* expanding across dry lake beds

Ecological regime	Predominantly clear-water, submerged macrophyte-dominated, driven by annual drying Occasional change to turbid, phytoplankton-dominated, driven by nutrient loading
Invertebrates and Reptiles	Long-necked turtles present in both lakes High invertebrate species richness and abundance Richest invertebrate assemblages supported by submerged plants and high maximum water levels
Birds	High diversity (85 species) of waterbirds Regularly supports > 5,000 waterbirds (maximum recorded 22,196 individuals at Thomsons Lake and 21,083 individuals at Forrestdale Lake) Breeding records for 27 species
Interconnections with other components and processes	Forrestdale and Thomsons Lakes are the largest wetlands (in area) on the Swan Coastal Plain. They are an important component of a landscape containing a large number (> 10,000) of basin and fringing wetlands. An estimated 70% of the wetlands of the coastal plain have been lost since European settlement.

Forrestdale and Thomsons Lakes were first listed under the Ramsar convention in 1990. Since this time, many of the components, processes, benefits and services critical to the ecological character of the site have been maintained, however, there have also been a number of changes to the wetlands. Major changes include:

- Maximum water depths at both lakes are substantially lower, the period of inundation substantially less, and annual drying is occurring earlier than at any time in the past. Although drier conditions will potentially result in a major change to the ecology of the site the extent to which these conditions, which are largely the result of climate change, groundwater abstraction and urban development, can be controlled or managed is not known.
- The introduced Bulrush *Typha orientalis* now covers expansive areas of the waters edge and is (along with other exotic and native species) encroaching across the dry lake beds at both lakes. *Typha* is displacing and changing riparian vegetation, which appears to be altering waterbird habitat. The invasion of *Typha* is facilitated by drier conditions and some active control measures have been implemented.
- The number of waterbirds and number of species recorded at Forrestdale and Thomsons Lakes have been variable, but overall have declined in recent years.

The attributes that are central to maintaining the ecological character of a Ramsar site have been described as “primary determinants”. In the context of the Forrestdale and Thomsons Lakes Ramsar site, primary determinants have been defined as those components and processes that are crucial to the maintenance of the components and processes for which the site has been listed. At Forrestdale and Thomsons Lakes these include:

- Seasonal hydrological regime
- Inter-annual variability resulting in wet and dry cycles depending on annual rainfall and evaporation rates
- Shallow (<3 m)
- Fresh to brackish
- Alkaline
- Mesotrophic to eutrophic
- Weakly coloured
- Zoniform distribution of fringing vegetation

- Provision of habitat for aquatic biota, especially waterbirds
- Clear water, aquatic plant-dominated ecological regime

The loss of or change to any one of these identifiers flags the likely occurrence of unacceptable ecological change. The primary determinants at Forrestdale and Thomsons Lakes can be illustrated in a conceptual model (Figure E1). Geomorphology and substrate type were used as the base layer in the model because these two factors exert considerable control over many wetland processes (Davis and Brock 2008). The model displays two temporal modes: a deep-water phase (present in winter and spring) and a shallow-water phase (present in summer and autumn). These phases conceptualise the intra-annual variation recorded at the wetland. Inter-annual variation also occurs, with the maximum water depth and the aerial extent to which the lake dries varying from year to year, depending on the combined effects of annual precipitation, height of the watertable and annual evaporation. However, additional models to describe inter-annual variation were not included as these are within the range encompassed by the deep-water and shallow-water phases illustrated.

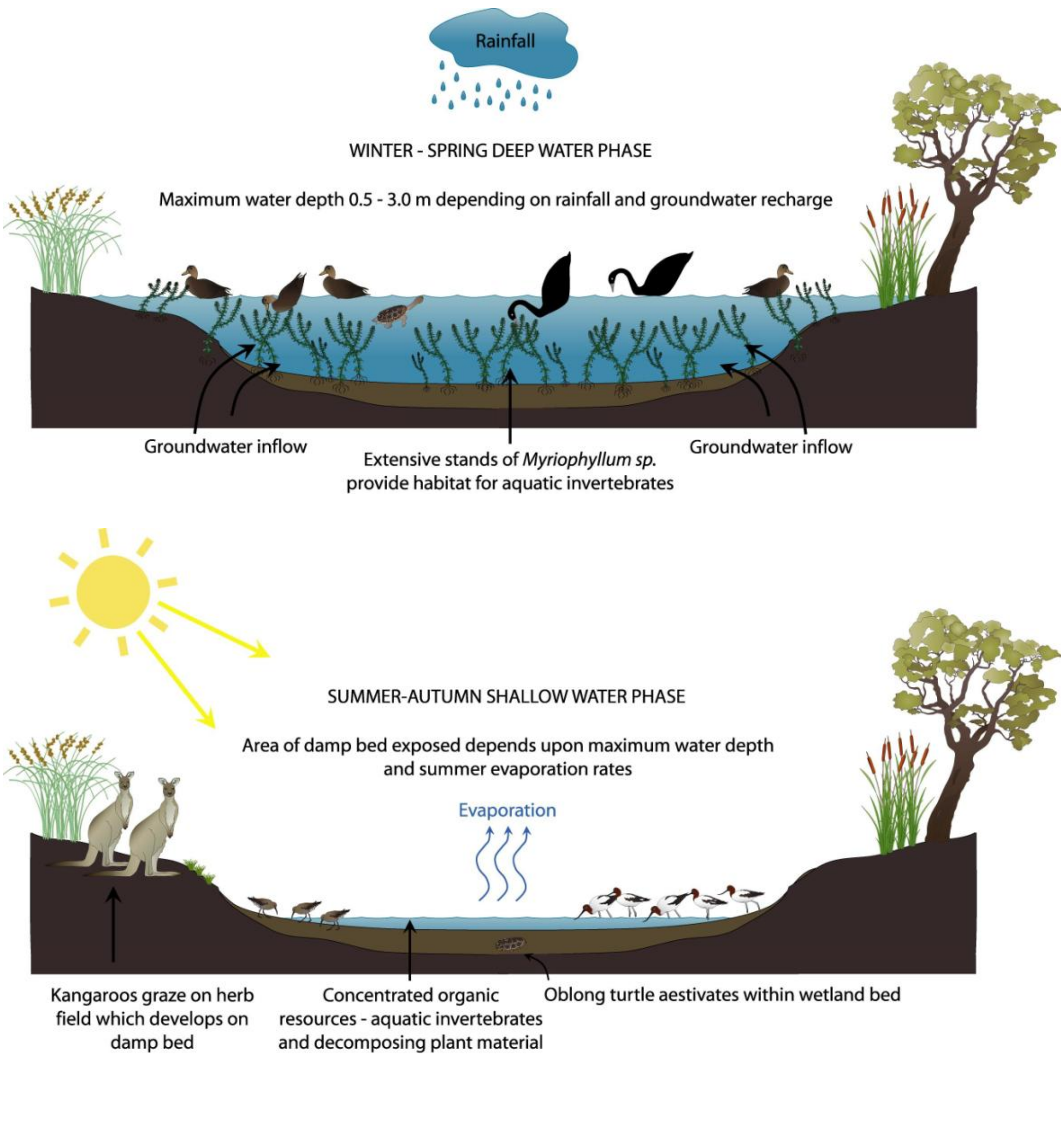

Figure E1: Conceptual ecological models of Forrestdale and Thomsons Lakes showing deep-water and shallow-water phases.

The major drivers and effects of ecological change to the Forrestdale and Thomsons Lakes Ramsar site have been identified (Figure E2). The primary direct drivers are the major external forces that influence wetlands. These were identified at Forrestdale and Thomsons Lakes as:

- Climate change
- Water supply (mainly the abstraction of groundwater for domestic, horticultural and industrial use); and
- Urbanization (and other land-use changes and impacts, including sub-surface drainage)

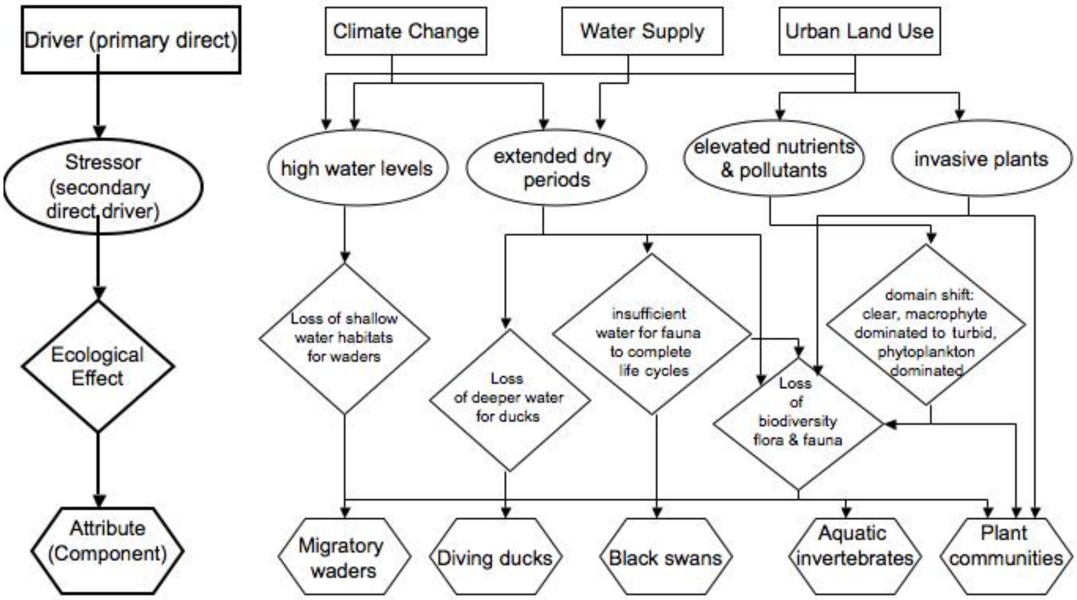

Figure E2: Driver/stressor model for Forrestdale and Thomsons Lakes showing drivers, stressors, ecological effects and the attribute/component affected.

"Limits of acceptable change" are the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. The Ramsar definition of an unacceptable change in ecological character indicates that it is a human-induced adverse alteration of wetland components, processes and benefits/services that is of concern. The setting of limits of acceptable change is a complex and difficult task, requires good knowledge of natural variations, the boom-and-bust cycles that can occur naturally in these species or communities, and is heavily reliant on good baseline or background data.

Unacceptable adverse ecological changes to Forrestdale and Thomsons Lakes would include changes to the unique set of identifiers, for example, the wetlands becoming:

- Permanently wet
- Permanently dry
- Deep (>3 m)
- Saline or hypersaline
- Acidic
- Eutrophic or hypertrophic

- Dominated by invasive plants
- Unsuitable as a habitat for aquatic biota, especially waterbirds
- Or undergoing an ecological regime shift – for example, from clear, aquatic plant-dominated to turbid, phytoplankton-dominated.

Limits of acceptable change for Forrestdale and Thomsons Lakes have been determined based on existing data and guidelines and have been set where sufficient baseline data is available. Although strict limits of acceptable change can not be set for these components, they form an important element of the monitoring program. Outcomes of the monitoring program are to be reviewed for broad trends and the information used to review and refine the limits of acceptable change for the site.

The key knowledge gaps that are required to fully describe and maintain the ecological character of Forrestdale and Thomsons Lakes and enable rigorous and defensible limits of acceptable change are outlined in Table E2.

Table E2: Key knowledge gaps.

Component/ Process	Knowledge gap
Water Depth and Period of Inundation	The impact of climate change, groundwater abstraction and drainage, as separate factors on wetland water levels is not known.
	The minimum period of inundation required for aquatic fauna to complete life cycles. Although estimated in this ECD, requires refinement to ensure that dominant, iconic, keystone and rare species are fully considered. This is particularly important for breeding waterbirds at Thomsons Lake where the predator-proof fence prevents movement to alternative water sources.
Water Quality	Although a reasonable baseline dataset exists it does not provide information on seasonal variation (the lakes are currently only monitored in spring and early summer). Several agencies (e.g. DEC, DoW, Water Corporation and Murdoch University) undertake monitoring but greater sharing and interpretation of information is needed.
Phytoplankton	Species composition and abundance has not been monitored regularly.
Aquatic Plants	There is little information on the species composition, distribution biomass and condition of submerged aquatic plants.
Littoral Vegetation	Extent and distribution of emergent macrophytes has not been regularly mapped.
	Extent, distribution and health of littoral vegetation have not been regularly mapped or monitored, including areas affected by 'dieback' (*Phytophthora cinnamomi*).
Waterbirds	There has been no systematic survey and reporting of abundance, species composition or breeding. Currently surveys are conducted 3 times per year; however this may be insufficient to determine changes to species assemblages and abundance.
	The effects of fox predation on waterbird breeding success and the interactive effects of predation and water level decline at Forrestdale Lake have been observed but not quantified.
Ecosystem components, processes and services review	Although there has been substantial monitoring and reporting of individual components and processes, data have not been compiled to assess ecosystem change, causes and relationships.

To address these knowledge gaps and detect and manage changes to the ecological character, the monitoring needs for the Forrestdale and Thomsons Lakes Ramsar site have been documented. This includes monitoring of the following at both lakes:

- Hydrology (surface and groundwater), particularly water depth and period of inundation;
- Water physicochemistry;

- Aquatic plants;
- Littoral vegetation;
- Wetland-associated and phreatophytic vegetation
- Aquatic invertebrates
- Waterbirds

Surveys of reptiles, amphibians and mammals would be useful, however, most are not locally restricted to either wetland and so obtaining this information is not of as high a priority, in the context of the Ramsar listing, as other attributes of the wetlands.

In addition to the required monitoring there are a number of areas where there is incomplete understanding of processes and threats. While these may not require the establishment of monitoring programs, there is a need for research or investigations to enable the site to be managed to maintain ecological character. Specifically these are:

- Separating the effects of groundwater abstraction from climatic change on wetland water balances. Concern has also been raised that the Southern Lakes Drainage Scheme is having an ongoing impact on the water regime at Thomsons Lake (R. Pickering, pers. comm.).
- The minimum period of inundation required for aquatic fauna to complete life cycles.
- Extent of littoral vegetation infected with the pathogen *Phytophthora cinnamomi* and actual threat to species present in the Ramsar site.
- The effects of fox predation on waterbird breeding success and the interactive effects of predation and water level decline at Forrestdale Lake.

1. Introduction

1.1 Site details

The objectives of the Ramsar Convention on Wetlands are to halt, and, where possible, reverse the loss and degradation of wetlands worldwide. At the time of writing (June 2009) 159 countries are signatories to the Ramsar Convention, which was ratified in Ramsar, Iran in 1971. These countries are required to nominate at least one wetland for the 'List of Wetlands of International Importance' according to their international importance in terms of ecology, botany, zoology, limnology or hydrology (Ramsar Convention 1987). This treaty currently lists more than 1,800 wetlands worldwide and Australia currently has 65 listed Wetlands of International Importance covering approximately 7.5 million hectares. Forrestdale and Thomsons Lakes are one of 12 Ramsar sites in Western Australia.

Forrestdale and Thomsons Lakes were together designated as wetlands of international importance under the Ramsar Convention in 1990. Forrestdale and Thomsons Lakes are located in the southern Perth metropolitan area in southwest Western Australia. The lakes are situated in the Perth Basin, on the Swan Coastal Plain, and are the best remaining examples of large brackish, seasonal lakes with extensive fringing sedgeland typical of the region. In a regional context, they constitute a major breeding, migration stop over and semi-permanent drought refuge area for waterbirds. The margins of both lakes also support a large number of terrestrial birds, and other vertebrate species.

A summary of the site details for the Ramsar site is provided in Table 1.1.

Table 1.1: Site details for the Forrestdale and Thomsons Lakes Ramsar site.

Site Name	Forrestdale and Thomsons Lakes, Western Australia
Location in coordinates	Forrestdale Lake : Latitude 32° 10' S; Longitude 115° 56' E Thomsons Lake: Latitude 32° 09' S; Longitude 115° 50' E
General location of the site	Forrestdale and Thomsons Lakes are located in the southern Perth metropolitan area, in southwestern Australia. Forrestdale Lake is located approximately 25 kilometres south east of Perth, in the City of Armadale. Thomsons Lake is located approximately 34 km southwest of Perth in the City of Cockburn.
Area	Forrestdale Lake: 246 ha and Thomsons Lake: 538 ha
Date of Ramsar site designation	7th June 1990
Ramsar criteria met by wetland	1 and 3
Management authority for the site	Vested with the Conservation Commission of Western Australia (Conservation Commission) and managed by the Western Australian Department of Environment and Conservation (DEC).
Date the ECD applies	1990
Status of description	This is the first ecological character description (ECD) for the site
Date of compilation	June 2009
Name(s) of compiler(s)	Kellie Maher and Jenny Davis on behalf of DEC, all enquires to Michael Coote, DEC, 17 Dick Perry Ave, Technology Park, Kensington, WA 6983, Australia, (Tel: +61-8-9219-8714; Fax: +61-8-9219-8750; email: Michael.Coote@dec.wa.gov.au).
References to the Ramsar information sheet (RIS)	Forrestdale and Thomsons Lakes, Western Australia. Wetlands International Site no. 5AU035; Ramsar site no. 481. RIS was originally compiled by CALM in 1990; updated by Roger Jaensch, Wetlands International – Oceania, on behalf of CALM, in 1998. Updated by CALM staff in 2003. Updated by Kellie Maher and Jenny Davis on behalf of DEC in 2009
References to management plan(s)	Forrestdale Lake Nature Reserve Management Plan 2005 and Thomsons Lake Nature Reserve Management Plan 2005, produced by the Conservation Commission and DEC.

The Department of Environment and Conservation (DEC) has proposed that the existing Forrestdale Lake Nature Reserve be expanded to include an adjacent Recreation Reserve, comprising 256 ha. This would increase the area of Forrestdale Lake Nature Reserve to 501 ha. The current management plan includes the existing nature reserve and proposed additions.

1.2 Purpose of Ecological Character Descriptions

Once a wetland has been placed on the Ramsar list, there is an expectation that planning and management will occur to maintain its ecological character and to promote its conservation and wise use. There is a requirement to report changes in ecological character and these may include the assessment of both natural and human induced change, and positive or negative change against established management objectives, which is a necessity for the development of suitable management strategies. A baseline description of the Ramsar wetland’s ecological character is needed to provide a benchmark against which a ‘change in ecological character’ can be assessed.

The Ramsar Convention (2005a) has defined ‘ecological character’ as “the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time”. Change in ecological character is considered under

Ramsar as "the human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service". In order to detect change it is necessary to establish a benchmark for management and planning purposes.

Ecological character descriptions (ECD) form the foundation on which a site management plan and associated monitoring and evaluation activities are based. Although the ecological assets for a site are described in the Ramsar Information Sheet at the time of designation, this information does not provide enough detail on the interactions between ecological components, processes and functions to constitute a comprehensive description of ecological character. In response to the shortfall, the Australian and state/territory governments have developed the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands. Module 2 of Australian National Guidelines for Ramsar Wetlands – Implementing the Ramsar Convention in Australia* (DEWHA 2008). The legal framework for ensuring the ecological character of all Australian Ramsar sites is maintained is the *Environment Protection and Biodiversity Conservation Act, 1999* (EPBC Act) (see Figure 1.1).

Fully documenting the attributes and threats to wetlands via an ECD is a fundamental part of managing wetlands successfully. An ECD should therefore describe and quantify ecosystem components, processes, interactions and benefits/services of the wetland. It is also important that information is provided on the benchmarks or ecologically significant limits of acceptable change that would indicate when the ecological character has or is likely to change. The general aims of an ECD have been outlined by McGrath (2006) as follows:

1. To assist in implementing Australia's obligations under the Ramsar Convention, as stated in Schedule 6 (Managing wetlands of international importance) of the *Environment Protection and Biodiversity Conservation Regulations 2000* (Cwlth):
    a) to describe and maintain the ecological character of declared Ramsar wetlands in Australia
    b) to formulate and implement planning that promotes:
        i) conservation of the wetland
        ii) wise and sustainable use of the wetland for the benefit of humanity in a way that is compatible with maintenance of the natural properties of the ecosystem.

2. To assist in fulfilling Australia's obligation under the Ramsar Convention, to arrange to be informed at the earliest possible time if the ecological character of any wetland in its territory and included in the Ramsar List has changed, is changing or is likely to change as the result of technological developments, pollution or other human interference.

3. To supplement the description of the ecological character contained in the Ramsar Information Sheet submitted under the Ramsar Convention for each listed wetland and, collectively, to form an official record of the ecological character of the site.

4. To assist the administration of the EPBC Act, particularly:
    a) to determine whether an action has, will have or is likely to have a significant impact on a declared Ramsar wetland in contravention of sections 16 and 17B of the EPBC Act, or

b) to assess the impacts that actions referred to the Minister under Part 7 of the EPBC Act have had, will have or are likely to have on a declared Ramsar wetland.

5. To assist any person considering taking an action that may impact on a declared Ramsar wetland whether to refer the action to the Minister under Part 7 of the EPBC Act for assessment and approval.

6. To inform members of the public who are interested generally in declared Ramsar wetlands to understand and value the wetlands.

Management plans are currently in place for Forrestdale and Thomsons Lakes and are effective for the period 2005–2015. Both plans identify the key values of the wetlands as those contributing to its Ramsar listing. There are also a number of monitoring and restoration programs for Forrestdale and Thomsons Lakes undertaken by DEC, Department of Water (DoW), Murdoch University, and the Friends of Forrestdale community group. DoW monitors environmental parameters including wetland vegetation, water quality, wetland birds and macroinvertebrates as part of the environmental conditions related to the Jandakot Mound Groundwater Resources (including Jandakot Groundwater Scheme, Stage 2) (EPA Assessment 1540-2, Statement 688). The aim is to provide an indication of whether changes in groundwater and wetland levels (primarily related to public and private groundwater abstraction, and climate) are having an impact on the identified ecological values of wetlands.

DEC has undertaken studies to determine the factors influencing waterbird usage of both lakes, including water chemistry, extent of vegetation and water levels. Murdoch University has undertaken extensive studies of the water chemistry and aquatic invertebrate fauna of both wetlands (Davis and Rolls 1987; Rolls 1989; Pinder *et al.* 1991; Balla and Davis 1993, 1995; Davis *et al.* 1993; McGuire and Davis 1999; Wild *et al.* 2003; Wild and Davis 2004; Davis *et al.* 2008). DEC, with assistance from the Friends of Forrestdale community group, undertakes regular monitoring of water levels, nutrients and chemistry in both lakes. The description of the ecological character of the Forrestdale and Thomsons Lakes Ramsar site will expand the description upon which current management plans are based and provide a synthesis of the key attributes of the ecology and function of these wetlands. The ECD should therefore improve decision-making and management of the Ramsar site (see Figure 1.1).

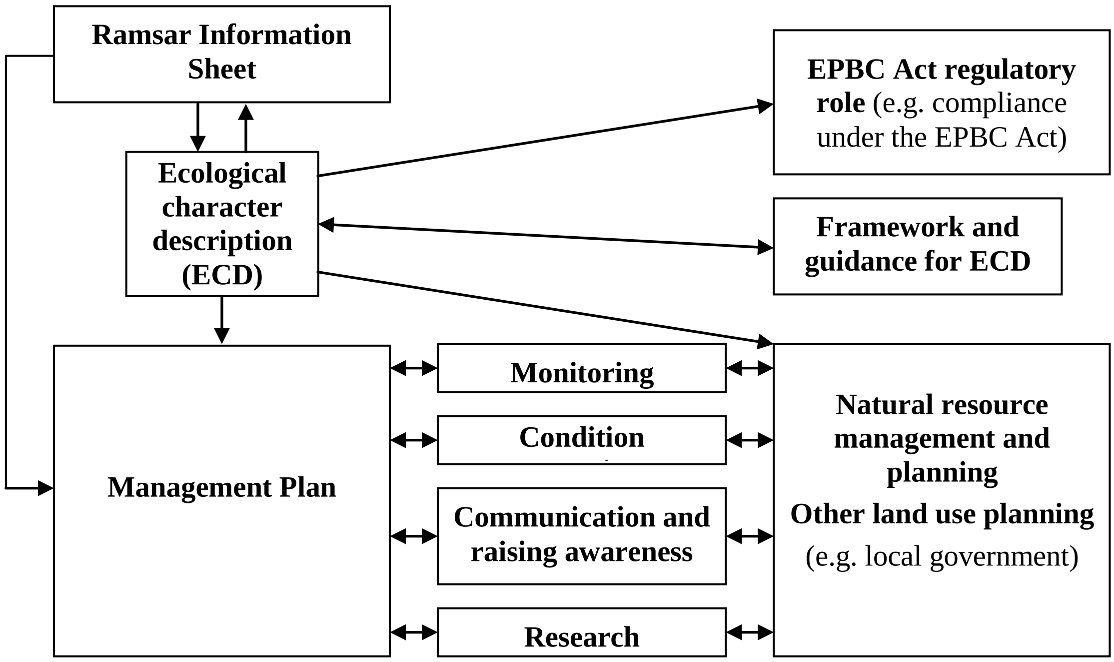

Figure 1.1: Relationship between the ecological character description and other documents (Source: Lambert and Elix 2006).

1.3 Objectives of the Forrestdale and Thomsons Lakes Ecological Character Description

The specific objectives of the ecological character description for the Forrestdale and Thomsons Lakes Ramsar site are to:

1. Describe the ecosystem components, processes, interactions and benefits/services of the wetlands at the time of Ramsar listing;

2. Develop a conceptual model for the wetlands that describes the 'ecological character' in terms of components, processes, interactions and benefits/services;

3. Quantify the limits of acceptable change for the critical components, processes and benefits/services of the wetlands;

4. Identify actual or likely threats/risks to the ecological components, processes or services of the wetlands;

5. Identify knowledge gaps in the data available for the wetlands;

1.4 Legislative Framework

1.4.1 International Treaties/Agreements

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

Ramsar Convention
The *Convention on Wetlands of International Importance, especially as Waterfowl Habitat*, is an intergovernmental treaty adopted in 1971 in the Iranian city of Ramsar, and is commonly known as the Ramsar Convention. Australia was among the first five countries to become Contracting Parties to the Convention. The Ramsar Convention is dedicated to the conservation and 'wise use' of wetlands. Wetlands are nominated according to their international importance in terms of ecology, botany, zoology, limnology or hydrology (Ramsar Convention 1987)

CAMBA, JAMBA and ROKAMBA
Australia currently has three bilateral agreements relating to conservation of migratory birds:

JAMBA: The Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment, 1974;

CAMBA: The Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment, 1986;

ROKAMBA: The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds and their Environment, 2006.

Convention on the Conservation of Migratory Species of Wild Animals
The Convention on the Conservation of Migratory Species of Wild Animals (also known as CMS or Bonn Convention) aims to conserve terrestrial, marine and avian migratory species throughout their range. For Australian purposes, many of the species are migratory birds. Species listed under this Convention are a matter of national environmental significance under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) assessment and approval provisions.

1.4.2 National Legislation and Policy

Environment Protection and Biodiversity Conservation Act 1999
This Act establishes a legislative framework for environmental protection and biodiversity conservation, including assessment and approvals of proposed actions, species and Ramsar site listing, recovery plans and management plans. The ecological character of Ramsar wetlands is one of the seven matters of national environmental significance under this Act, as are migratory species listed under the Act, listed

threatened species and ecological communities, World Heritage properties, Commonwealth marine areas, the national heritage values of National Heritage places, and nuclear actions (including uranium mines). Any action that has had, will have, or is likely to have a significant impact on a matter of national environmental significance such as Ramsar wetlands and migratory species listed under international treaties, is required to undergo an environmental assessment and approvals process.

The EPBC Act also establishes standards for managing Ramsar wetlands through the Australian Ramsar Management Principles, which are stated as Regulations under the Act and which describe the principles and guidelines for the management of Ramsar wetlands (Environment Australia 2001).

Native Title Act 1993

The Native Title Act requires that native title claimants and representative bodies be advised when a management plan is being prepared or major public works undertaken on the conservation estate. The South-West Aboriginal Land and Sea Council is the native title representative body for the Ramsar site and has a number of functions prescribed under the Native Title Act.

Wetlands Policy of the Commonwealth Government of Australia 1997

This policy provides strategies to ensure that the activities of the Australian Government promote the conservation, ecologically sustainable use and, where possible, enhancement of wetland functions. A principle aim is to ensure that the Australian Government's actions are consistent with those expected under the Ramsar Convention and, in particular, to promote the adoption of 'wise use' principles for managing wetlands (ANCA 1997).

1.4.3 Western Australia State Legislation and Policy

Wildlife Conservation Act 1950

This Act is the principal Western Australian legislation relating directly to biodiversity conservation and is administered by DEC. The Act provides for the conservation and protection of wildlife, including provisions for special protection of declared threatened (declared rare) flora, and for threatened fauna. The Act also administers the approvals required to take declared rare flora and threatened fauna.

Conservation and Land Management Act 1984

This Act is administered by DEC and applies to public lands managed by DEC. It sets the framework for the creation and management of marine and terrestrial parks, reserves and management areas in Western Australia, and deals with the protection of flora and fauna within reserve systems. DEC is required to prepare management plans for these areas in accordance with the legislative specifications of this Act. The specified objectives of these plans are to maintain and restore the natural environment and to protect, care for, and promote the study of indigenous flora and fauna, and to preserve any feature of archaeological, historic or scientific interest.

Environmental Protection Act 1986

The *Environmental Protection Act 1986* provides for the creation of the Environmental Protection Authority, which was established as an independent authority with the broad objective of protecting Western Australia's environment. The Act also provides for the prevention, control and abatement of pollution, and for the conservation, preservation, protection, enhancement and management of the environment. Activities that impact on wetlands, such as filling, draining, mining, discharging effluent, removing water or damaging vegetation, are prohibited without authorisation under this Act.

Aboriginal Heritage Act 1972

All registered sites within Forrestdale Lake and Thomsons Lake Nature Reserves are protected under this Act. The Act ensures the protection of places and objects customarily used by or traditional to, the original inhabitants of Australia. A Register of Aboriginal Sites is maintained under the Act, as a record of places and objects of significance to which the Act applies. The presence of an Aboriginal site places restrictions on what can be done to the land. Anyone who wants to use land for research, development or any other cause, must investigate whether there is an Aboriginal heritage site on the land.

Wetlands Conservation Policy for Western Australia 1997

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

1.5 Methodology

The method used to develop the ecological character description for the Forrestdale and Thomsons Lakes Ramsar Site is based on the approach provided in the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEWHA 2008). The main tasks are listed below, more detailed descriptions of each of the steps and outputs required are provided in the source document.

1. Introduction to the description, including:
    a) Site details
    b) Statement of purpose for description
    c) Relevant legislation and treaties

2. Describe the site, including:
    a) Site location
    b) Maps, images and photographs
    c) Land tenure
    d) Ramsar criteria met
    e) Wetland types

3. Describe the ecological character of the site at the time of its Ramsar listing, including:
    a) Describe components, processes, benefits and services of the wetlands that most strongly determine the ecological character the site
    b) Develop a conceptual model for the wetlands
    c) Articulate natural variability and set limits of acceptable change for the critical components, processes and services of the site.

4. Identify actual or likely threats/risks to the site

5. Describe any changes to ecological character since time of listing

6. Summarise the knowledge gaps

7. Make any recommendations for monitoring

8. Identify communication, education and public awareness messages

9. Prepare a Ramsar Information Sheet for the site

2. Description of Forrestdale and Thomsons Lakes

2.1 Site location

The Forrestdale and Thomsons Lakes Ramsar site is located within the southern Perth metropolitan area, in southwestern Australia. Forrestdale Lake is located approximately 25 kilometres south east of Perth, in the City of Armadale. Thomsons Lake is located approximately 34 km southwest of Perth in the City of Cockburn (Figure 2.1). The wetlands are located approximately 8.5 kilometres apart, separated by freehold residential, rural and semi-rural (rural residential) land. The Ramsar site includes 246 ha at Forrestdale Lake and 538 ha at Thomsons Lake.

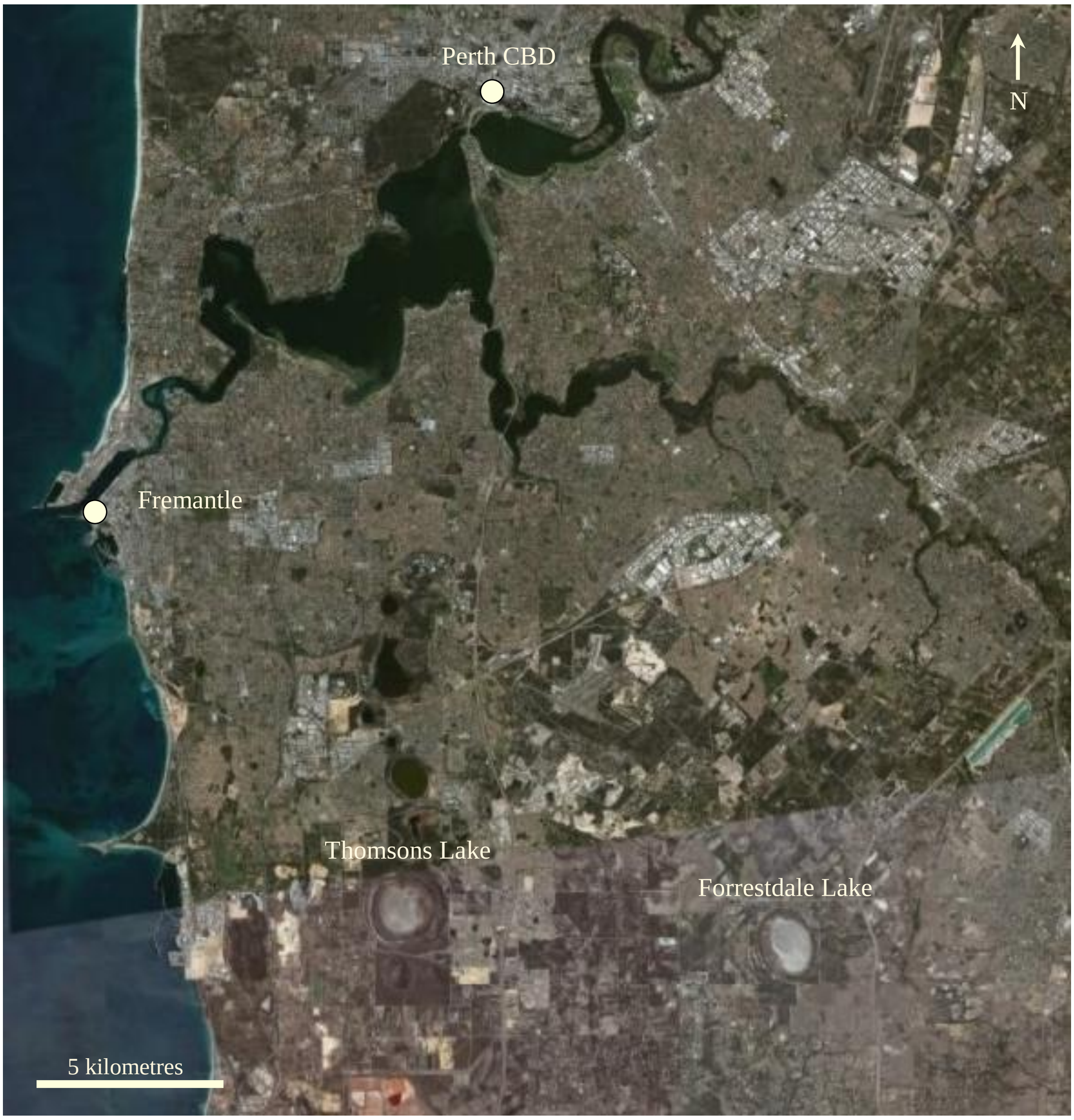

Figure 2.1: Location of Forrestdale and Thomsons Lakes in Perth, Western Australia (Source: Google Earth 2008).

Forrestdale and Thomsons Lakes are situated in the Swan Coastal Plain bioregion within the South-West Coast Drainage Division. The Swan Coastal Plain bioregion is a long, narrow coastal strip of land extending from Geraldton in the north to Dunsborough in the south. The bioregion is 550 km long and only 6 to 35 km wide. It is bounded to the east by the Gingin and Darling Fault Scarps, which rise to over 200 m above sea level. Over a quarter of the land within the Swan Coastal Plain is wetland and a further 17 % is seasonally waterlogged palusplain and floodplain (Balla 1994). The Swan Coastal Plain bioregion contains 3 other Ramsar sites (Peel-Yalgorup, Vasse-Wonnerup and Becher Point), and 29 wetland sites of national importance covering an area of 30,470 ha, including Forrestdale and Thomsons Lakes.

Forrestdale and Thomsons Lakes are examples of interdunal groundwater wetlands. Thomsons Lake is located on the western edge of the Jandakot Groundwater Mound (JGM) and Forrestdale Lake is situated on the eastern margin of the JGM where the mound intersects the Perth Groundwater Area. The mound is a region of elevated groundwater beneath the Swan Coastal Plain. A map of groundwater contours for the Jandakot Mound is available from DoW (Department of Water 2004) and illustrates the positions of the lakes relative to the watertable. This information could be used to guide decision-making when a proposed activity might have an impact on the wetlands, with respect to the groundwater component of the water balance. Hydrological research is currently being undertaken by DoW and CSIRO to more fully elucidate the local interactions of groundwater and surface waters at Forrestdale Lake.

With the exception of rainfall, there are generally no natural surface water inflows to the lakes. The lack of inflowing streams and the low topography of the surface catchments suggest that surface run-off probably had little effect on their depth when they were in an undisturbed condition.

Thomsons Lake is bounded to the east and northwest by rural living blocks and urban developments. This lake is surrounded by a much larger area of native vegetation (Figure 2.10) than Forrestdale Lake (Figure 2.11). Thomsons Lake Nature Reserve is enclosed within a predator-proof fence. As a consequence access is limited and it is used principally for bird watching and nature walks. Thomsons Lake is subject to the Southern Lakes Drainage Scheme, which controls the maximum water levels of the lake. Stormwater from nearby suburbs is diverted away from the wetland in order to minimise changes to water levels and protect it from nutrient loading. A stormwater drain is located on the east side of Thomsons Lake: to discharge overflow water should the Bartram Road Buffer Lakes be unable to meet the required capacity of a one-in-one hundred year storm event; to ensure that Thomsons Lake does not become permanently inundated and; to supplement the lake with water to maintain an absolute minimum level of 10.8 m AHD (see Section 3.2).

The area to the northeast of Forrestdale Lake is urban and houses are located within 50 m of the lake. The western side of the lake has been developed for residential development and rural-living blocks to within about 100 m of the lake. There is a substantial area of natural open woodland on the eastern side of the lake, which is used for horse-riding and general recreation by nearby residents. Forrestdale Lake receives a small amount of stormwater from adjacent residential areas. The nutrients in the stormwater originate from a variety of point and diffuse sources associated with rural land use, including intensive animal feedlots and pens, and fertilised crops and gardens.

Groundwater containing nutrients, discharges into the lake primarily from semi-rural blocks in the west and also from residential land i.e. septic tanks in the Forrestdale Township to the northeast.

2.2 Climate

The Swan Coastal Plain experiences a Mediterranean climate with a hot dry summer (December to February) and cool wet winter (June to August). The four aspects of climate that most directly affect wetland ecology are rainfall, temperature, evaporation and wind. Summer temperatures range from a mean daily maximum of 31.8˚C to a minimum of 17.4˚C in February. Mild winter temperatures range from a mean daily maximum of 17.9˚C to a minimum of 8.1°C in July (Figure 2.2).

Perth's long-term average annual rainfall is 856 mm (Bureau of Meteorology 2008). However, the annual total can vary considerably from year to year (Figure 2.3). Rainfall is highest in June, with most rainfall occurring between May and September (Figure 2.4). However, the amount of rainfall that occurs within each month can also vary substantially from year to year (Figure 2.5). Winter rainfall in the southwest of Western Australia has decreased by about 15–20% since mid–1970s (IOCI 2002). The recent rainfall decrease was only observed in early winter (May–July) rainfall; late winter (August–October) rainfall has actually increased, although by a smaller amount. Temperatures, both day-time and night-time, have increased gradually but substantially over the last 50 years, particularly in winter and autumn.

Perth’s average annual evaporation is 2,056 mm (Bureau of Meteorology 2008), and the annual total varies to a lesser extent than rainfall (Figure 2.6). Evaporation is greatest during summer and lowest during winter (Figure 2.7), with daily average evaporation rates varying from 10 mm in summer to 2 mm in winter. Monthly patterns of evaporation are consistent and show very little variation from year to year (Figure 2.8). The western coast of Australia is characterised by high winds, and Perth is the windiest city in Australia (IOCI 2002). Winds in the Perth region are 14.1–18.6 km/hour on average and generally higher in the afternoon than the morning. Winds are generally higher during the summer months than winter (Figure 2.9).

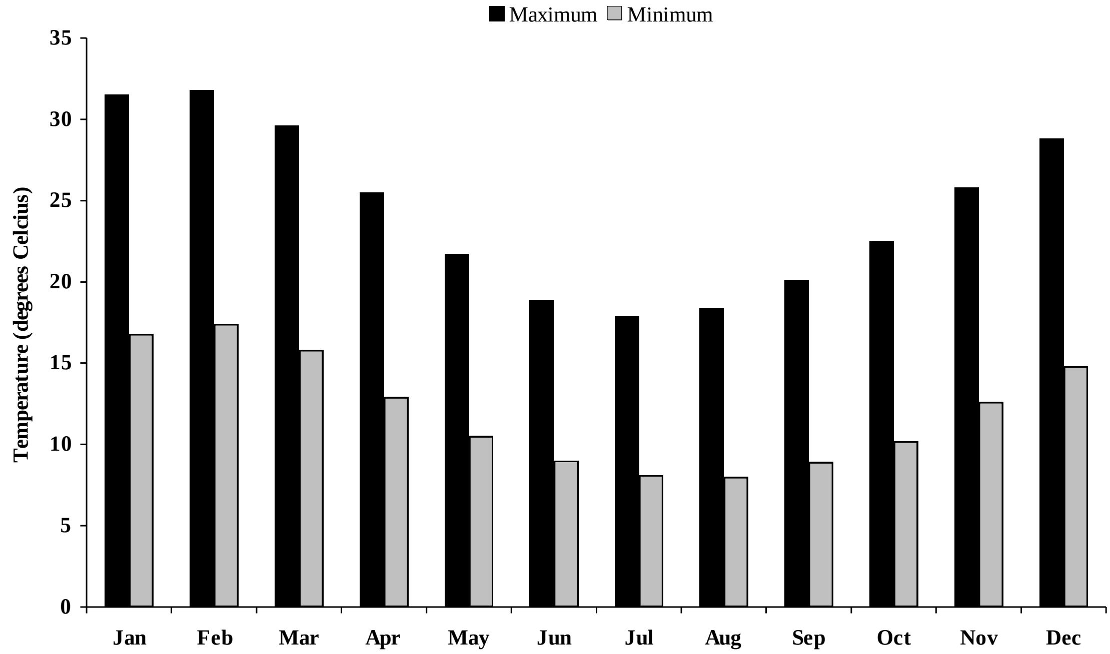

Figure 2.2: Mean maximum and minimum monthly temperatures at Perth Airport (Source: Bureau of Meteorology 2008).

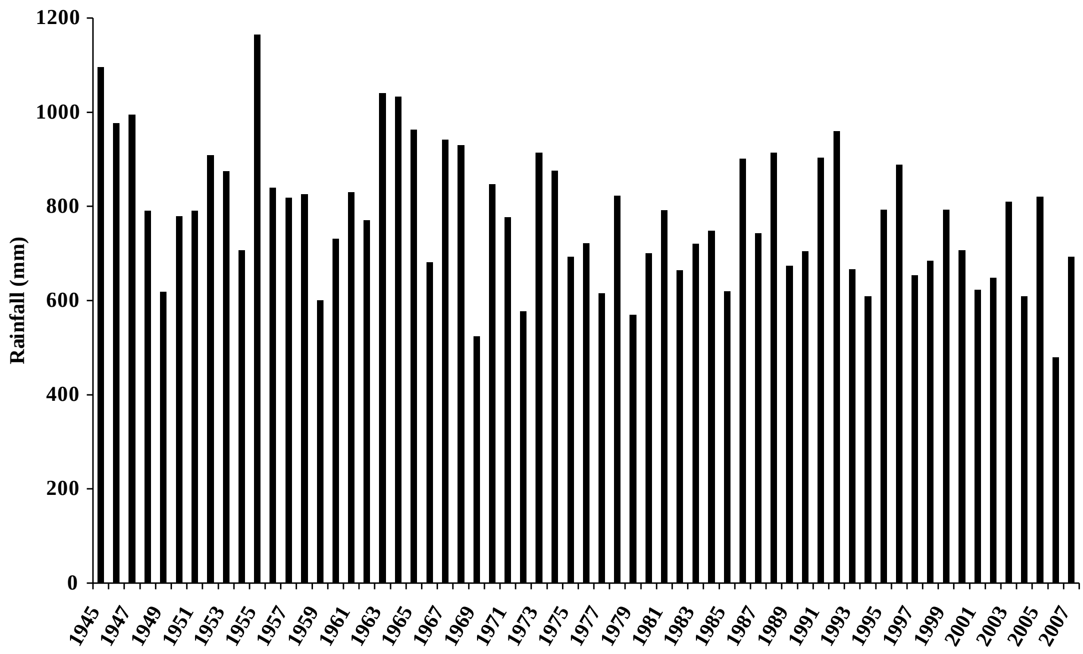

Figure 2.3: Annual rainfall recorded at Perth Airport from 1945 to 2007 (Source: Bureau of Meteorology 2008).

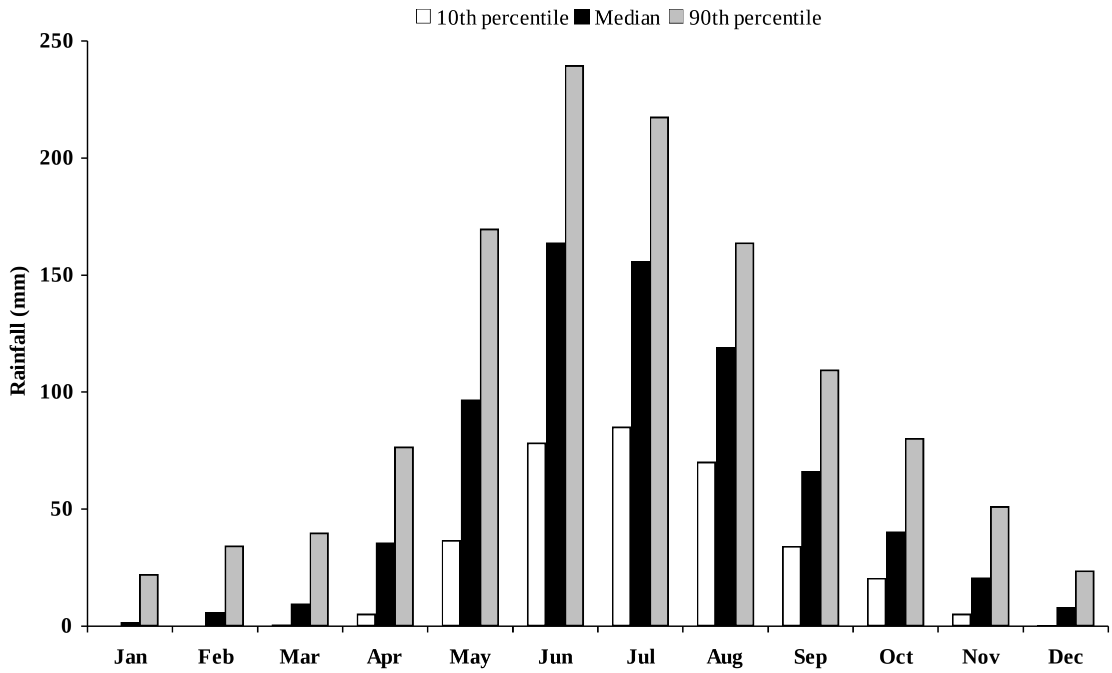

Figure 2.4: Median (10th and 90th percentile) monthly rainfall at Perth Airport (Source: Bureau of Meteorology 2008).

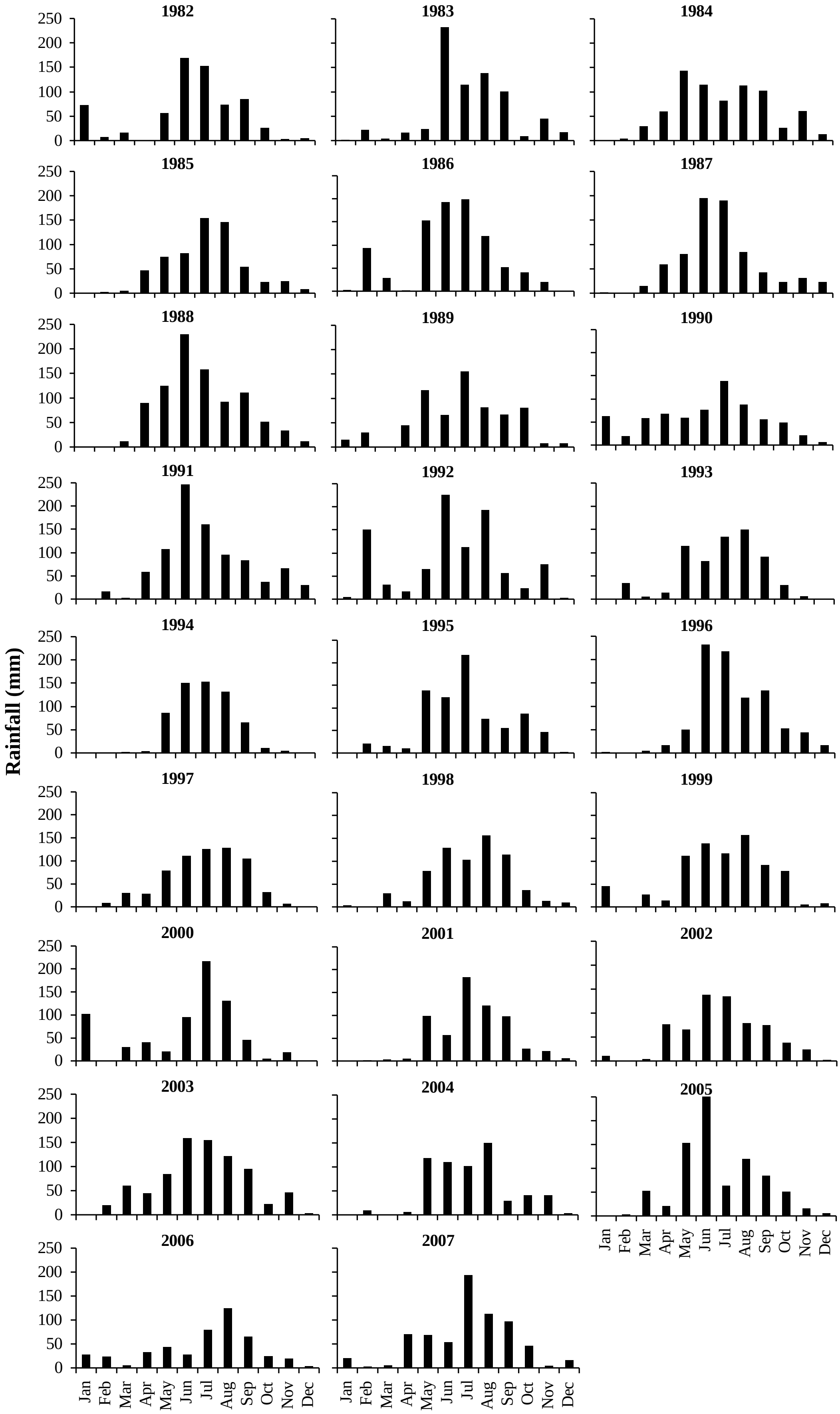

Figure 2.5: Monthly rainfall recorded at Perth Airport from 1982 to 2007 (Source: Bureau of Meteorology 2008).

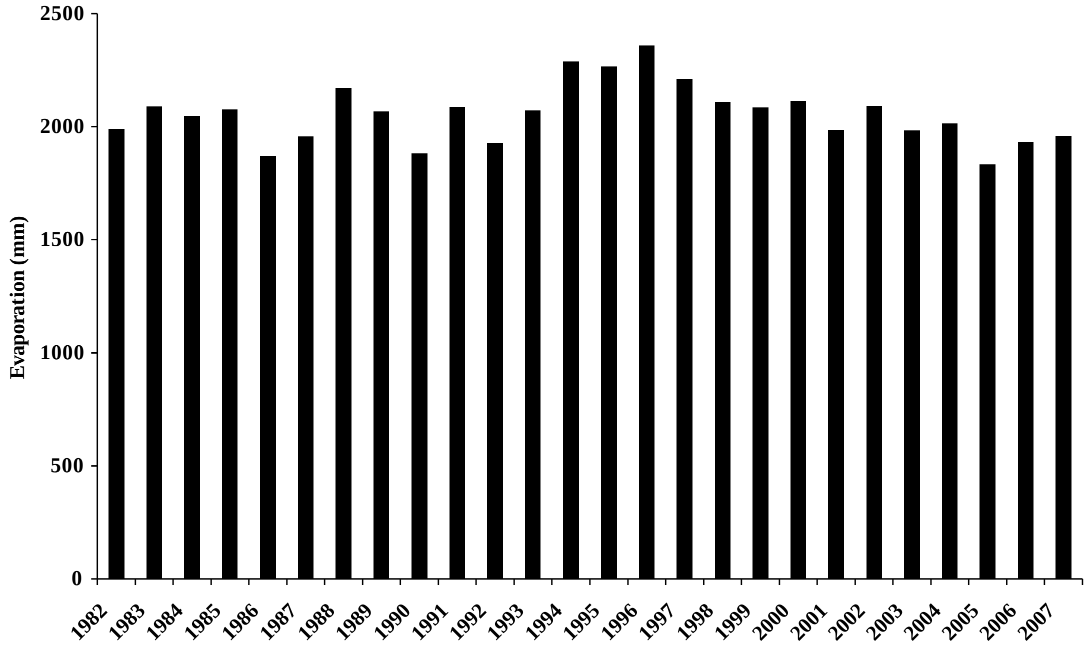

Figure 2.6: Annual evaporation recorded at Perth Airport from 1982 to 2007 (Source: Bureau of Meteorology 2008).

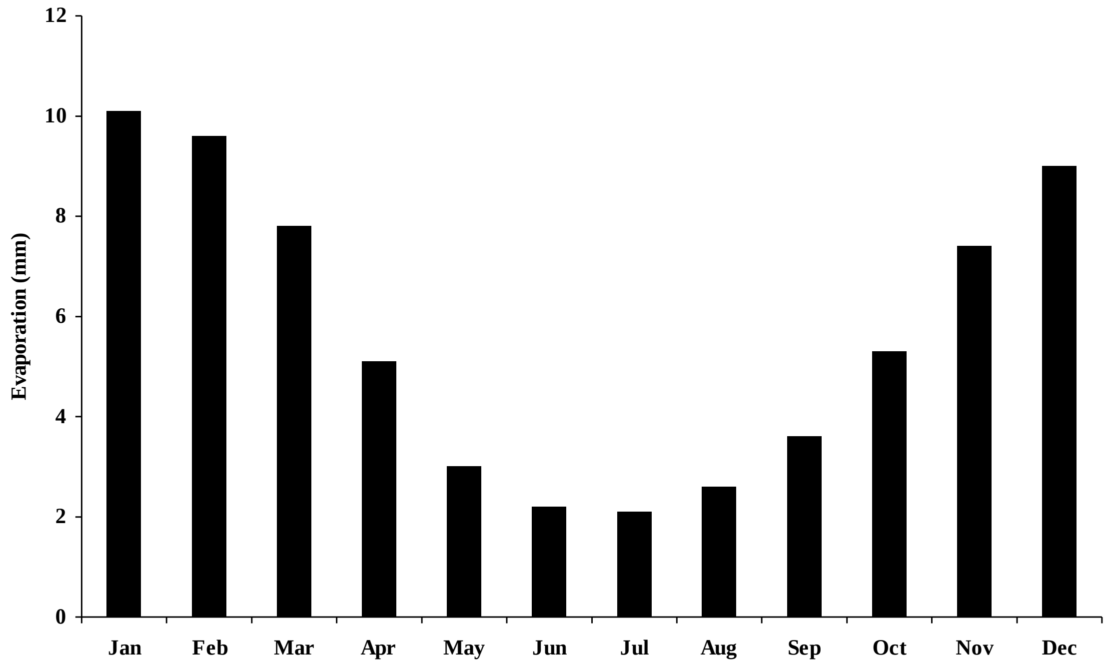

Figure 2.7: Mean monthly evaporation at Perth Airport (Source: Bureau of Meteorology 2008).

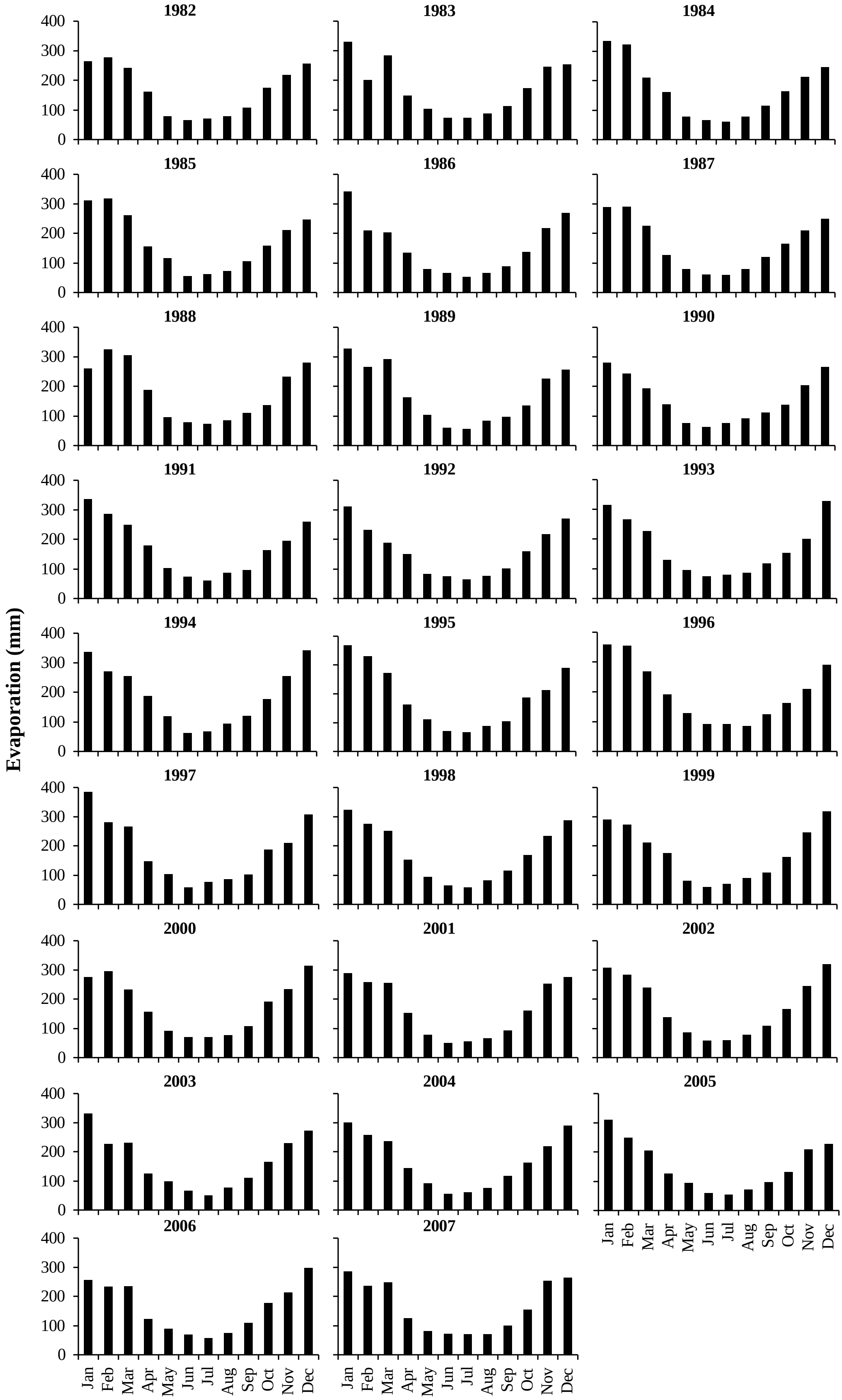

Figure 2.8: Monthly evaporation at Perth Airport 1982–2007 (Source: Bureau of Meteorology 2008).

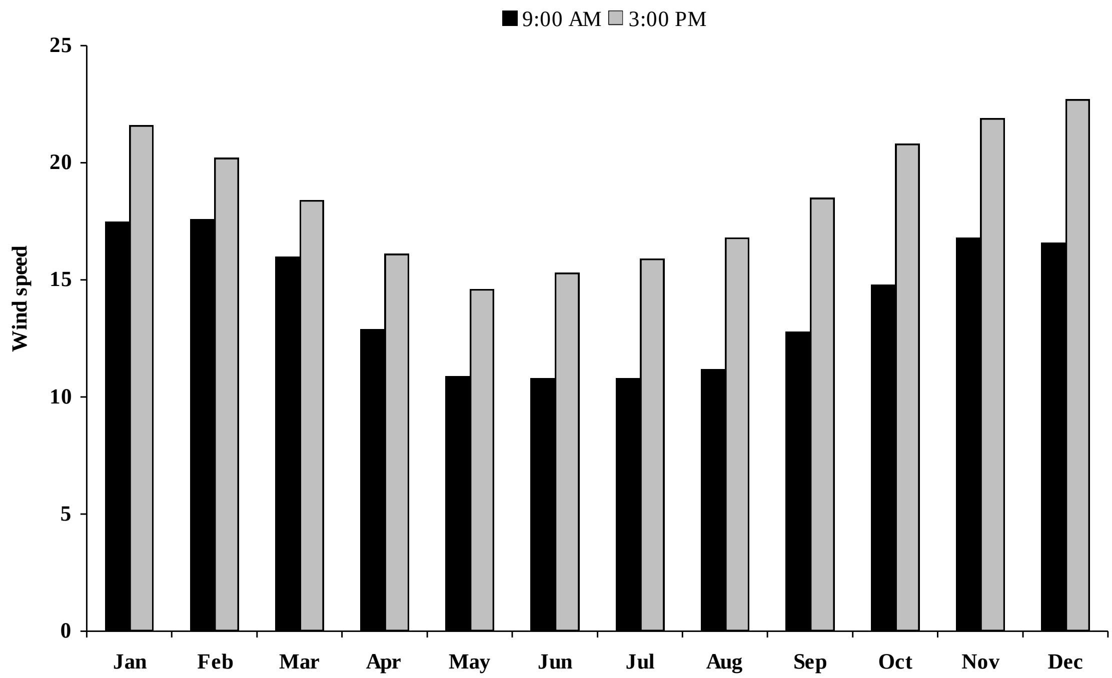

Figure 2.9: Mean wind speed at Perth Airport (Source: Bureau of Meteorology 2008).

2.3 Land tenure

Within the Ramsar site the wetland area at Thomsons Lake is within Nature Reserve 15556, which is vested in the Conservation Commission of Western Australia and managed by DEC (Figure 2.10). The wetland area at Forrestdale Lake is within Nature Reserve 24781 and has the same vesting and management (Figure 2.11). Both lakes are surrounded by freehold residential, rural and semi-rural (rural residential) land. Currently, Thomsons Lake Nature Reserve covers an area of 538 ha and Forrestdale Lake Reserve 246 ha. Adjoining the eastern side of Forrestdale Lake Nature Reserve is reserve (27165) vested in the City of Armadale for the purpose of recreation. Adjoining the southwestern side of Forrestdale Lake Nature Reserve is a parcel of bushland owned by the Western Australian Planning Commission. Both of these areas have been proposed for future addition to the Nature Reserve.

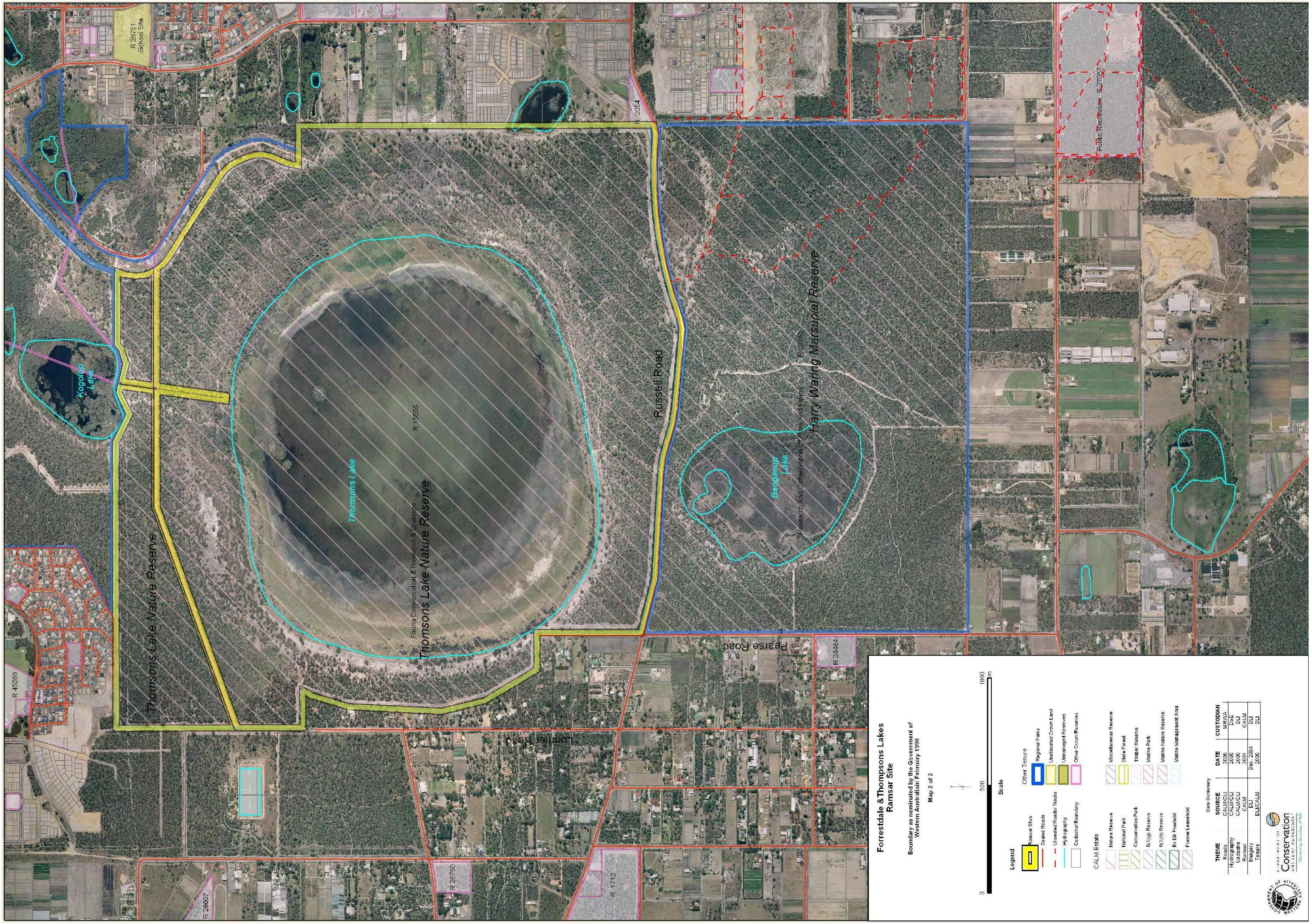

Figure 2.10: The local settings, Ramsar site boundary and land tenure of Thomsons Lake.

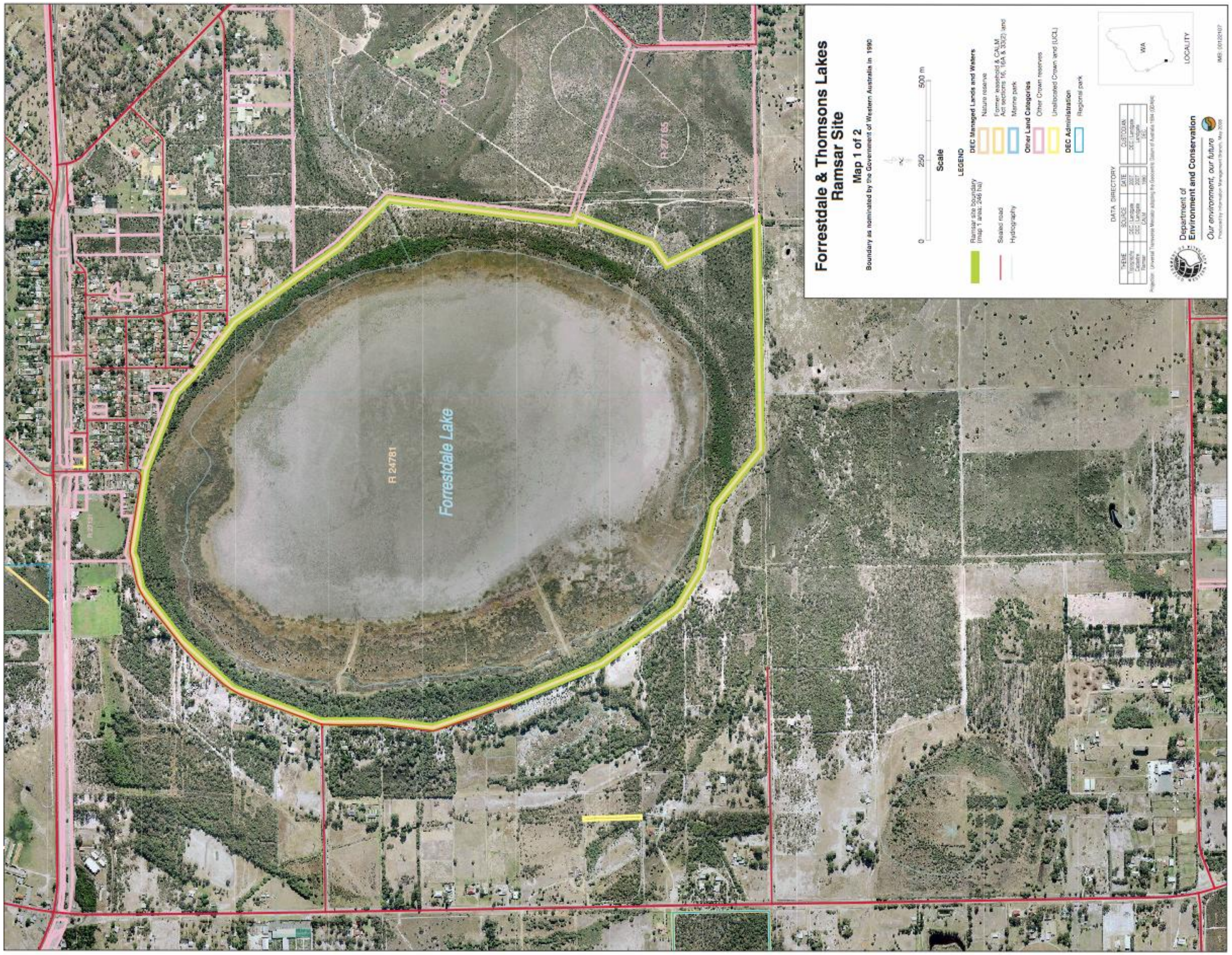

Figure 2.11: The local settings, Ramsar site boundary and land tenure of Forrestdale Lake.

2.4 Ramsar Criteria

2.4.1 Criteria under which the site was designated (1990)

At the time that the Forrestdale and Thomsons Lakes Ramsar site was originally nominated as a Wetland of International Importance, there were six criteria against which a wetland site could qualify (Table 2.1: Criterion 1–6). The Ramsar site was considered to meet three of these criteria:

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

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

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

A review of the Ramsar Information Sheet was undertaken in 2003 and the Ramsar site was also considered to meet Criterion 5.

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

2.4.2 Ramsar Criteria currently met

Additional Criteria for Identifying Wetlands of International Importance were adopted by the 7th (1999) and 9th (2005) Meetings of the Conference of the Contracting Parties, which superseded earlier Criteria adopted by the 4th and 6th Meetings of the COP (1990 and 1996) (Table 2.1: additional criteria 7–9). The Criteria currently met by the site are:

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.

Forrestdale and Thomsons Lakes are the best remaining examples of large brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain, within the South-West Coast Drainage Division. While these types of wetland were formerly common, extensive development of the Swan Coastal Plain has resulted in the loss of many of these wetlands, and most of the remaining wetlands of this type have been degraded through drainage, eutrophication and the loss of fringing vegetation.

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.

Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain with 85 species of waterbird occurring at the two lakes, including 29 migratory species listed under the EPBC Act. In addition, 27 waterbird species have

been recorded breeding at the lakes. The Ramsar site contains rich and diverse communities of aquatic invertebrates that are representative of relatively undisturbed, large, shallow Swan Coastal Plain wetlands dominated by submerged macrophytes. Macroinvertebrates are an important component of wetland food webs, comprising much of the diet of many faunal species, including migratory waders and other waterbirds, and turtles. There are two WA listed Threatened Ecological Communities at Forrestdale Lake Nature Reserve, two 'Declared Rare Flora' species listed under WA legislation and nine Priority taxa. Thomsons Lake Nature Reserve contains one 'Declared Rare Flora' species listed under WA legislation and three Priority taxa.

2.4.3 Ramsar Criteria no longer met

It is important to appreciate that the criteria for listing a wetland as a Ramsar site have been developed and refined over the years. When this site was listed in 1990, there were 13 criteria. These have been reduced to 9 current criteria, with considerable explanation of the terminologies used.

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

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

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

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

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

1980, and up to 26 have been observed since 1981. Therefore, the Long-toed Stint did not fulfil the 1% criteria at this Ramsar site in 1990 and numbers continue to be insufficient to meet Criterion 6.

Forrestdale and Thomsons Lakes have supported more than 1% of the population of 4 waterbirds in several years: Australasian Shoveler, Black-winged Stilt, Blue-billed Duck, and Red-capped Plover (section 3.4.2). However, the wetlands have not "regularly" supported 1% of the population, particularly in recent years. Therefore Forrestdale and Thomsons Lakes do not meet the current requirements for listing under Criterion 6.

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

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

Table 2.1: Current criteria for Identifying Wetlands of International Importance.

Number	Basis	Description
Group A. Sites containing representative, rare or unique wetland types		
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.
Group B. Sites of international importance for conserving biological diversity		
Criterion 2	Species and ecological communities	A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.
Criterion 3	Species and ecological communities	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	Species and ecological communities	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	Waterbirds	A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.
Criterion 6	Waterbirds	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.
Criterion 7	Fish	A wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity.
Criterion 8	Fish	A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.
Criterion 9	Other taxa	A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species.

2.5 Wetland types

The Ramsar site includes 246 ha at Forrestdale Lake and 538 ha at Thomsons Lake of inland type P wetlands: seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes. Forrestdale Lake has an area of open water covering approximately 221 hectares, or 90 % of the existing Nature Reserve, when full. Thomsons Lake has an area of open water covering approximately 151 ha, or 27 % of the total Nature Reserve, when full.

3. Ecosystem components, processes, benefits and services

The basis of an ECD is the identification, description and where possible, quantification of the critical ecosystem components, processes, benefits and services that are:

- Important determinants of the site's unique character
- Important for supporting the Ramsar criteria under which the site was listed
- For which change is reasonably likely to occur over short or medium time scales (< 100 years)
- That will cause significant negative consequences if change occurs.

This section documents the critical aspects of the ecology of the Forrestdale and Thomsons Lakes Ramsar site, the driving forces behind them, and relationships between them. A summary of the critical ecosystem components and processes is provided in Table 3.1, and a summary of the benefits and services in Table 3.6.

Table 3.1: Critical ecosystem components and processes of Forrestdale and Thomsons Lakes.

Component/Process	Summary Description
Geomorphology and Geology	Located within interdunal depressions Soils considered infertile Underlain by pyritic peaty sediments (potentially acid sulfate soils)
Hydrology	Groundwater fed Little natural surface drainage Shallow (< 2 m), circular to oval in shape Seasonal drying
Physico-chemistry	Continuous or discontinuous warm polymictic lakes (wind-mixed) Weakly coloured with low turbidity Fresh to brackish Neutral to alkaline pH Moderately enriched; nutrients accumulate in the sediment Release of phosphorus is reduced with the current summer drying regime
Phytoplankton	Occasional cyanobacteria (blue-green algae) blooms
Aquatic Plants	Extensive stands of submerged and floating macrophytes
Littoral Vegetation	Edge of lakes: *Typha*, *Baumea*, *Juncus* and *Bolboschoenus* Beyond waters edge: *Melaleuca*, *Banksia*, *Eucalyptus* and *Acacia* Threatened ecological community 'shrublands on dry clay flats' and 'herb-rich shrublands in clay pans' at Forrestdale Lake (WA listed) *Typha orientalis* expanding across dry lake beds
Ecological regime	Predominantly clear-water, submerged macrophyte-dominated, driven by annual drying Occasional change to turbid, phytoplankton-dominated, driven by nutrient loading
Invertebrates and	Long-necked turtles present in both lakes

Reptiles	High invertebrate species richness and abundance Richest invertebrate assemblages supported by submerged plants and high maximum water levels
Birds	High diversity (85 species) of waterbirds Regularly supports > 5,000 waterbirds (maximum recorded 21,083 individuals at Thomsons Lake and 22,196 individuals at Forrestdale Lake) Breeding records for 27 species
Interconnections with other components and processes	Forrestdale and Thomsons Lakes are the largest wetlands (in area) on the Swan Coastal Plain. They are an important component of a landscape containing a large number (> 10,000) of basin and fringing wetlands. However an estimated 70% of the wetlands of the coastal plain have been lost since European settlement.

3.1 Geomorphology and Geology

In the Perth region, the Swan Coastal Plain is about 34 km wide in the north, 23 km in the south, and is bounded to the east by the Gingin and Darling Fault Scarps, which rise to over 200 m above sea level. The scarps represent the eastern boundary of Tertiary and Quaternary marine erosion. The Swan Coastal Plain consists of a series of distinct landforms, roughly parallel to the coast i.e. in an approximately north-south direction. The Quindalup and Spearwood Dune systems lie closest to the coast, with the Bassendean Dune system further east. The dune systems have occurred as a result of accumulation and subsequent distribution of beach sands of successive shorelines. The major factors influencing their formation are thought to be a series of marine transgressions and prevailing westerly winds. Wetlands occur within interdunal depressions in these three systems and lie along the boundaries between adjacent systems (Cargeeg *et al.* 1987). Thomsons Lake is situated on the junction between the Bassendean system to the east and the younger Spearwood system to the west. Forrestdale Lake is situated on the eastern edge of the Bassendean dune system.

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

3.2 Hydrology

Forrestdale and Thomsons Lakes are situated on the Jandakot Groundwater Mound, which is a region of elevated groundwater table beneath the Swan Coastal Plain. Groundwater discharges from the mound into low lying depressions that support groundwater dependant vegetation and wetland systems. There is no natural surface

drainage to the lakes apart from direct rainfall. However, Forrestdale Lake receives a small amount of drainage from adjacent residential areas. A drainage scheme diverts water from residential subdivisions to the east of Thomsons Lake, away from the lake in order to minimise changes to water levels and protect it from nutrient loading. Agricultural drains are used to direct drainage into Thomsons Lake from Kogolup South Eye and the area east of the lake. The drain from Kogolup South is still present but was blocked when pipes were laid between the two lakes. The topography of Forrestdale and Thomsons Lakes is illustrated in Figure 3.1 and Figure 3.2; bathymetry Figure 3.3 and Figure 3.4; and cross-section and water level record in Figure 3.5 and Figure 3.6.

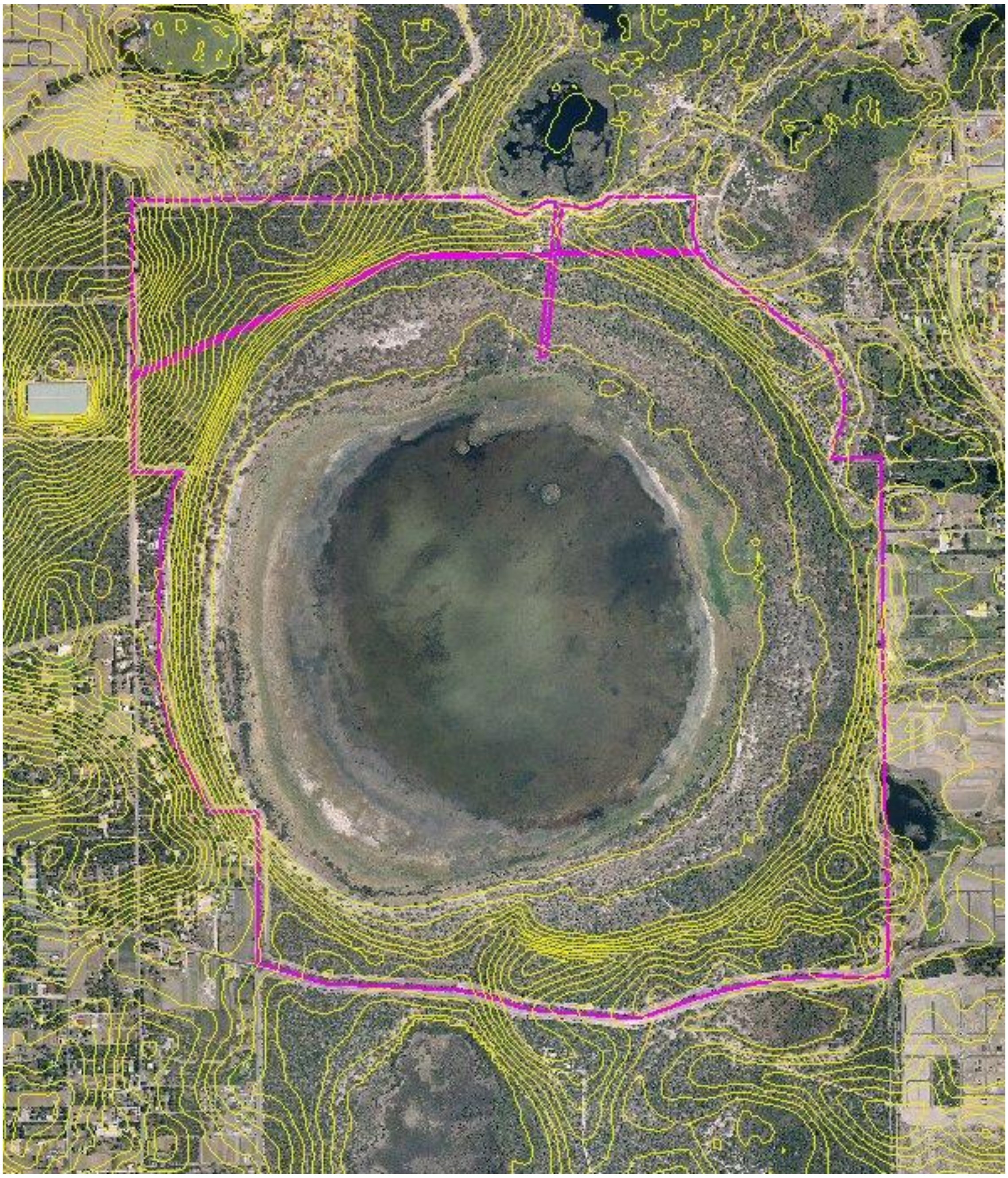

Figure 3.1: Thomsons Lake with 2m contour lines (yellow) and Ramsar boundary (pink); scale 1: 20,000 (Source: WetlandBase 2008).

Figure 3.2: Forrestdale Lake with 2m contour lines (yellow) and Ramsar boundary (pink); scale 1: 20,000 (Source: WetlandBase 2008).

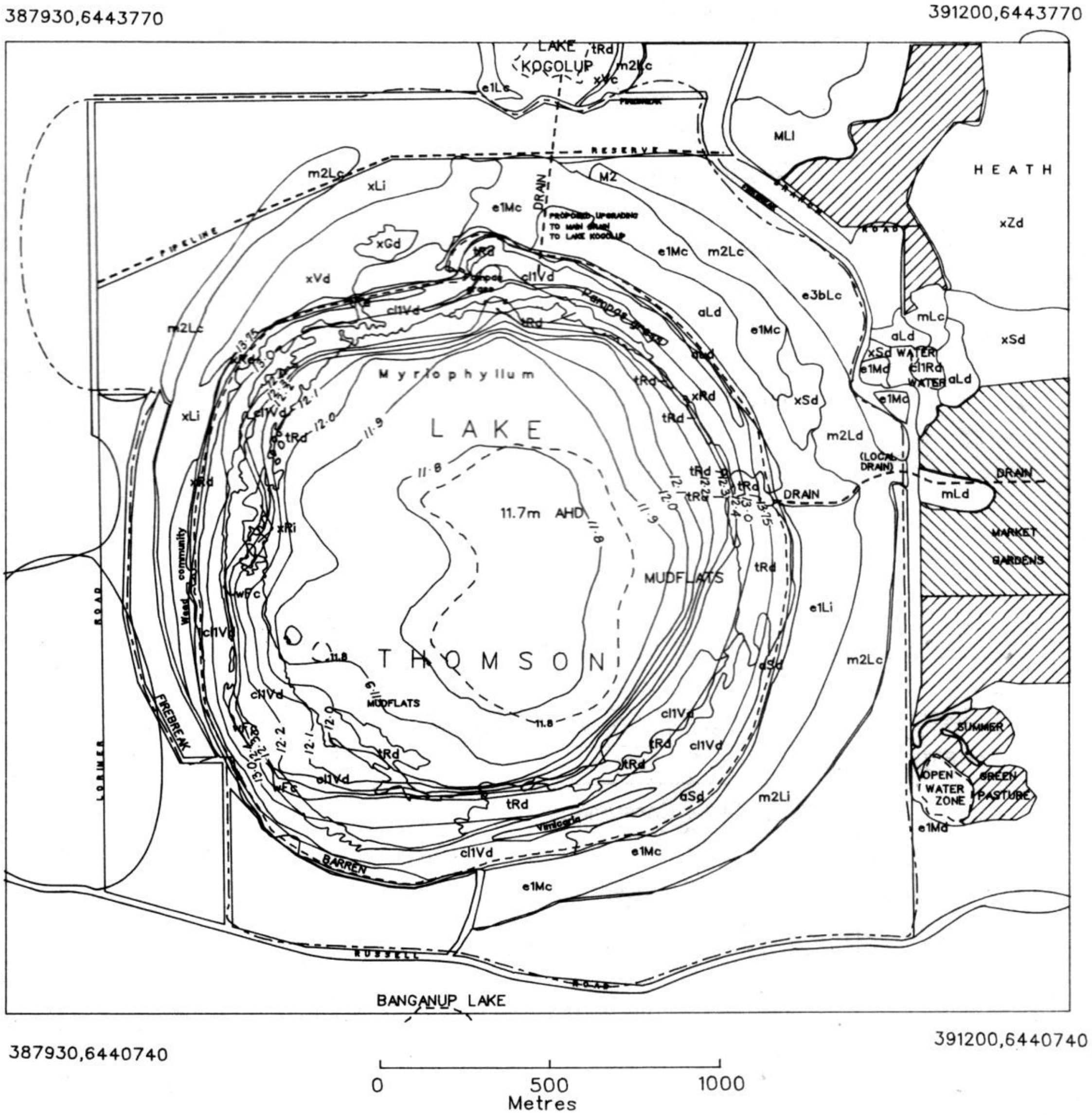

Figure 3.3: Bathymetry and vegetation of Thomsons Lake (Water Authority 1991). See following page for key to vegetation type.

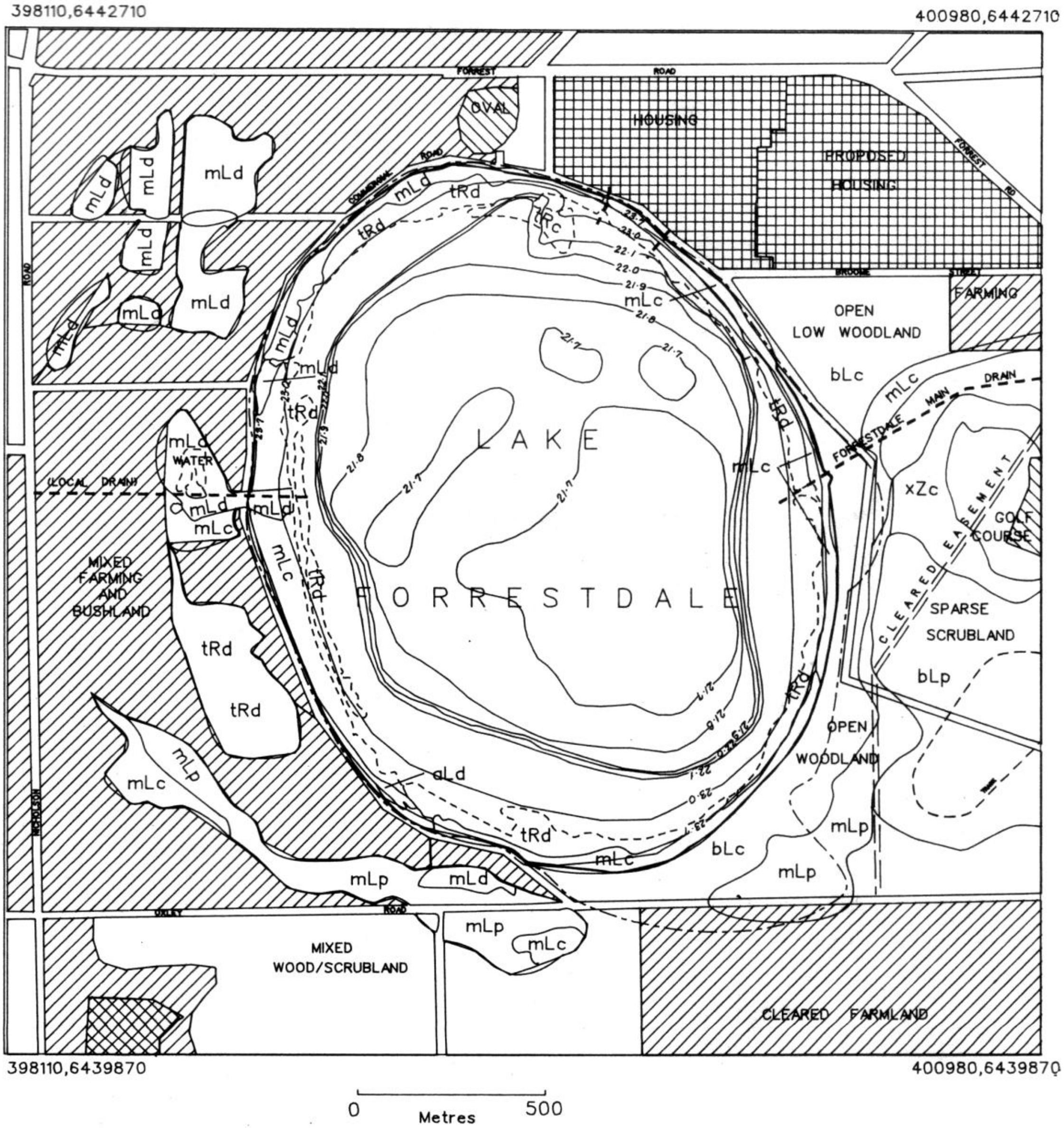

Figure 3.4: Bathymetry and vegetation of Forrestdale Lake (Water Authority 1991). See following page for key to vegetation type.

Key to Vegetation Classification for Forrestdale and Thomsons Lakes (Figures 3.3 and 3.4)

i) Dominant genus and species – lower case letter on left;
ii) Physiognomy of dominant stratum – upper case letter in centre; and
iii) Projective vegetation cover – lower case letter on right.

i) Dominant genera and species

a	*Acacia*
b_2	*Banksia littoralis*
c	*Casuarina*
cl_1	*Baumea articulata*
cl_2	*Baumea juncea*
d	*Dryandra*
e_1	*Eucalyptus rudis*
e_2	*Eucalyptus gomphocephala*
e_3	*Eucalyptus marginata*
e_4	*Corymbia calophylla*
e_5	*Eucalyptus todtiana*
g	*Ghania trifida*
h	Coastal heath
j	*Juncus*
k	Halophytes
l	*Leptocarpus*
m	*Melaleuca sp*
m_1	*Melaleuca rhaphiophylla*
m_2	*Melaleuca preissiana*
m_3	*Melaleuca lateritia*
m_4	*Melaleuca teretifolia*
m_5	*Melaleuca cuticularis*
p	*Callitris*
s	*Scirpus*
t	*Typha*
w	Weeds or introduced grasses
x	Mixed or other

ii) Physiognomy of dominant species

T	Tall trees > 30 m tall
M	Medium trees 10–30 m tall
L	Low trees < 10 m tall
S	Shrubs > 1 m tall
Z	Dwarf shrubs < 1 m tall
R	Rushes and sedges > 1 m tall
V	Rushes and sedges < 1 m tall
G	Bunch grasses
H	Hummock grasses
F	Forbs
L	Lichens and mosses
C	Succulents

iii) Canopy cover

d	Dense cover > 70% foliage cover
c	Mid dense 30–70% foliage cover
i	Incomplete canopy-open, not touching
r	Rare but conspicuous foliage cover < 10%
b	Vegetation largely absent
p	Scattered groups – no definite foliage cover

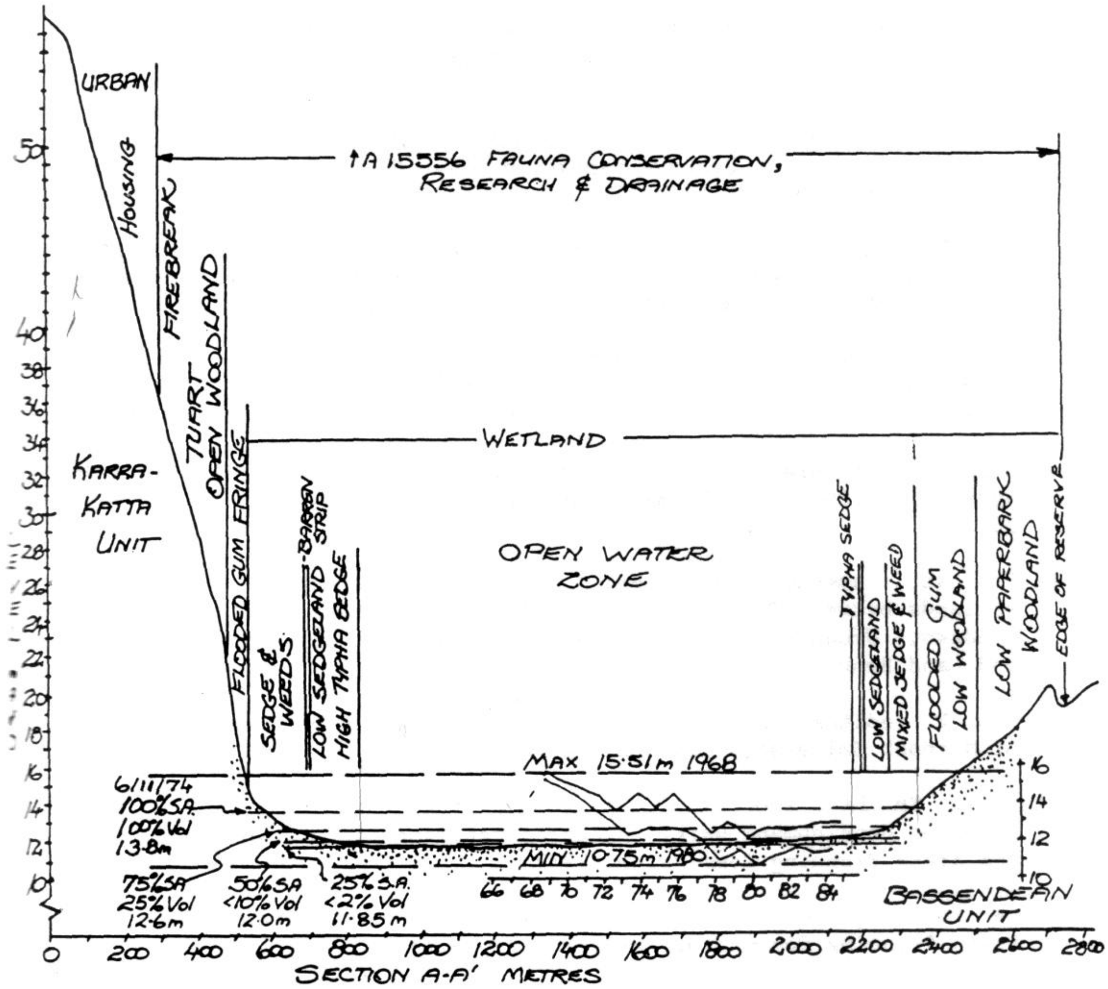

Figure 3.5: Diagrammatic cross-section and water level record of Thomsons Lake (Source: Arnold 1990).

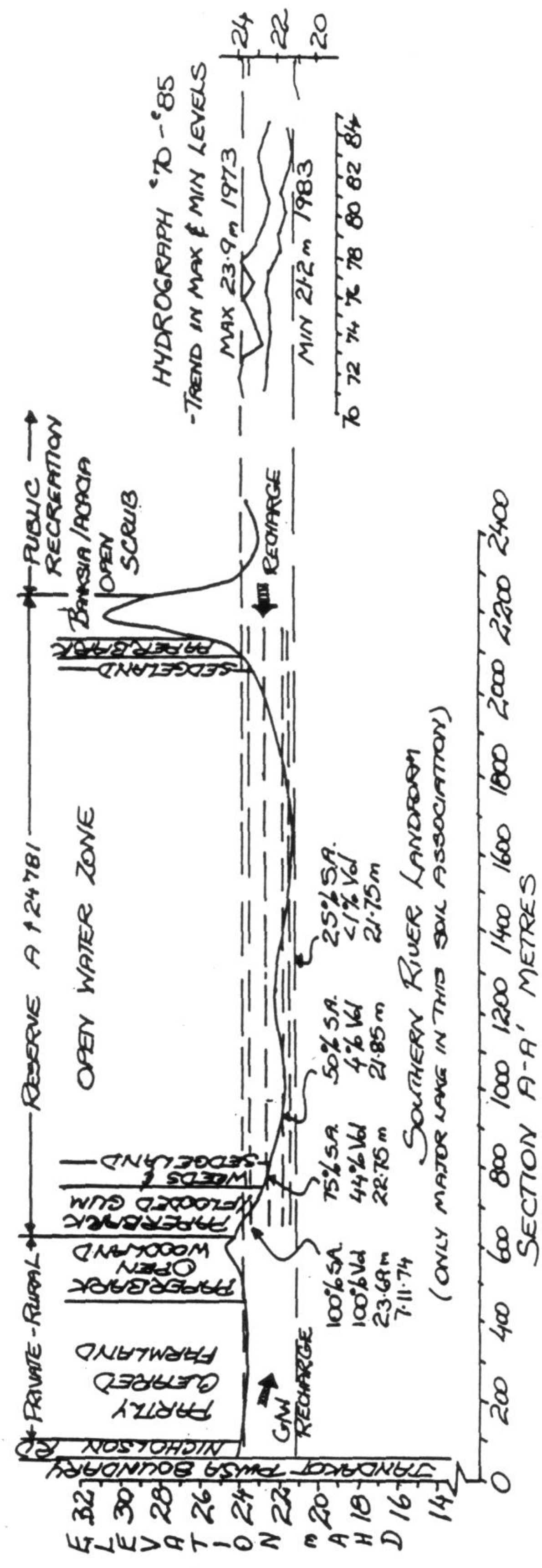

Figure 3.6: Diagrammatic cross-section and water level record of Forrestdale Lake (Source: Arnold 1990).

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

Wetlands in the south west of Western Australia are influenced greatly by the Mediterranean climate, and seasonal drying is a feature of the lakes. The duration and time of drying depends on evaporation rates and the amount of water entering the lake during winter and spring. In wetter years, the lakes do not tend to dry completely, whereas in drier years they have dried completely, i.e. no free surface water is present in summer and autumn for weeks or months at a time. The average annual evaporation in Perth is 2,056 mm or about twice the average annual rainfall (Bureau of Meteorology 2008). This process contributes significantly to the rapid decline in water level over summer.

Maximum water depth

In 1990, when Forrestdale and Thomsons Lakes were designated as a Ramsar site, the water depth at Thomsons Lake ranged from a minimum of 59 cm in May to a maximum of 98 cm in October, and at Forrestdale Lake ranged from 35 cm in March to 65 cm in September. Maximum water depths in Forrestdale and Thomsons Lakes were much greater in the 1950s and 60s in both wetlands, with average annual maximum depths of 274 cm at Thomsons Lake and 216 cm at Forrestdale Lake. The relatively high water levels at Thomsons Lake during the 1960s and 70s may have been the result of excessive inundation caused by clearing of the surrounding *Banksia* woodland for cattle grazing and market gardening (Crook and Evans 1981). Rapid changes in water level may have become more common since groundwater abstraction began in 1979, and the frequency at which rapid changes in depths occur may have also increased (Davis *et al.* 2001). Concern has also been raised the Southern Lakes Drainage Scheme is having an ongoing impact on the water regime at Thomsons Lake (R. Pickering, pers. comm.). Maximum water levels have been steadily declining in both lakes since the 1960s (Figure 3.9). However, high levels were recorded between 1992 and 1994 as a result of good rainfall in preceding years (1991–1992; Figure 2.3).

Average maximum water depths from 1980 to 1999, the decades before and after the Ramsar site was listed, were 105 cm (range 38–206 cm) at Thomsons Lake, and 103 cm (range 47–187 cm) at Forrestdale Lake. Since 2000, average maximum water levels have declined to 65 cm at Thomsons Lake, and 59 cm at Forrestdale Lake. These changes are continuing despite Thomsons Lake being supplemented with water during spring since 2004.

Strict criteria have been imposed for water level management in both lakes. In 1992, Environmental Water Provisions (EWPs) were set for a number of wetlands including Forrestdale and Thomsons Lakes, and these were updated in 2004. The EWPs include a preferred minimum water level and an absolute minimum level, and were set to ensure the maintenance of the lake's habitat value for migratory birds and rare, threatened and priority flora and fauna. The preferred minimum water level of Thomsons Lake is 11.3–11.8 m AHD, with an absolute minimum of 10.8 m AHD (Department of Environment

2004). The lake bed level used by the Department of Environment in setting EWPs is 11.8 m AHD. This equates to a preferred minimum water level that is at the lake bed surface to 0.5 m below the lake bed, and an absolute minimum water level of 1.0 m below the lake bed surface. The absolute minimum level is the point at which emergent macrophytes can no longer access water (Townley *et al.* 1993). However, the length of time at which groundwater remains at or near this level is most critical. If groundwater did not exceed this level for more than 3–4 months each year, most species of emergent macrophyte would not survive for longer than 1–2 years (Froend *et al.* 1993). The current staff gauge from which water depth readings are recorded was installed in summer 2002/03; a photograph of the gauge is provided in Figure 3.7. A level of 11.8 m AHD has been used as the lake bed level (i.e. sediment surface) for the purposes of calculating water depth in this report.

The current criteria for the Jandakot Mound, limit the allowances for water levels to fall between the preferred and absolute minimum values for no more than two in six years. The 'two in six year' approach was adopted as a simplistic means of accounting for and mimicking the occurrence of drier years, during which water levels would be expected to be lower as a direct consequence of lower rainfall. The criterion effectively requires that, on average, water levels should not be below the preferred minima for more than one third of years, and for no longer than two consecutive years in any six year period (Department of Environment 2004).

It is important to note the maximum permitted water level at Thomsons Lake is 12.8 m AHD, at which time water is pumped out to a level of 12.6 m AHD (CALM 2005b). As the lake bed level is at approximately 11.8 m AHD, water can no longer reach depths of more than 1.0 m for an extended period of time. The maximum levels were developed with the Environment Protection Authority's (EPA) approval, as an environmental condition on the rezoning of land to the east of Thomsons Lake from rural to urban (CALM 2005b).

Figure 3.7: Staff gauge at Thomsons Lake from which water depth measurements are currently recorded (taken by Jenny Davis in June 2008).

At Forrestdale Lake the preferred summer minimum is 21.2–21.6 m AHD (reading from the staff gauge) and an absolute summer minimum of 20.2 m AHD (reading from monitoring well) (Department of Environment 2004). The lake bed level used by the Department of Environment in setting EWPs is 21.6 m AHD. This equates to a preferred minimum water level that is at the lake bed surface to 0.4 m below the lake bed, and an absolute minimum water level of 1.4 m below the lake bed surface. A level of 21.5 m AHD has been used as the lake bed level (i.e. sediment surface) for the purposes of calculating water depth in this report. An overflow drain is also present at Forrestdale Lake (Forrestdale Main Drain), which runs from the lake's eastern side in a northerly direction (Figure 3.4); however it has not flowed now for a number of years (CALM 2005a). The current staff gauge from which water depth readings are recorded was installed in summer 1993; a photograph of the gauge is provided in Figure 3.8. It should be noted that the staff gauges at both lakes are not located at the absolute lowest point of the lake bed. Therefore, a dry reading may be recorded from the staff gauge when some water (shallow) may still be present on other areas of the lake bed.

Figure 3.8: Staff gauge at Forrestdale Lake from which water depth measurements are currently recorded (taken by Jenny Davis in May 2008).

Annual period of inundation/drying

Forrestdale and Thomsons Lakes appear to have experienced phases of annual drying and permanent water presence since monthly measurements of water depth began in 1972 (Figure 3.10). Both lakes have experienced two phases where water was present permanently (in most years): 1972–1977 and 1989–1995 at Thomsons Lake; and 1972–1982 and 1989–1993 at Forrestdale Lake. The lakes have also experienced two periods of annual drying (in most years): 1978–1988 and 1996–present at Thomsons Lake; and 1983–1988 and 1994–present at Forrestdale Lake. Neither lake dried completely in 1990 when they were designated as a Ramsar site, but have dried completely in most years since that time.

The duration of time that water is present in Forrestdale and Thomsons Lakes is currently less than any time in the past, including the previous dry phase (Figure 3.11). In the dry phase during the 1980s, the average annual period of inundation was 8.6 months (± SE 0.44) at Thomsons Lake and 10.2 months (± SE 0.73) at Forrestdale Lake. The annual period of inundation has declined by around 2 months at Thomsons Lake and almost 4 months at Forrestdale Lake. In the present annual drying phase, the average annual period of inundation is 6.7 months per year (± SE 0.56) at Thomsons Lake and 6.4 (± SE 0.45) months at Forrestdale Lake. As noted previously, these changes are continuing despite Thomsons Lake being supplemented with water during spring since 2004.

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

Timing of inundation/drying during dry phases

In addition to drying for longer periods of time, Forrestdale and Thomsons Lakes are also drying out earlier than in previous years (Figure 3.12 and Figure 3.13). During the annual drying phase in the 1980s, both lakes tended to dry completely in January, February or March. Since 2000, the lakes have been drying mostly during December and January. Prior to this time, Thomsons Lake had dried in December only once, in 1980, and Forrestdale Lake had not dried before January.

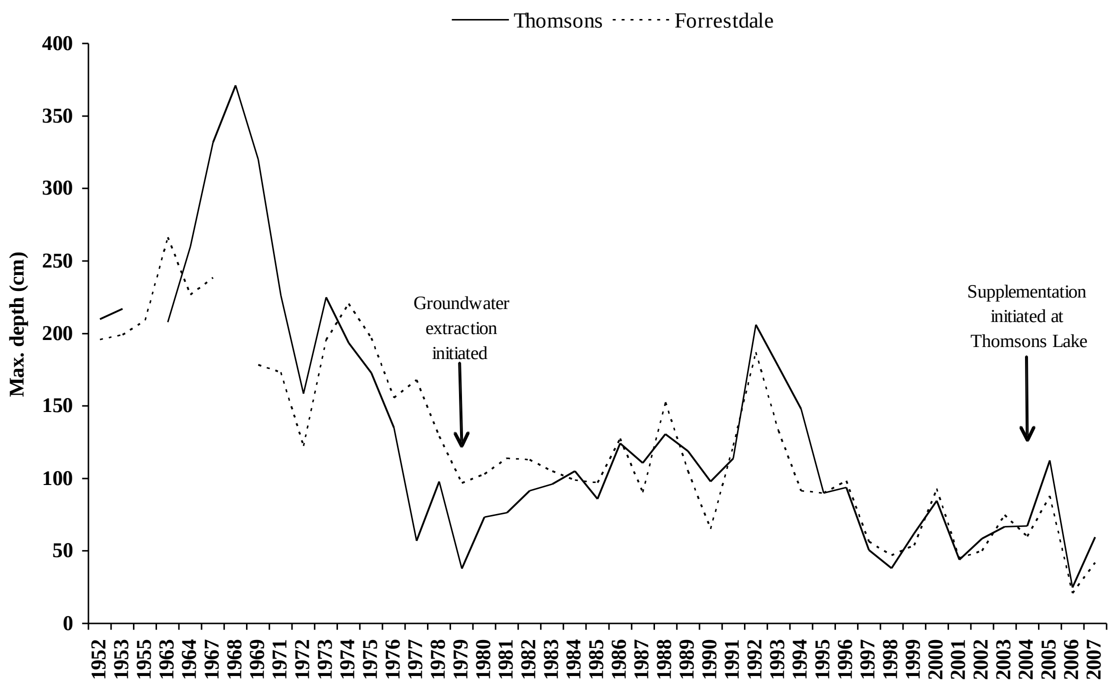

Figure 3.9: Maximum depth of Forrestdale and Thomsons Lakes 1952–2007.

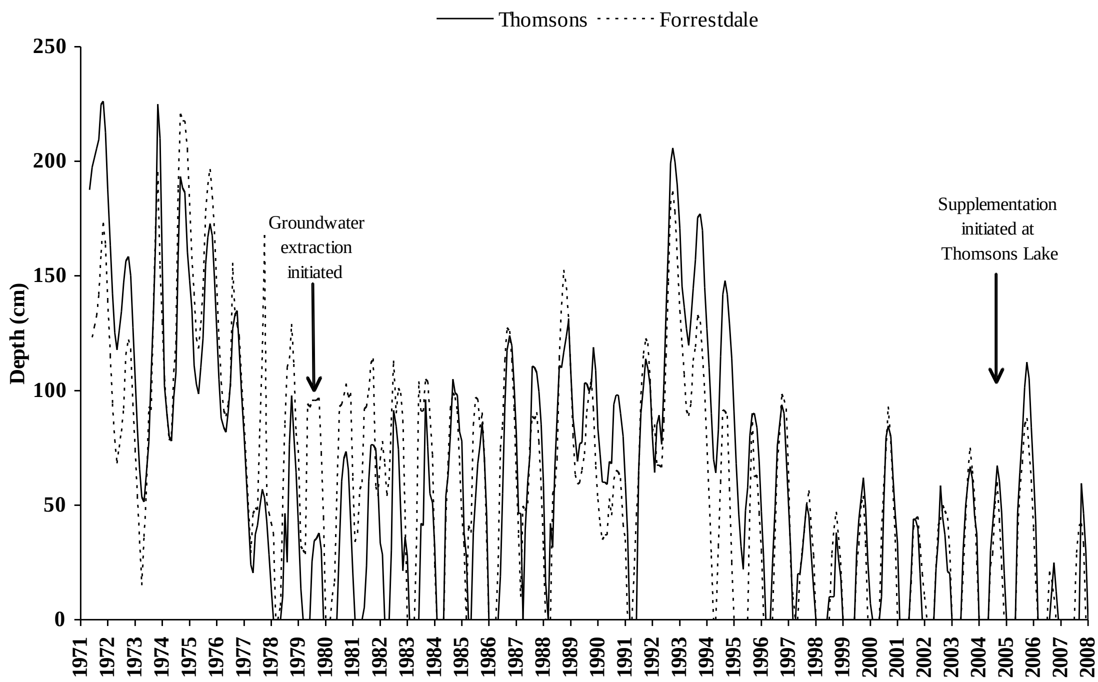

Figure 3.10: Annual depth variation in Forrestdale and Thomsons Lakes from January 1971 to January 2008.

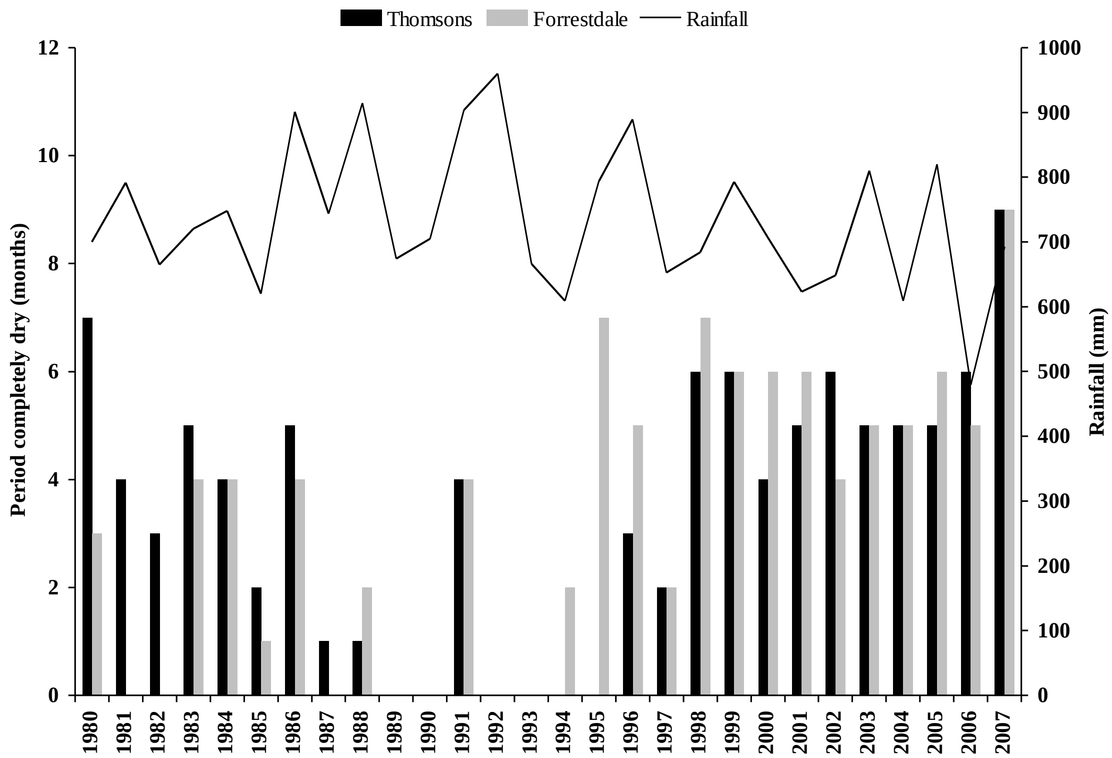

Figure 3.11: Number of months that Forrestdale and Thomsons Lakes were completely dry each year from 1980 to 2007 and total annual rainfall.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007									x	x	x	x
2006	x	x							x	x	x	
2005						x	x	x	x	x	x	x
2004						x	x	x	x	x	x	x
2003					x	x	x	x	x	x	x	x
2002						x	x	x	x	x	x	
2001	x						x	x	x	x	x	
2000	x					x	x	x	x	x	x	x
1999							x	x	x	x	x	x
1998							x	x	x	x	x	x
1997	x	x			x	x	x	x	x	x	x	x
1996	x	x				x	x	x	x	x	x	x
1995	x	x	x	x	x	x	x	x	x	x	x	x
1994	x	x	x	x	x	x	x	x	x	x	x	x
1993	x	x	x	x	x	x	x	x	x	x	x	x
1992	x	x	x	x	x	x	x	x	x	x	x	x
1991	x	x					x	x	x	x	x	x
1990	x	x	x	x	x	x	x	x	x	x	x	x
1989	x	x	x	x	x	x	x	x	x	x	x	x
1988	x	x		x	x	x	x	x	x	x	x	x
1987	x	x	x		x	x	x	x	x	x	x	x
1986						x	x	x	x	x	x	x
1985	x	x	x			x	x	x	x	x	x	x
1984	x					x	x	x	x	x	x	x
1983	x						x	x	x	x	x	x
1982	x	x				x	x	x	x	x	x	x
1981	x					x	x	x	x	x	x	x
1980							x	x	x	x	x	x
1979	x	x					x	x	x	x	x	
1978	x					x	x	x	x	x	x	x
1977	x	x	x	x	x	x	x	x	x	x	x	x
1976	x	x	x	x	x	x	x	x	x	x	x	x
1975	x	x	x	x	x	x	x	x	x	x	x	x
1974	x	x	x	x	x	x	x	x	x	x	x	x
1973	x	x	x	x	x	x	x	x	x	x	x	x
1972	x	x	x	x	x	x	x	x	x	x	x	x

Figure 3.12: Timing of water presence in Thomsons Lake (x = water present).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007								x	x	x	x	
2006	x	x						x	x	x	x	
2005						x	x	x	x	x	x	x
2004						x	x	x	x	x	x	
2003						x	x	x	x	x	x	x
2002	x					x	x	x	x	x	x	x
2001							x	x	x	x	x	x
2000						x	x	x	x	x	x	x
1999							x	x	x	x	x	
1998								x	x	x	x	x
1997	x	x	x			x	x	x	x	x	x	x
1996	x						x	x	x	x	x	x
1995								x	x	x	x	x
1994	x	x	x			x	x	x	x	x	x	x
1993	x	x	x	x	x	x	x	x	x	x	x	x
1992	x	x	x	x	x	x	x	x	x	x	x	x
1991	x					x	x	x	x	x	x	x
1990	x	x	x	x	x	x	x	x	x	x	x	x
1989	x	x	x	x	x	x	x	x	x	x	x	x
1988	x	x			x	x	x	x	x	x	x	x
1987	x	x	x	x	x	x	x	x	x	x	x	x
1986					x	x	x	x	x	x	x	x
1985	x	x		x	x	x	x	x	x	x	x	x
1984	x					x	x	x	x	x	x	x
1983					x	x	x	x	x	x	x	x
1982	x	x	x	x	x	x	x	x	x	x	x	x
1981	x	x	x	x	x	x	x	x	x	x	x	x
1980				x	x	x	x	x	x	x	x	x
1979	x	x	x	x	x	x	x	x	x	x	x	x
1978	x	x			x	x	x	x	x	x	x	x
1977	x	x	x	x	x	x	x	x	x	x	x	x
1976	x	x	x	x	x	x	x	x	x	x	x	x
1975	x	x	x	x	x	x	x	x	x	x	x	x
1974	x	x	x	x	x	x	x	x	x	x	x	x
1973	x	x	x	x	x	x	x	x	x	x	x	x
1972	x	x	x	x	x	x	x	x	x	x	x	x

Figure 3.13: Timing of water presence in Forrestdale Lake (x = water present).

3.3 Physico-chemistry

Temperature, mixing and thermal stratification

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

Light, colour and turbidity

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

Coloured compounds mostly consist of the breakdown products from plant material and phytoplankton, largely humic and fulvic acids. The lakes are weakly coloured (Thomsons Lake = 6–27 g440/m; Forrestdale Lake = 6–24 g440/m; Figure 3.14), and are generally clear (Figure 3.15), probably because there is little inflow of surface water. However, turbidity may increase during the first winter inflows as some sediment may be carried into the lakes (Davis *et al.* 1993), or as the result of wind induced re-suspension of bed sediments with shallower water depths. The turbidity of Thomsons Lake was high in spring 1990 (75.0 NTU) due to the large standing crop of phytoplankton in the lake (Figure 3.16). However the lake has generally maintained low turbidity levels during spring (1–27 NTU). Forrestdale Lake has also maintained low turbidity levels during spring (1–38 NTU).

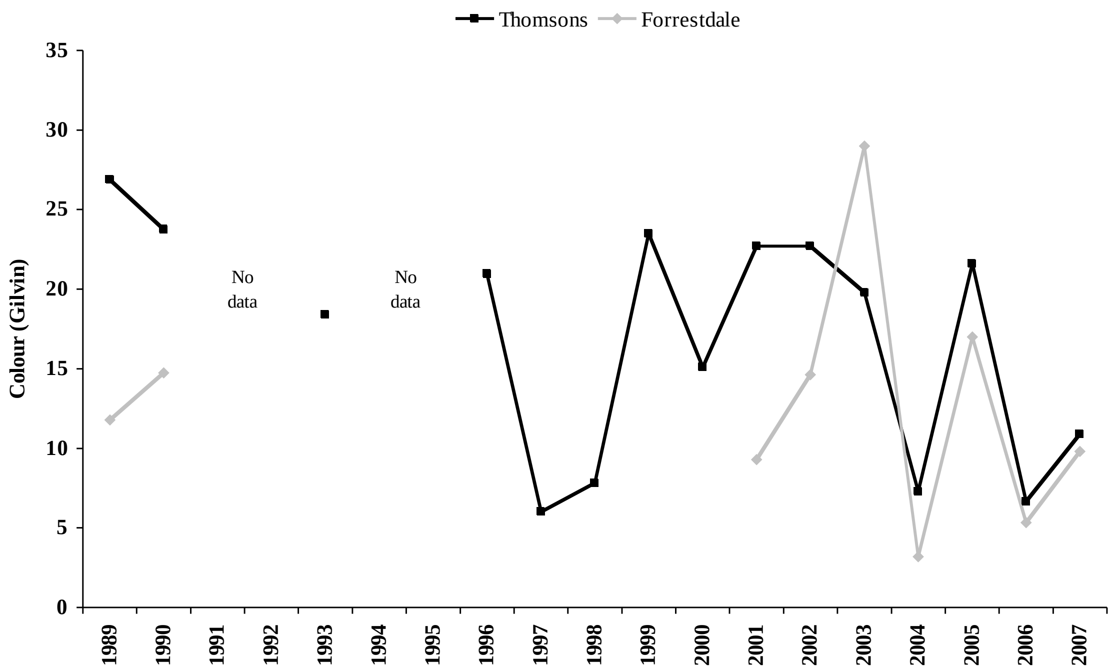

Figure 3.14: Colour values recorded in spring each year at Forrestdale and Thomsons Lakes, from 1989 to 2007.

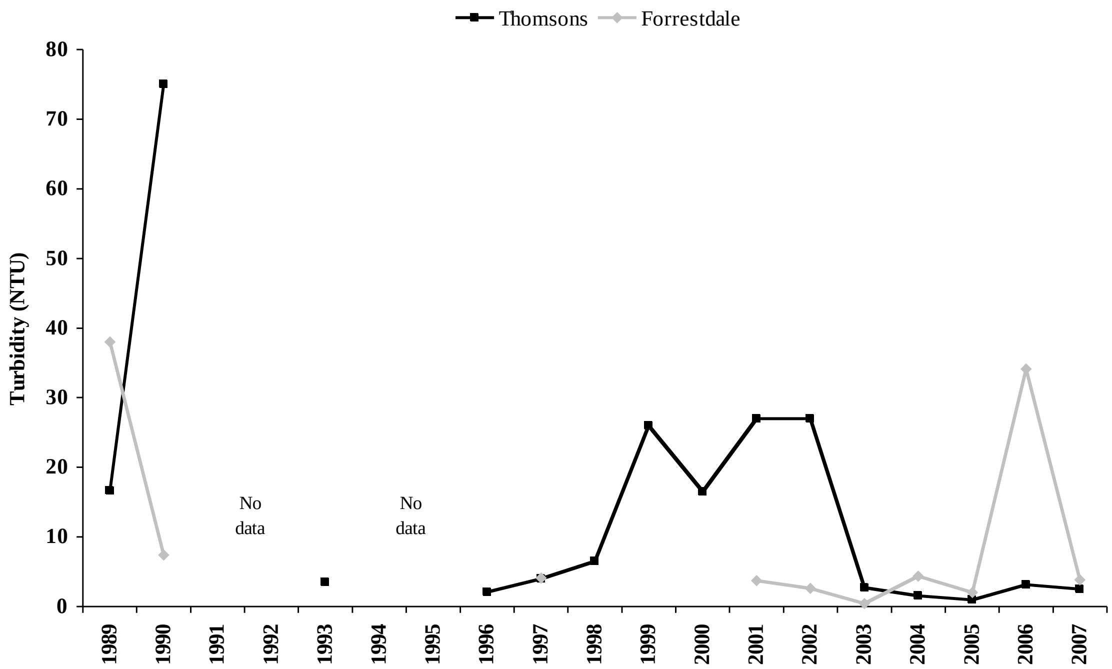

Figure 3.15: Turbidity values recorded in spring each year at Forrestdale and Thomsons Lakes, from 1989 to 2007.

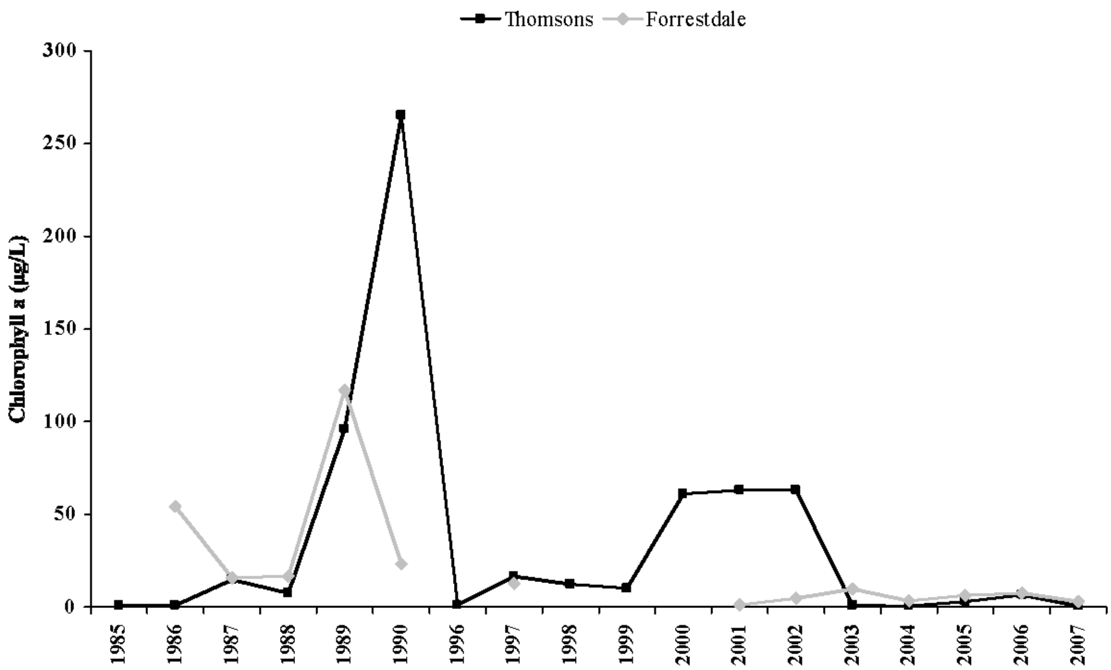

Figure 3.16: Values of chlorophyll *a* recorded in spring each year at Forrestdale and Thomsons Lakes, from 1989 to 2007.

Salinity and pH

The major factors that control the salinity of freshwaters are the catchment geology, atmospheric precipitation and evaporation-precipitation processes. There are also a number of pollutants such as wastewater from septic systems, roads, and agricultural areas that may contribute salts. Lakes that are very shallow and have a large surface area, such as Forrestdale and Thomsons, tend to evaporate rapidly in summer and reach high salinities as a result of evapoconcentration (Davis *et al.* 1993). Such seasonal patterns were evident at both lakes, but were much stronger at Forrestdale Lake (Figure 3.17). From May 1985 to May 1990, the salinity of Thomsons Lake ranged from fresh in winter (as low as 1,290 µS cm^{-1}) to brackish in summer (up to 8,350 µS cm^{-1}). Forrestdale Lake was also fresh during winter (as low as 1,200 µS cm^{-1}) but reached much higher salinities in summer before the lake dried out (up to 19,900 µS cm^{-1}).

Salinity levels have remained relatively stable in both lakes over the longer term (Figure 3.18). From 1972 to 2007, Thomsons Lake has remained fresh to brackish during spring when the water levels in the lakes are highest (1,579–6,430 µS cm^{-1}). Forrestdale Lake has generally remained fresh to brackish during spring (1,590–6,951 µS cm^{-1}). However, conductivity was much higher than usual in spring 2006 (15,900 µS cm^{-1}) because the lake was drying out and water depth at the time of sampling was only 10 cm. The unusually low water depth and early drying of the lake was probably due to extremely low rainfall during winter and spring and subsequently low groundwater recharge. Conductivity returned to normal levels in spring 2007. Thomsons Lake did not experience similarly high levels of salinity in 2006 because it was supplemented with additional water over this period of time.

Salinity is a major factor influencing the invertebrate species composition of wetlands (Davis *et al.* 1993). Apart from wetlands in the western Beeliar chain, which are naturally saline (due to a prior marine influence), anthropogenic salinisation does not

seem to have affected wetlands on the Swan Coastal Plain. The flora and fauna that have evolved in these wetlands are able to cope with moderate levels of salinity, but few can survive unnaturally high salinities. Increased salinity levels in the wetlands would cause the invertebrate communities to shift to more salt tolerant species and so reduce the number of species present (Balla 1994).

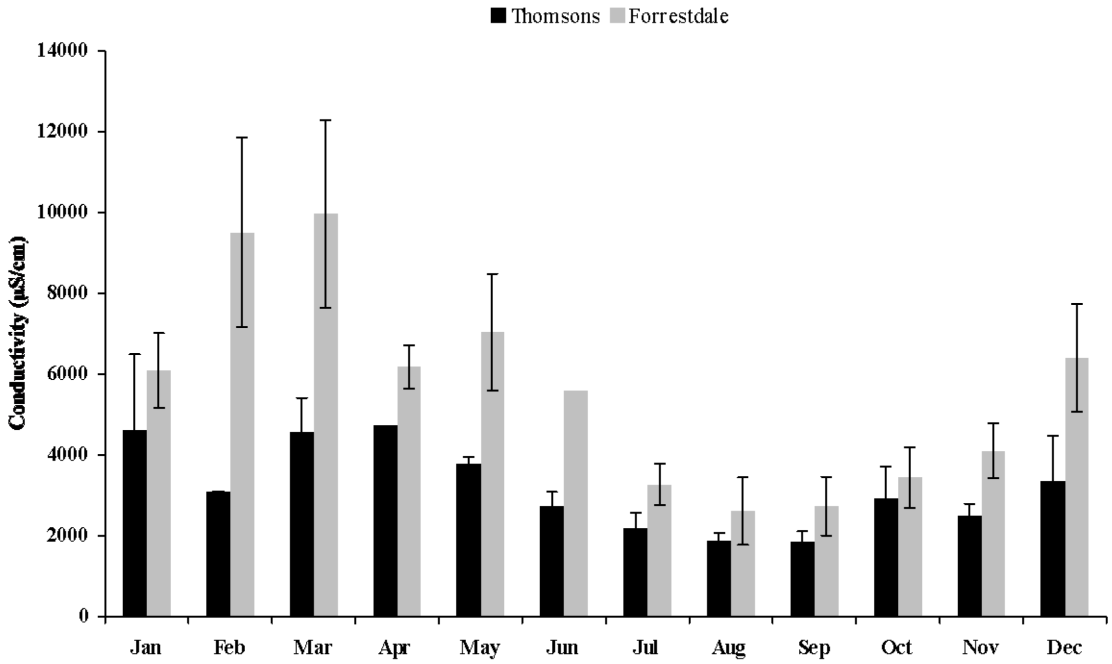

Figure 3.17: Mean seasonal conductivity variation (data range: 1985–1997) at Forrestdale and Thomsons Lakes.

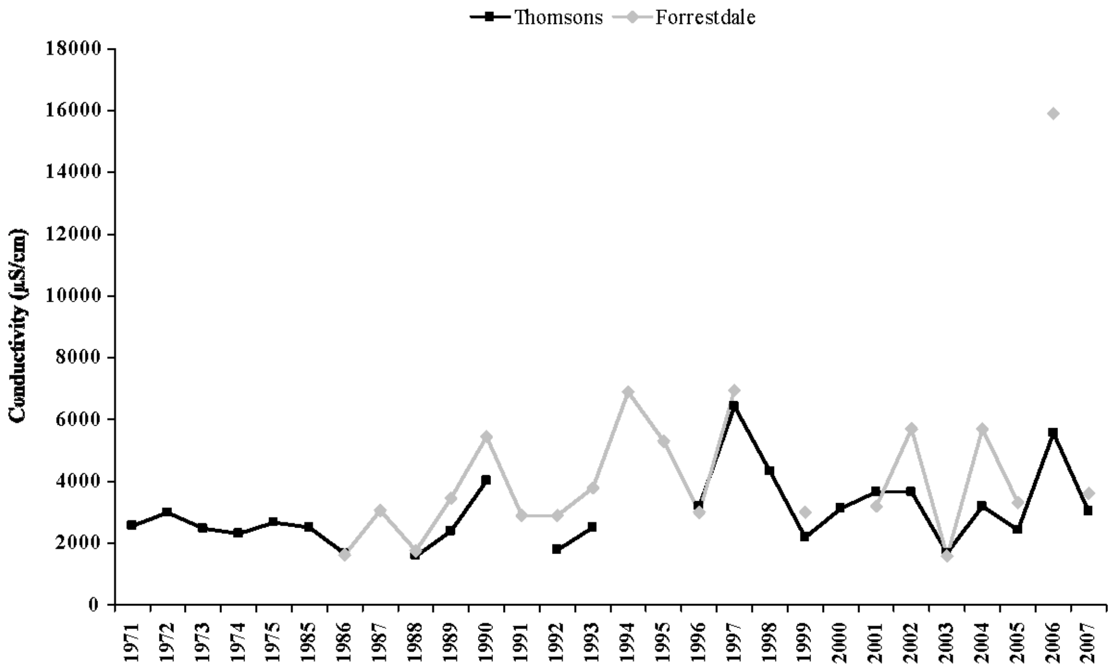

Figure 3.18: Conductivity levels recorded in spring each year at Forrestdale and Thomsons Lakes, from 1971 to 2007.

Forrestdale and Thomsons Lakes are within the Tamala limestone formation. Such wetlands generally have high carbonate-bicarbonate levels in the water and this is reflected in that the wetlands in winter have alkaline water i.e. pH > 7 (Davis *et al.* 1993). Both lakes have a neutral to alkaline pH. From 1972 to 2007 the pH of the water at Thomsons Lake in spring has ranged from 7.2 to 9.9. The pH of Forrestdale Lake has been similar, ranging from 7.2 to 9.9 over the period 1986 to 2007 (Figure 3.19).

pH appears to be the most important correlate for the potential presence and proliferation of cyanobacteria in wetlands of the Swan Coastal Plain during the warmest months (Davis *et al.* 1993). Cyanobacteria or blue-green algae tend to form large scums that are aesthetically unpleasant and release noxious odours on decay. They release toxins that are harmful and potentially fatal to a wide range of fauna. Wetlands with a pH greater than 9 have been associated with highly nutrient enriched conditions and algal blooms (Davis *et al.* 1993).

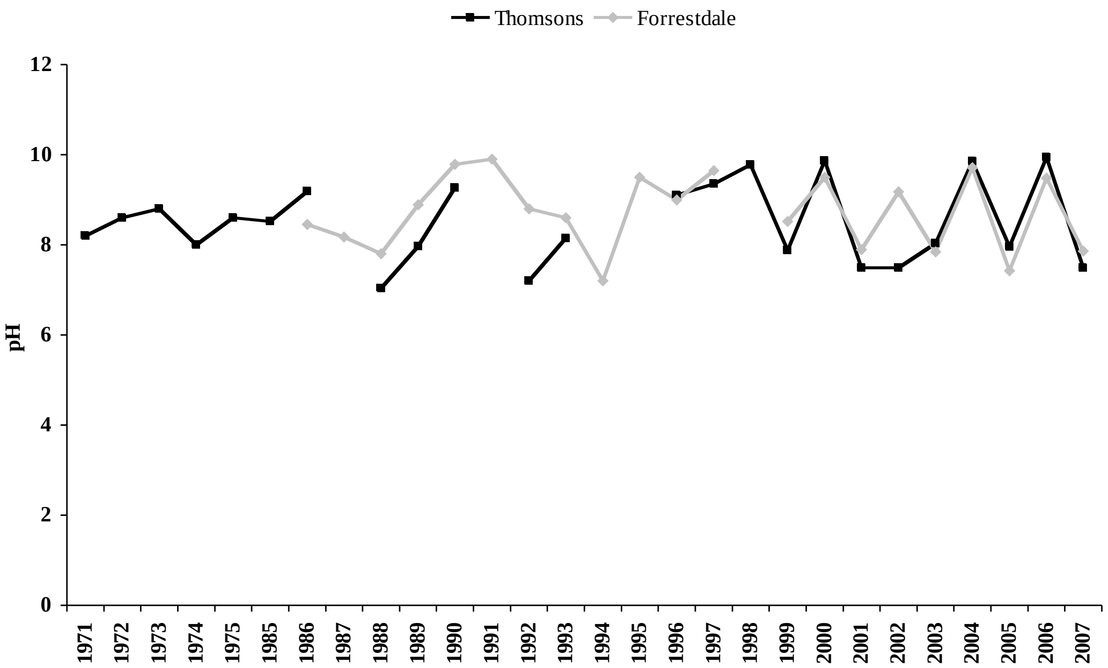

Figure 3.19: Values of pH recorded in spring each year at Forrestdale and Thomsons Lakes, from 1971 to 2007.

Nutrients

Both lakes have been moderately enriched since measurements began in the early 1970s (Figure 3.20 and Figure 3.21). Nutrient levels recorded in spring at Thomsons Lake have ranged from 28–338 μg/L of total phosphorus and 1,386–6,800 μg/L of total nitrogen. Nutrient levels are similar at Forrestdale Lake, ranging from 43–389 μg/L of total phosphorus and 2,352–9,500 μg/L of total nitrogen. The level of nitrogen in Forrestdale Lake was higher than usual in spring 2006 (9,500 μg/L), most likely due to evapoconcentration effects, as the lake was drying out at the time of sampling and water depth was only 10 cm. Nitrogen levels were within the normal range at Forrestdale Lake in spring 2007. Occasional algal blooms have been recorded e.g. in 1990 at Forrestdale Lake (Figure 3.16). Phosphorus levels have been lower since 2002–03 largely due to the more frequent and extended duration of complete drying.

Phosphorus is of great importance in freshwater ecosystems because it is often the nutrient limiting primary production (Davis *et al.* 1993). In their natural state, Forrestdale and Thomsons Lakes probably received and lost most of their phosphorus through groundwater flow and sedimentation. However, since European settlement, these wetlands have had artificial drains entering or leaving them and these drains have probably largely altered the dynamics of phosphorus budgets in these wetlands.

As basin wetlands with little to no flushing, Swan Coastal Plain wetlands have very long water residence times. Therefore, the nutrients that enter the lake will tend to accumulate and a large proportion will eventually become trapped in the sediment. A large reservoir of nutrients is held in the sediments and under certain conditions these may be released and recycled to the water column, providing a potentially major source of nutrients. The release of phosphorus from lake sediments into the water column is reduced with the current summer drying regime at Forrestdale and Thomsons Lakes. Nutrient export during such dry phases occurs through a variety of mechanisms including use of nutrients by plants and animals, volatilisation of the nutrients to the atmosphere, wind blowing the nutrients (in the form of dead plant and animal material) out of the dry lake, and oxidation of nutrients so that they are accessible and used as soon as the lake floods instead of accumulating over time (CALM 2005a, b).

Nutrient enrichment can result in the loss of submerged macrophytes and their replacement with green algae and cyanobacteria (blue-green algae). Such algal blooms have been recorded occasionally at the lakes. Large algal blooms can result in foul odours, low oxygen levels, and can have toxic effects on invertebrates and birds (Balla 1994). Low dissolved oxygen concentrations result in a reduction in invertebrate diversity, with only the most tolerant of species surviving in large numbers. Low oxygen levels and elevated water temperatures result in conditions favourable to growth of the bacterium, *Clostridium botulinum*, and subsequent outbreaks of botulism among waterfowl (Balla 1994). A small outbreak of botulism occurred at Forrestdale Lake in 1984; however no further outbreaks have been recorded (Bartle *et al.* 1987). Decaying algal blooms also provide an extensive food source for larval midges (Pinder *et al.* 1991). Concentrations of total phosphorus above 100μg/L are often associated with poor water quality and midge swarms. Phosphorus levels have regularly exceeded 100 μg/L at both lakes over the past 25 years (Figure 3.20). Midge swarms have been the subject of complaints by local residents at Forrestdale Lake for many years. The problem has been exacerbated at this lake by the lack of a buffer between the lake and adjacent residential areas. However, there have been few problems from midges over

the past few years as a result of the lake drying out early in summer before major midge swarms develop (CALM 2005a).

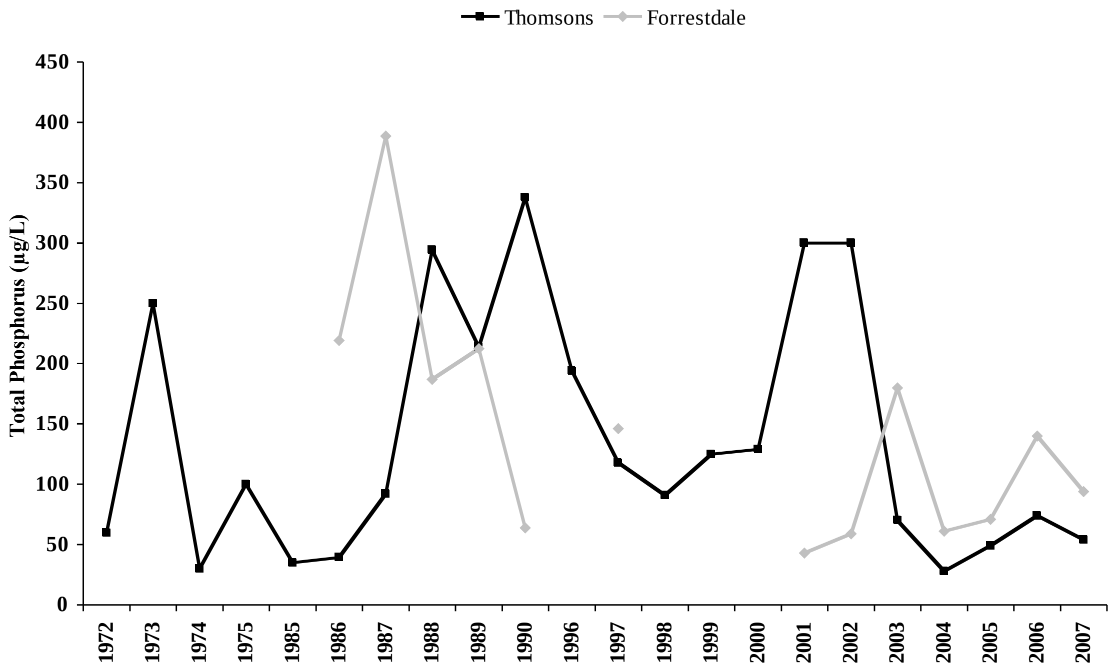

Figure 3.20: Concentration of total phosphorus recorded in spring each year at Forrestdale and Thomsons Lakes, from 1972 to 2007.

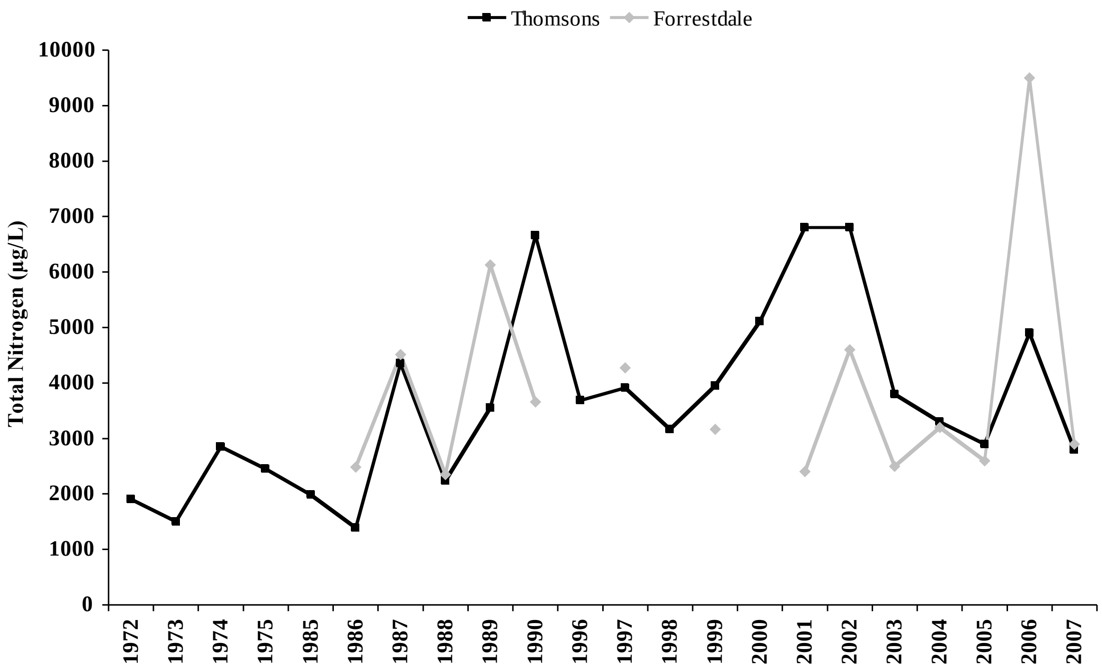

Figure 3.21: Concentration of total nitrogen recorded in spring each year at Forrestdale and Thomsons Lakes, from 1972 to 2007.

3.4 Fauna

3.4.1 Mammals

Seven species have been recorded at Forrestdale and Thomsons Lakes (Appendix C: Amphibians, Reptiles and Mammals); however, surveys for mammal species within the reserves have been limited. Six species of mammal have been recorded at Thomsons Lake including the Quenda (*Isoodon obesulus fusciventer*); the Western Grey Kangaroo (*Macropus fuliginosus*), Western Brush Wallaby (*Macropus irma*); the Brush-tailed Possum (*Trichosurus vulpecula*); the Numbat (*Myrmecobius fasciatus*), although not recorded in the reserve since 1984; and the Native Water Rat (*Hydromys chrysogaster*). The Swan Coastal Plain has nine species of insectivorous bats, some of which are likely to use the reserve for occasional foraging, if not permanently (CALM 2001). Four mammal species have been identified at Forrestdale Lake including the Quenda; Western Grey Kangaroo; the White-striped Mastiff Bat (*Tararida australis*); and the Western Brush Wallaby (*Macropus irma*), although few have been recorded since the 1960s and are believed to no longer inhabit the area. Introduced mammal fauna that occur at the Reserves include mice, rats, foxes, feral and domestic cats, dogs and rabbits.

3.4.2 Reptiles and Amphibians

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

Long-necked turtles (*Chelodina oblonga*) are present in both lakes. Other reptile species comprising 12 lizard species and 3 species of snake have been recorded at Thomsons Lake Reserve (Crook and Evans 1981). Nine lizard species and 5 snake species have been recorded at Forrestdale Lake Reserve (Bartle *et al.* 1987). Three of the reptile species are significant because they are scarce or rare in the area and have relatively localised distributions: the Swamp Skink (*Acritoscincus trilineatum*); Lined Skink (*Lerista lineata*) and; Crowned Snake (*Notechis coronatus*) (State of Western Australia 2000).

3.4.3 Aquatic Invertebrates

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

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

The aquatic invertebrate fauna of the wetlands on the Swan Coastal Plain is diverse and abundant. Over 280 invertebrate species have been collected from 40 wetlands on the Swan Coastal Plain (Davis *et al.* 1993). Macroinvertebrates have been the subject of several studies at Thomsons Lake and Forrestdale Lake (Davis and Rolls 1987; Rolls 1989; Pinder *et al.* 1991; Balla and Davis 1993, 1995; Davis *et al.* 1993; McGuire and Davis 1999; Wild *et al.* 2003; Wild and Davis 2004; Davis *et al.* 2008). A large diversity of species exists within the Ramsar site. Macroinvertebrates from a total of 59 families and 3 taxa identified only to order, have been collected at Thomsons Lake from 1985–2007, including 2 annelids, 4 molluscs, 15 crustaceans, 8 arachnids and 33 insects (Appendix B: Macroinvertebrates). Macroinvertebrates from a total of 40 families and 3 taxa identified only to order, have been collected at Forrestdale Lake from 1986–2007, including 2 molluscs, 12 crustaceans, 7 arachnids and 22 insects (Appendix B: Macroinvertebrates). Fewer invertebrate families have been recorded at Forrestdale Lake, most likely because less frequent sampling has been carried out than at Thomsons Lake (Figure 3.22).

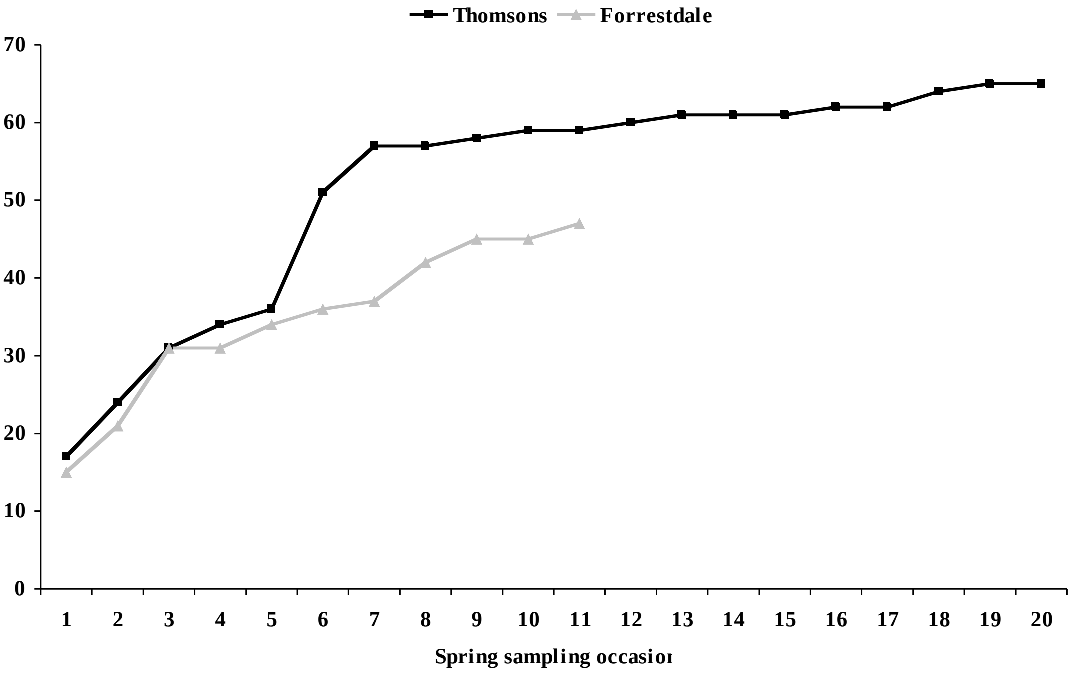

Figure 3.22: Cumulative richness of invertebrate families at Forrestdale and Thomsons Lake over the period 1985–2007.

Species richness at Forrestdale and Thomsons Lakes has remained relatively stable (Figure 3.23 and Figure 3.24). However, Forrestdale Lake was poor in invertebrate families in spring 2006, which indicates that this lake had not filled sufficiently to support the macroinvertebrate community previously recorded. Davis *et al.* (2008) found that high invertebrate richness in a number of wetlands on the Jandakot Mound corresponded to high maximum water levels (e.g. 1992 and 1993 Figure 3.23), and that the lowest richness occurred at the lowest water levels.

The relationship between maximum water depth and the number of invertebrate families at Thomsons Lake describes a threshold system where the number of invertebrate families ranges between around 15 to 26 when maximum water depths are between approximately 35 cm and 160 cm, but increases when maximum water depths exceed 160 cm (33 to 39 families; Figure 3.25), and decreases when maximum water depths are below 35 cm (Figure 3.26). High richness of invertebrate families (>30) has not been recorded at Forrestdale Lake, most likely because it was not sampled in 1992 and 1993 when water levels were highest. Davis *et al.* (2008) suggest that if a similar increase in richness occurs when water levels similar to those recorded in 1992 are present again, it would suggest that the aquatic invertebrate fauna is well adapted to prolonged dry phases. However, they warn that if it does not, then it can be concluded that water levels in the wetlands have fallen below those experienced naturally in the past and resulted in a loss of ‘resilience’ in the invertebrate biota.

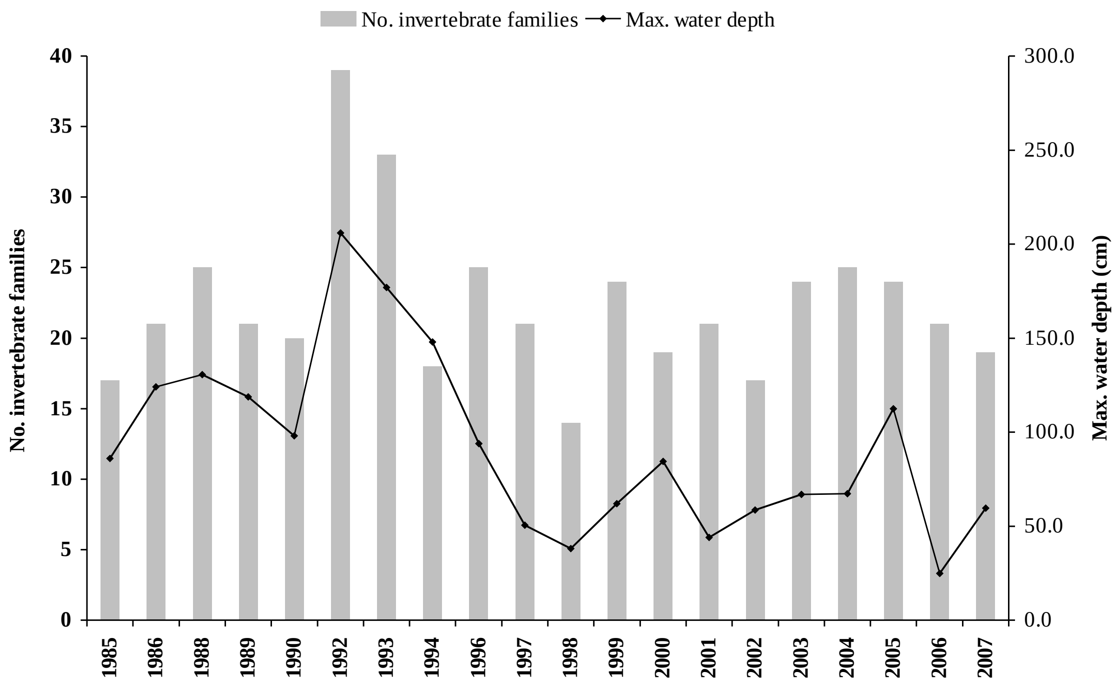

Figure 3.23: Total number of invertebrate families and maximum annual water depth recorded at Thomsons Lake over the period 1985 to 2007.

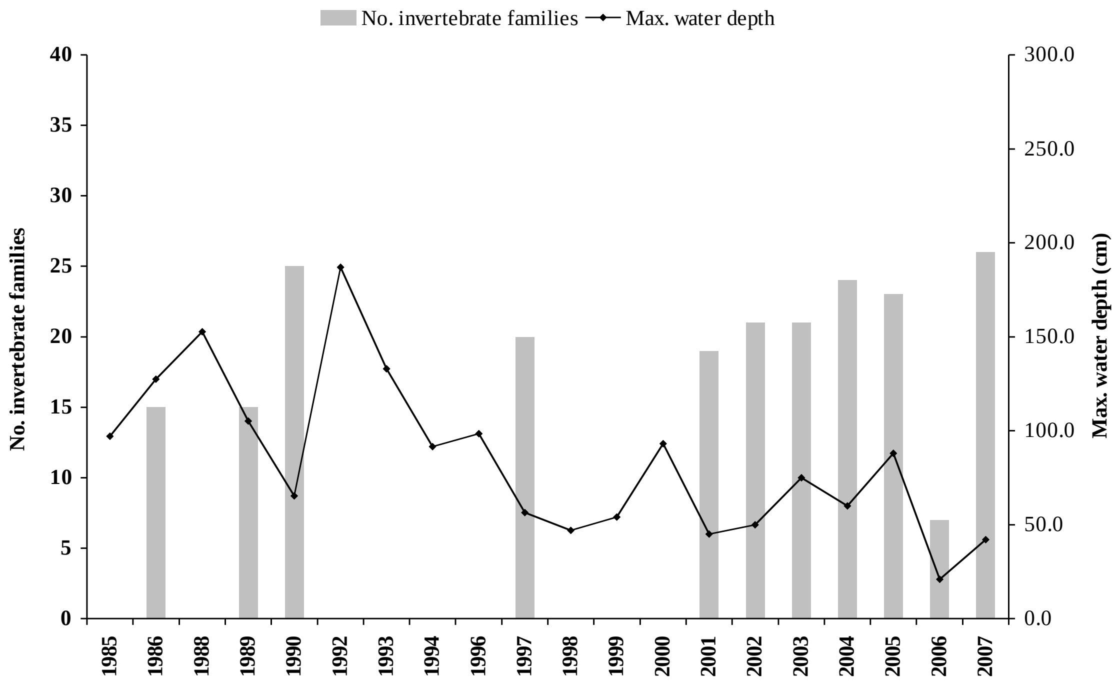

Figure 3.24: Total number of invertebrate families and maximum annual water depth recorded at Forrestdale Lake over the period 1985 to 2007.

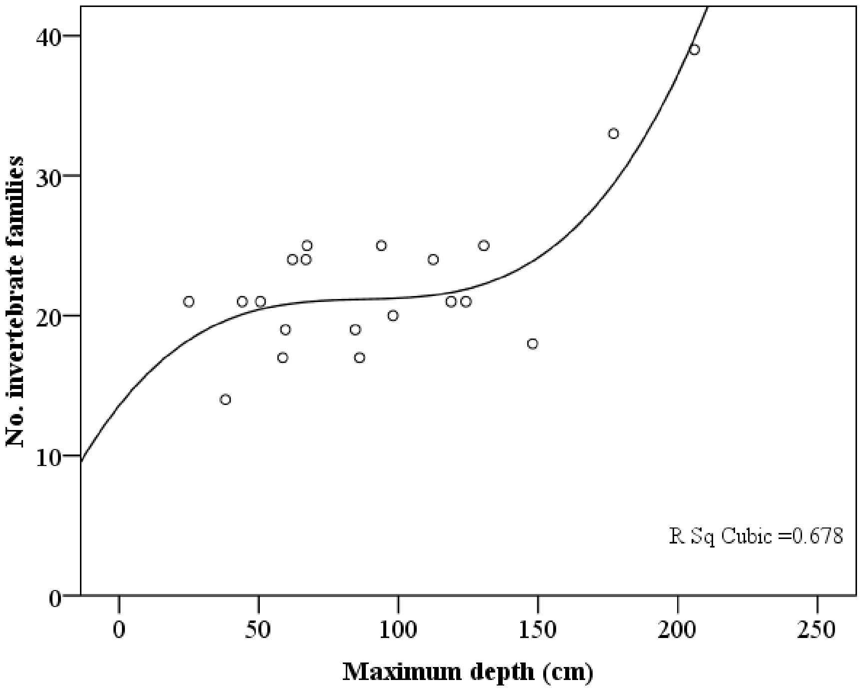

Figure 3.25: Scatter plot showing the 'threshold' relationship between the number of invertebrate families and maximum annual water depth at Thomsons Lake from 1985 to 2007, with a fitted cubic regression curve ($R^2 = 0.678$, d.f. = 16, $P < 0.001$).

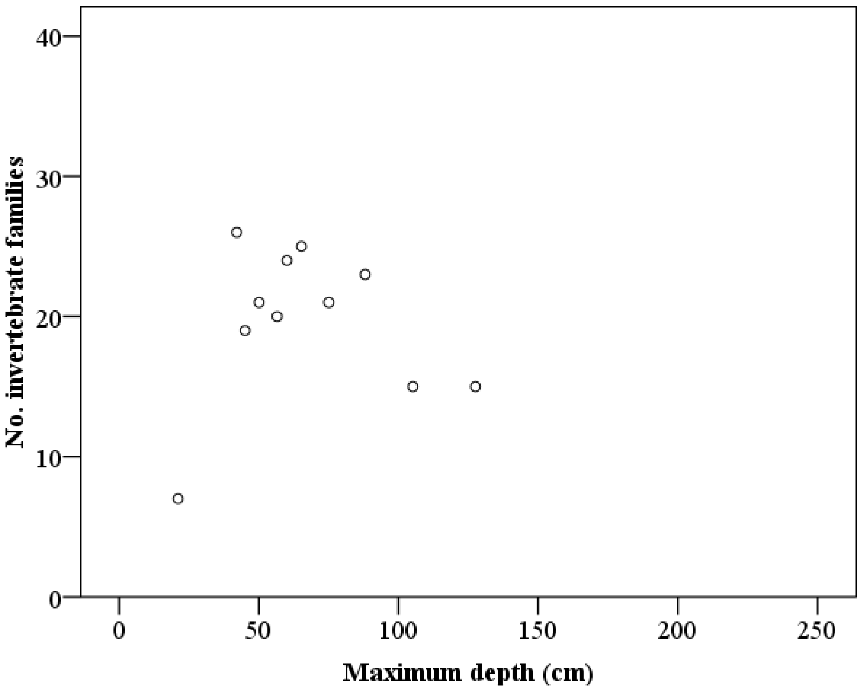

Figure 3.26: Scatter plot showing the relationship between the number of invertebrate families and maximum annual water depth at Forrestdale Lake from 1985 to 2007.

3.4.4 Terrestrial birds

The margins of both lakes support diverse and abundant terrestrial bird life; 66 species have been recorded at Thomsons Lake and 81 species at Forrestdale Lake. Both lakes provide habitat for Carnaby's Black-cockatoo (*Calyptorhynchus latirostris*), which is listed as endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, as rare or is likely to become extinct under the *Wildlife Conservation Act 1950* (Wildlife Conservation (Specially Protected Fauna) Notice 2008) and as endangered on the IUCN Red List of Threatened Species.

3.4.5 Waterbirds

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

Jaensch (2002) described a series of guilds, grouping species that share a common set of ecological requirements or behaviour patterns. The data on waterbirds of the Forrestdale and Thomsons Lakes Ramsar site have been organised according to these guilds and are contained in Appendix A in the following tables:

- A1 – Species recorded from the Ramsar site
- A2 – Feeding habitats
- A3 – Dietary preferences
- A4 – Nesting sites
- A5 – Other behaviour

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

Diversity and abundance

Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain with 85 species of waterbird occurring at the two lakes (Table 3.2) and 27 have been recorded breeding. Twenty nine of the recorded species are protected by the Japan-Australia Migratory Bird Agreement (JAMBA), the China-Australia Migratory Bird Agreement (CAMBA), Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA) and the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention). Seventy-three waterbird species have been recorded at Thomsons Lake, including 20 species that are protected by JAMBA, CAMBA, ROKAMBA and Bonn Convention. Seventy-six waterbird species have been recorded

at Forrestdale Lake, with 23 of these protected by JAMBA, CAMBA, ROKAMBA and Bonn Convention. All migratory species listed under JAMBA, CAMBA, ROKAMBA and Bonn Convention are protected by the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

Table 3.2: Number of waterbird species found within the Forrestdale and Thomsons Lakes Ramsar site (1954–2007) (see Appendix A for species list).

Waterbird Group	Families	Typical foraging and feeding information	No. species
Ducks, geese and swans	Anatidae	Shallow or deeper open water foragers, vegetarian (Black Swan) or omnivorous with diet including leaves, seeds and invertebrates	12
Grebes	Podicipedidae	Deeper open waters feeding mainly on fish	3
Pelicans, Cormorants, Darters	Pelecanidae, Phalacrocoracidae, Anhingidae	Deeper open waters feeding mainly on fish	6
Herons, Egrets, Ibises, Spoonbills	Ardeidae Threskiornithidae	Shallow water or mudflats, feeding mainly on animals (fish and invertebrates)	14
Hawks and Eagles	Accipitridae	Shallow or deeper open water, feeding on fish and occasionally waterbirds and carrion	4
Crakes, rails, coots, water-hens	Rallidae	Coots in open water; others in shallow water or within cover of salt marsh. Omnivores	8
Shorebirds	Scolopacidae, Recurvirostridae, Charadriidae	Shallow water mudflats and salt marsh, feeding mainly on animals (invertebrates and fish)	33
Gulls and terns	Laridae	Terns, over open water feeding on fish; gulls, opportunistic feeders over a wide range of habitats	3
Old World Warblers	Silviidae	Dense riparian vegetation, feeding on invertebrates (mainly insects) and occasionally seeds	2
Total			85

Although there are waterbird records dating from the early 1980s, there has been no systematic survey and reporting of abundance, species composition or breeding in all years. Observations of the waterbird species present at Forrestdale and Thomsons Lakes, counts of bird abundance and breeding records used in this report are described in Table 3.3. The number of surveys conducted at each lake has ranged from 0 to 50 per year since 1981. Some caution must be applied to the interpretation of the survey data because the differences in the number of surveys conducted each year, and in monitoring methods, will have had an impact on some bird records. As part of the monitoring programme for the Public Environmental Review and Environmental Management Programme of the Jandakot Groundwater Scheme Stage 2, waterbirds have been monitored at twelve wetlands associated with the Jandakot Mound since 1996 by Bamford Consulting Ecologists.

Table 3.3: Surveys and observations of waterbird species present at Forrestdale and Thomsons Lakes used in this ecological character description. S = species present; N = total number of each species present; B = breeding records.

Survey Name	Years	Timing of surveys	Data recorded	Reference
Waterbirds in Nature Reserves of South West WA	1981–1988	Every month (Sep 1981–Jun 1988)	S, N and B	Jaensch *et al.* 1988
Wetlands of the Swan Coastal Plain Survey	1990–1992	April, July, October and January (Apr 1990–Jan 1992)	S, N and B	Storey *et al.* 1993
Annual Waterfowl Counts in South West WA	1988–1992	Late spring and early autumn	S and N for 13 native and 3 exotic species of waterfowl	Halse *et al.* 1990, 1992, 1994, 1995.
Environmental Investigations for the Jandakot Groundwater Scheme Stage 2: Wetland Waterbird Monitoring	1996–2007	Winter, early spring and early summer	S, N and B	Bamford and Bamford 1998, 1999, 2000, 2001, 2003, 2004; Bamford and Wilcox 2005; Bamford and Bancroft 2006, 2007
Birds Australia Atlas	1998–2007	All months	S, N and B, ranging from all species in lake area to one-off sightings of specific species. Duration variable.	Barrett *et al.* 2003
Thomsons Lake Nature Reserve Management Plan	1954–1979	All months	S and B	Crook and Evans 1981
Forrestdale Lake Nature Reserve Management Plan	1981–1986	All months	S and B	Bartle *et al.* 1987

Forrestdale and Thomsons Lakes provides important habitat for waterbirds on the Swan Coastal Plain. The highest number of waterbirds counted at Thomsons Lake was 21,083 in February 1987, and more than 10,000 waterbirds have been recorded in several years (Figure 3.27). Species occurring in significant numbers at Thomsons Lake include:

Australasian Shoveler	2,000	Mar 1982
Australian Shelduck	1,600	Nov 1982
Black-winged Stilt	3,000	Feb 1986
Curlew Sandpiper	2,500	Mar 1983
Eurasian Coot	7,000	Feb 1987
Grey Teal	6,000	Feb 1986
Hoary-headed Grebe	1,500	Nov 1982
Pacific Black Duck	4,500	Dec 1985
Red-capped Plover	1,000	Feb 1986
Red-necked Avocet	2,000	Mar 1983
Red-necked Stint	2,500	Mar 1983
Sharp-tailed Sandpiper	1,000	Jan 1986

The highest number of waterbirds counted at Forrestdale Lake was 22,196 in January 1986 and at least 10,000 have been recorded in several years (Figure 3.28). Species occurring in significant numbers at Forrestdale Lake include:

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

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

It appears that these two counts alone were used as justification to support Criterion 5. Single counts are used at some Ramsar sites where little information is known, to establish the importance of the site for a species, particularly if the areas are remote or there are other constraints in undertaking regular waterbird surveys. However, in this case, there are a sufficient number of waterbird surveys to apply the current Ramsar definition of "regularly" under this Criterion (see definition in 2.4.3). The existing waterbird data for the site does not support the current Ramsar definition of "regularly" and it is therefore now not considered that the site meets Criterion 5.

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

Forrestdale and Thomsons Lakes have supported more than 1% of the population of 4 waterbirds in several years: Australasian Shoveler, Black-winged Stilt, Blue-billed Duck, and Red-capped Plover (Table 3.4). However, for listing under Criterion 6, the wetland must "regularly" support 1% of the population. Since Forrestdale and Thomsons Lakes have not supported 1% of the population of these waterbirds in recent times (from 4 to 18 years) the Ramsar site does not meet the requirements for listing under Criterion 6.

Table 3.4: Years in which species with 1% of the individuals in a population were supported by Forrestdale and Thomsons Lakes, using estimates provided in the 4th edition of the Waterbird Population Estimates (Wetlands International 2006). TL = Thomsons Lake; FL = Forrestdale Lake.

	Australasian Shoveler		Blue-billed Duck		Black-winged Stilt		Red-capped Plover	
1% count	120		50		3000		950	
	TL	FL	TL	FL	TL	FL	TL	FL
1981								
1982	X	X	X	X				X
1983	X	X	X					X
1984	X	X	X					
1985	X	X	X			X		
1986	X		X	X	X	X	X	
1987	X	X	X			X		X
1988		X	X			X		X
1989	X	X	X	X				
1990	X		X					
1991	X							
1992	X	X	X					
1993								
1994								
1995								
1996	X			X				
1997	X	X						
1998								
1999								
2000				X				
2001								X
2002								
2003	X							
2004						X		
2005								
2006								
No. years	13	9	10	4	1	4	1	4

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

vulnerable species in the IUCN Red List of Threatened Species. However, this species has not been recorded at Thomsons Lake since 1991.

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

Variability

Large, open wetlands on the Jandakot Mound support maximum numbers of waterbirds when water levels are low, declining in early summer. Waterbird numbers are especially high on Forrestdale and Thomsons Lakes when they are extremely shallow and appear to be important for foraging by ducks and waders. These wetlands are usually dry by late summer (Bamford and Bancroft 2007). Waterbird numbers on wetlands of the Swan Coastal Plain are determined both by local conditions, such as rainfall, and by the availability of wetlands elsewhere in the state.

The maximum number of waterbirds appears to have declined at Forrestdale and Thomsons Lakes since the mid 1980s (Figure 3.27 and Figure 3.28) and the number of species recorded at each lake has been variable (Figure 3.30 and Figure 3.31). However there has been no systematic survey and reporting of abundance, species composition or breeding. The number of surveys conducted each year has varied dramatically, and appears to affect the maximum number of birds and species recorded (Figure 3.29 and Figure 3.32). The data used in this ECD (Table 3.3) are conservative and additional species including the Sharp-tail Sandpiper, Curlew Sandpiper, Sanderling, Red-necked Stint and Grey Plover, have been recorded at the lake recently (Pickering, pers. comm.).

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

In their study of wetlands on the Jandakot Mound, Bamford and Bancroft (2007) found that local conditions were particularly important for diving waterbirds that do not use inland wetlands and migratory waders (shorebirds). Blue-billed and Musk Ducks have

declined in abundance on the Jandakot Wetlands, probably because successive years of low water levels have led to poor breeding success (Bamford and Bancroft 2007). As these waterbirds require deep permanent water (Frith 1957; Braithwaite and Frith 1968), their reduced abundance is expected to some degree during annual drying phases that do not favour these, or other, diving species. The Eurasian Coot, a primarily herbivorous species that forages on submerged aquatic plants, has also decreased in abundance in recent years, which suggests that such vegetation has decreased in abundance (Bamford and Bancroft 2007). Seasonal drying generally favours wading birds that require shallow water or exposed mudflats, however these species have also dramatically declined in abundance (Bamford and Bancroft 2007).

The decline in the number of migratory waterbird individuals (Figure 3.33 and Figure 3.34) and number of species (Figure 3.36 and Figure 3.37) recorded at Forrestdale and Thomsons Lakes is also evident when all available data (Table 3.3) are pooled. The decline in the abundance of migratory waterbirds is particularly noticeable, despite similar numbers of observations having been conducted in some years. For example, many more migratory waders were recorded at Forrestdale Lake in 1991 and 1997 than any year since 1998, despite a similar or greater number of surveys having been conducted each year (Figure 3.34). Although the number of surveys conducted each year has varied, increased sampling effort does not appear to have as strong an effect on the number of birds or species recorded (Figure 3.35 and Figure 3.38). Bamford and Bancroft (2007) attributed the ‘virtual disappearance’ of migratory waders to loss of habitat due to the encroachment of riparian vegetation across the lake floor, which has covered the open muddy shallows utilised by migratory shorebirds.

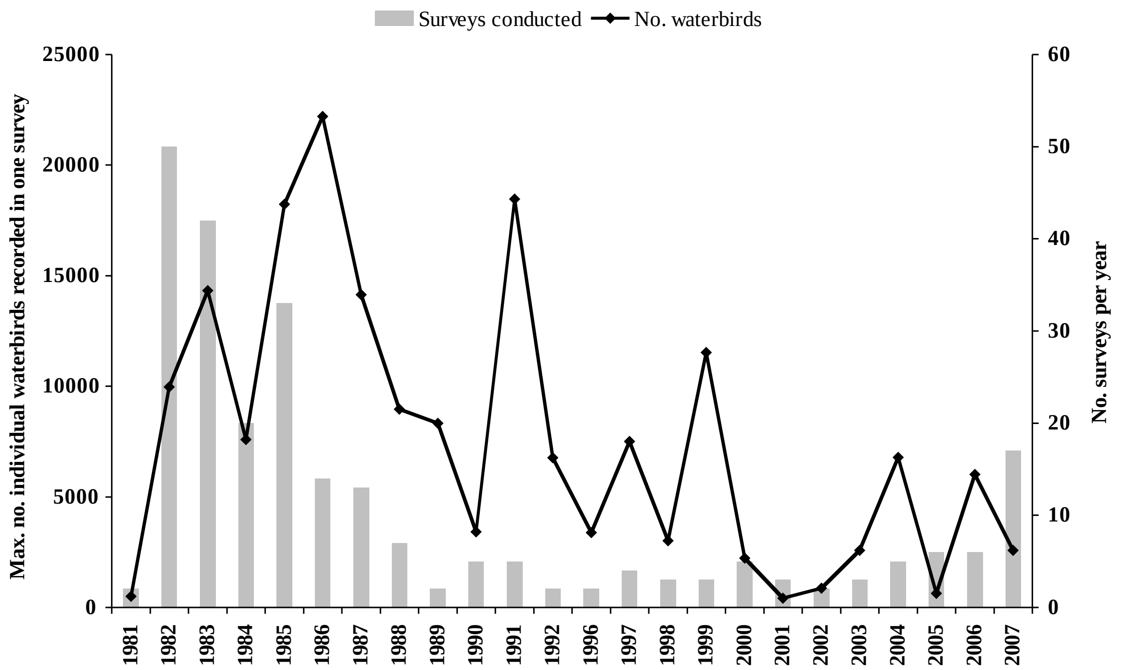

Figure 3.27: Maximum number of waterbird individuals (native species only) recorded in an individual survey from 1981 to 2007 at Thomsons Lake, and the number of surveys conducted each year.

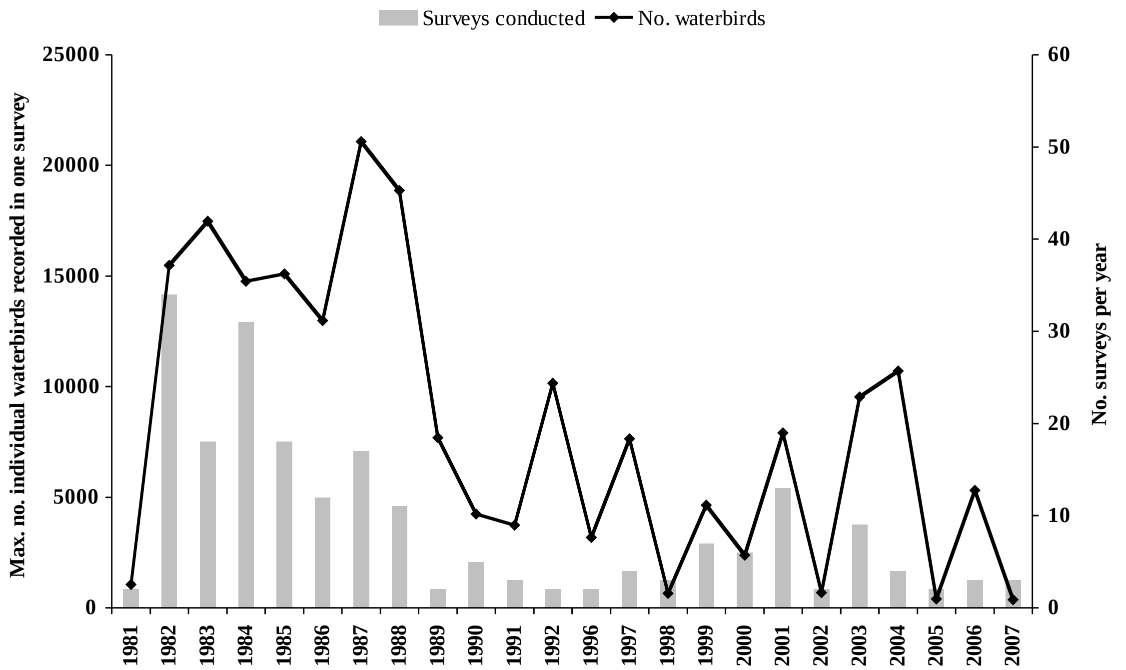

Figure 3.28: Maximum number of waterbird individuals (native species only) recorded in an individual survey from 1981 to 2007 at Forrestdale Lake, and the number of surveys conducted each year.

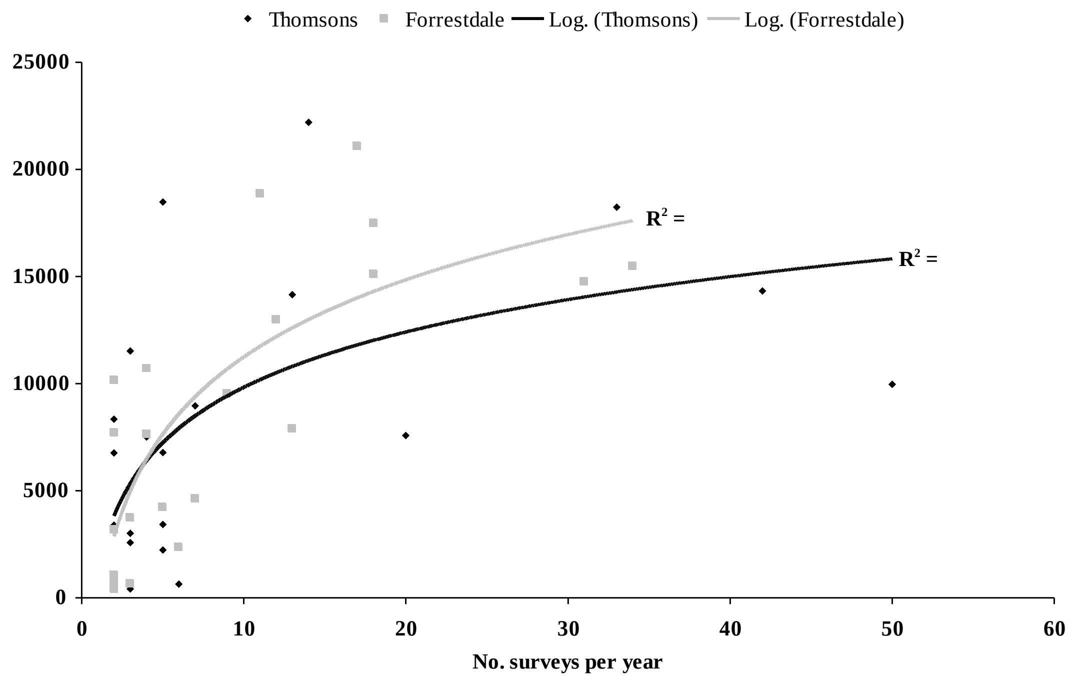

Figure 3.29: Scatter plot and log relationship curve between the maximum number of waterbird individuals recorded in each year and the number of surveys conducted per year from 1981 to 2007 at Forrestdale and Thomsons Lakes.

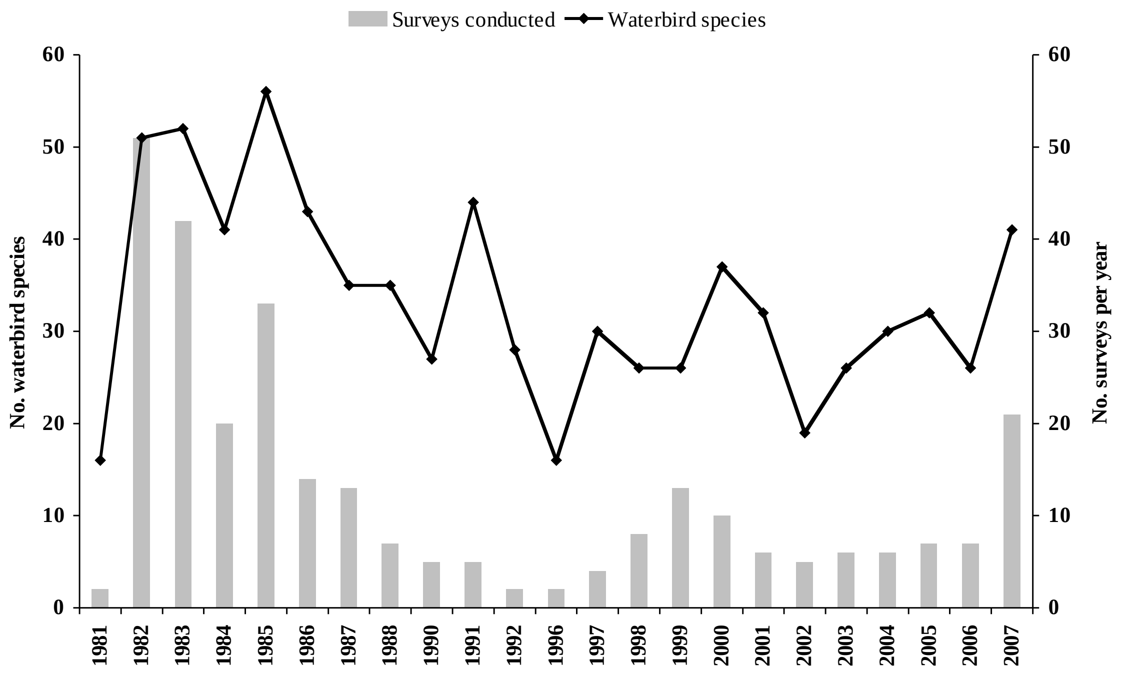

Figure 3.30: Total number of waterbird species (native species only) recorded each year at Thomsons Lake, from 1981 to 2007, and the number of surveys conducted each year.

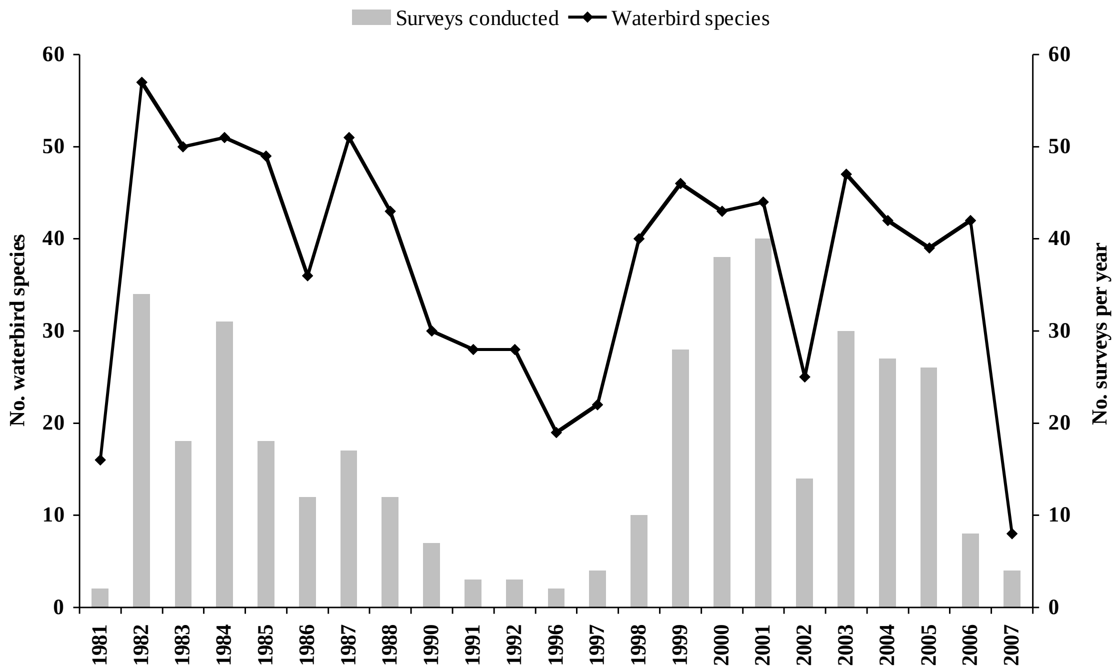

Figure 3.31: Total number of waterbird species (native species only) recorded each year at Forrestdale Lake, from 1981 to 2007, and the number of surveys conducted each year.

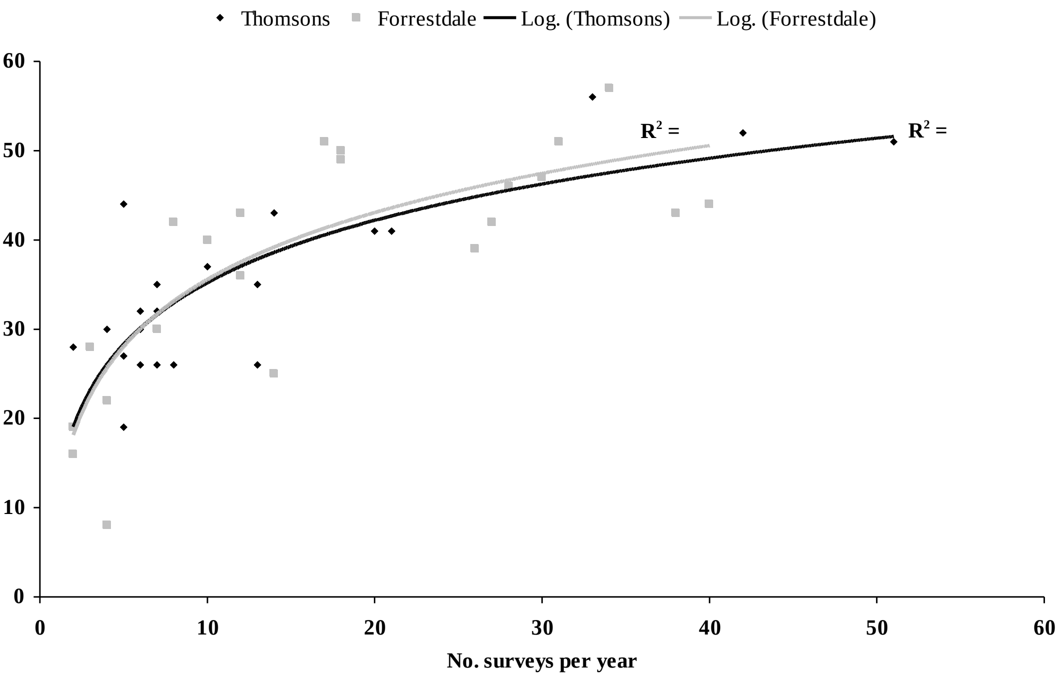

Figure 3.32: Scatter plot and log relationship curve between the maximum number of waterbird species recorded in each year and the number of surveys conducted per year from 1981 to 2007 at Forrestdale and Thomsons Lakes.

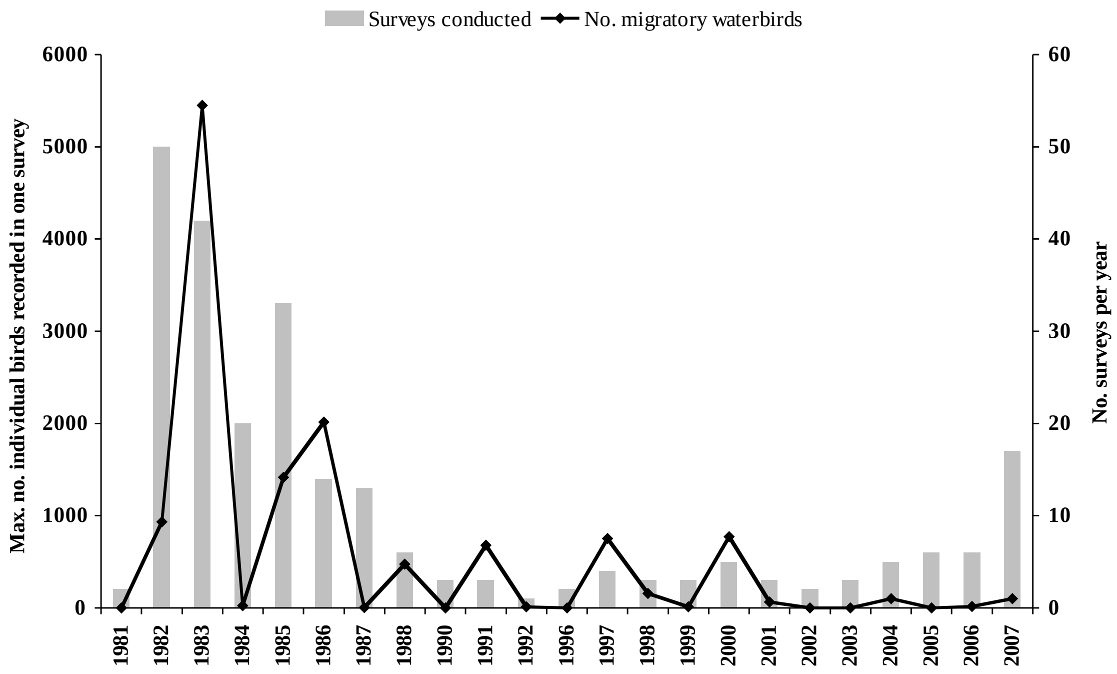

Figure 3.33: Maximum number of migratory wader individuals recorded in an individual survey from 1981 to 2007 at Thomsons Lake, and the number of surveys conducted each year.

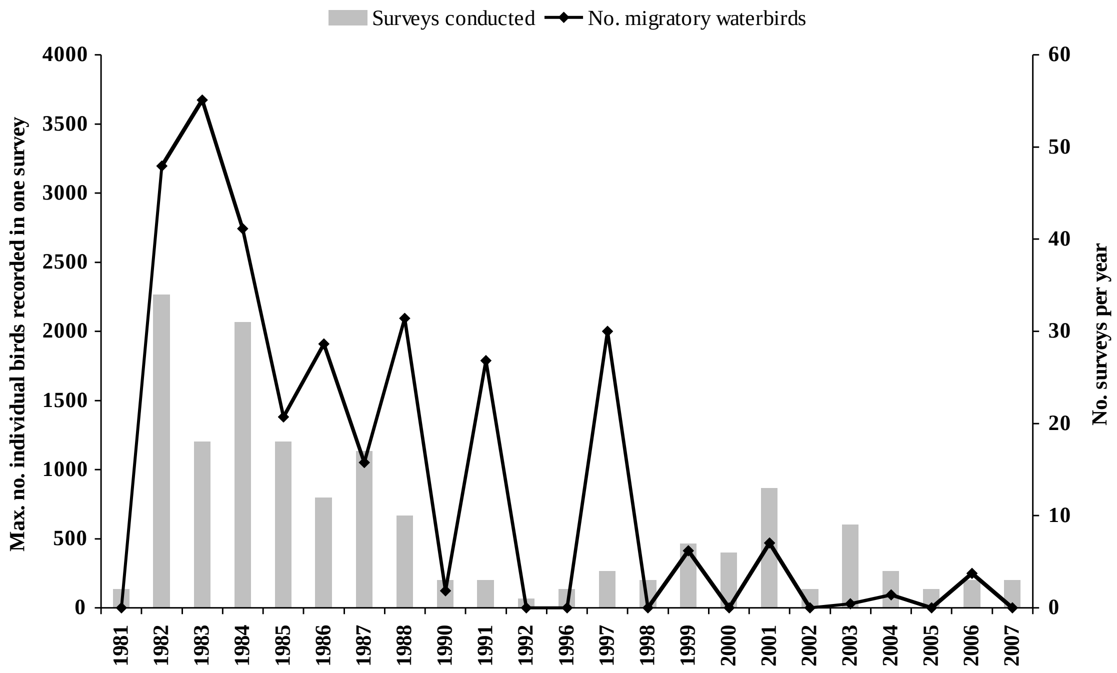

Figure 3.34: Maximum number of migratory wader individuals recorded in an individual survey from 1981 to 2007 at Forrestdale Lake, and the number of surveys conducted each year.

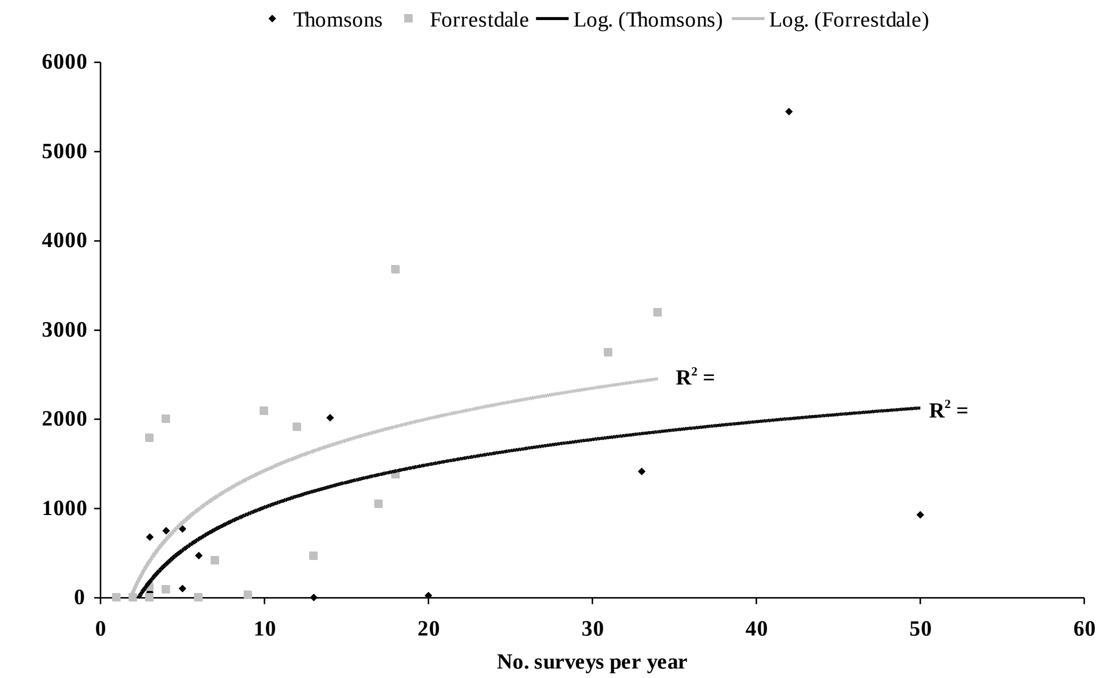

Figure 3.35: Scatter plot and log relationship curve between the maximum number of migratory wader individuals recorded in each year and the number of surveys conducted per year from 1981 to 2007 at Forrestdale and Thomsons Lakes.

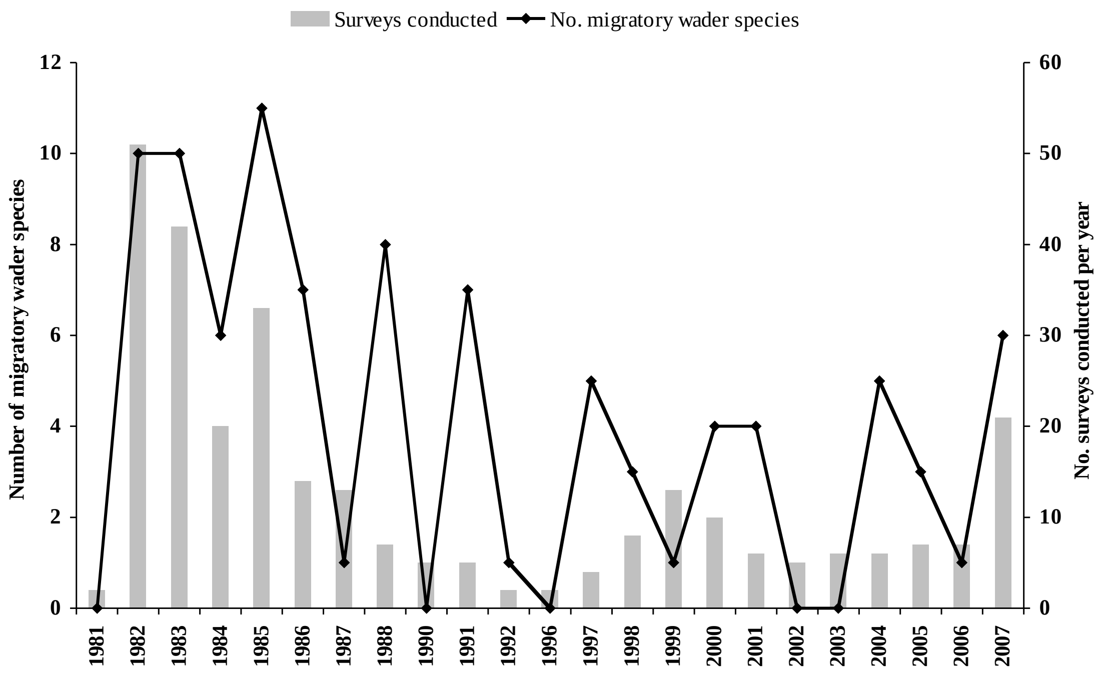

Figure 3.36: Total number of migratory wader species recorded each year at Thomsons Lake, from 1981 to 2007, and the number of surveys conducted each year.

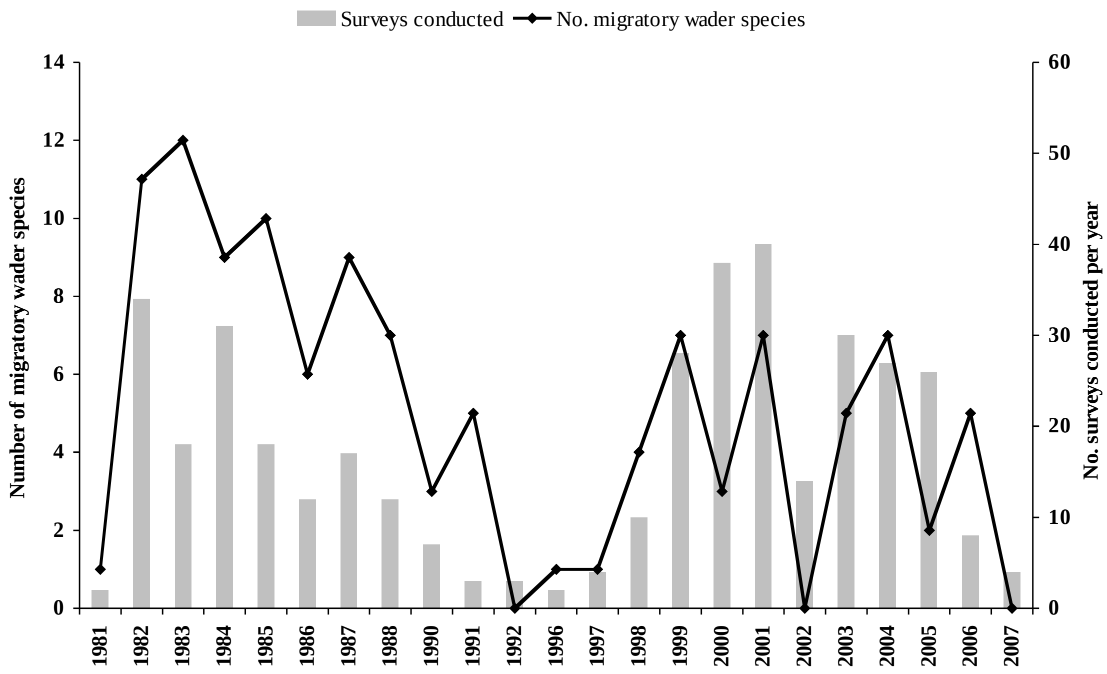

Figure 3.37: Total number of migratory wader species recorded each year at Forrestdale Lake, from 1981 to 2007, and the number of surveys conducted each year.

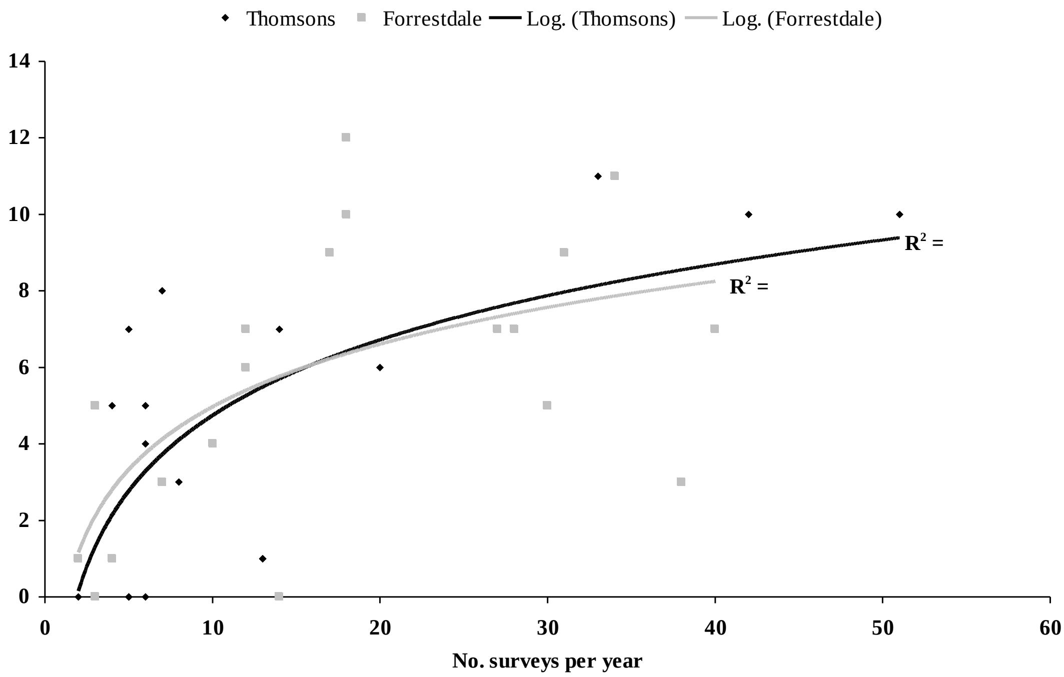

Figure 3.38: Scatter plot and log relationship curve between the maximum number of migratory wader species recorded in each year and the number of surveys conducted per year from 1981 to 2007 at Forrestdale and Thomsons Lakes.

Breeding

Twenty-seven waterbird species have been recorded breeding at Forrestdale and Thomsons Lakes, including 15 species at Thomsons Lake, and 24 at Forrestdale Lake (Table 3.5).

Table 3.5: Breeding records at Thomsons Lake (TL) and Forrestdale Lake (FL) in 5-year periods from 1981 to 2007. Breeding records usually consisted of nests with eggs or adult birds with dependent young.

Waterbird species	1981–1985		1988–1992		1996–2000		2001–2007	
	TL	FL	TL	FL	TL	FL	TL	FL
Australasian Grebe		X				X		X
Australasian Shoveler		X				X		X
Australian Little Bittern		X		X				
Australian Shelduck		X			X	X	X	X
Australian White Ibis						X		
Australian Wood Duck				X		X		X
Baillon's Crake	X							
Banded Lapwing						X		X
Black Swan	X	X	X	X	X	X	X	X
Black-winged Stilt								X
Blue-billed Duck	X	X	X	X				X
Australian Reed-Warbler	X	X		X				
Dusky Moorhen		X						X
Eurasian Coot		X	X	X		X		X
Grey Teal		X	X	X	X	X		X
Hardhead	X	X		X		X		X
Hoary-headed Grebe						X		X
Little Grassbird	X							
Little Pied Cormorant						X		
Musk Duck		X	X	X		X		X
Pacific Black Duck	X	X		X	X	X	X	X
Pink-eared Duck		X		X				X
Purple Swamphen	X	X	X	X		X	X	X
Red-capped Plover	X	X		X	X	X		X
Spotless Crake	X	X						
Swamp Harrier	X							
White-faced Heron		X				X		X
Total no. species	11	18	6	13	5	17	4	19

Breeding typically occurs when water levels are high in late winter/early spring and a high winter/spring peak water level appears to be required to trigger breeding or allow breeding to be successful. Bamford and Bancroft (2007) found that breeding of most waterbirds has been relatively poor across the wetlands on the Jandakot Mound since 1997, and especially poor in 2006 when water levels were at their lowest. Such poor breeding was partly due to local factors, such as low peak water levels and short periods of inundation. For example, the Eurasian Coot has made extensive use of small wetlands to breed, but few breeding records have been made in recent years. It nests in the forks of flooded trees, and trees in small wetlands have rarely been surrounded by water since the early 2000s.

Thomsons Lake was one of few known breeding localities for Baillon's Crake, *Porzana pusilla*, and the only remaining wetland within the Perth metropolitan area where

Swamp Harrier *Circus approximans* was known to breed; however, these species have not been recorded breeding at this lake since the mid-1980s.

As noted previously, differences in the number of surveys conducted each year and monitoring methods will have had an impact on some bird records, including breeding counts. More frequent surveys were conducted during the 1980s, which may contribute to breeding records for some species being higher during this period of time. Monitoring methods between the major surveys i.e. Jaensch *et al.* 1988 and Bamford and Bancroft 2007 may also contribute to differences in the breeding records; however both involved systematic searching i.e. actively looking for nests, not just opportunistic sightings.

3.5 Vegetation

Phytoplankton

Relatively little is known about the phytoplankton communities of Forrestdale and Thomsons Lakes. Davis *et al.* (1993) identified phytoplankton at 41 wetlands on the Swan Coastal Plain in 1989–1990, the most common genera being the cyanobacteria *Anabaena* and *Microcystis*. Excessive growth of phytoplankton and cyclic algal blooms are usually indicative of severe eutrophication in wetlands. The abundance of phytoplankton in Forrestdale and Thomsons Lakes may be an important indicator of the ecological state of the wetlands (see Section 3.6).

Aquatic plants

Extensive stands of the submerged macrophyte *Myriophyllum salusigenium* have been recorded in open water at Thomsons Lake (Halse *et al.* 1993). The floating macrophyte *Lemna* has also been recorded in this lake (Balla 1992). The submerged macrophytes *Ruppia polycarpa* and *Potamogeton pectinatus* sometimes form dense stands at Forrestdale Lake and 26 species of algae, notably *Chara*, have also been recorded (Bartle *et al.* 1987). However, the extent of aquatic plant communities of Forrestdale and Thomsons Lakes has not been mapped, and has not been monitored regularly. Like phytoplankton, the abundance of aquatic plants may also be an important indicator of the ecological state of the wetlands (see Section 3.6).

Littoral vegetation

The vegetation of Forrestdale and Thomsons Lakes has been mapped using aerial photographs, with limited ground checking (Figure 3.3 and Figure 3.4; Arnold 1990). *Typha orientalis* and *Baumea articulata* grow around the edge of Thomsons Lake. As water levels drop, *Bolboschoenus caldwellii* becomes established on the newly exposed mudflats inside the fringing zone. In 2008, the small perennial herb *Suaeda australis* was abundant across much of the dry lake bed at both Forrestdale and Thomsons Lakes. This plant is more commonly found at coastal sites, saline swamps and creeks. Behind the fringing zone is a belt of *Baumea juncea* and *B. articulata* with emergent *Viminaria juncea* and *Acacia saligna* shrubs. This gives way to a belt of trees, *Eucalyptus rudis* and *Melaleuca preissiana*, and the shrub *Jacksonia furcellata*. As the ground rises these are replaced by open forest or woodland dominated by *Eucalyptus marginata*, *Banksia menziesii* and *B. attenuata*.

Keighery (2002a) surveyed the vascular flora of Thomsons Lake and identified 491 taxa, including 360 native and 131 introduced species (Appendix D: Flora). Previous

flora surveys at Thomsons Lake Nature Reserve identified one Priority taxa *Dodonaea hackettiana* (State of Western Australia 2000). Keighery (2002a) further identified one 'Declared Rare Flora' species listed under the *Wildlife Conservation Act 1950*, *Caladenia huegelii*, and two Priority taxa, *Cardamine paucijuga* and *Eryngium pinnatifidum* subsp. *palustre* ms.

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

Keighery (2002b) surveyed the vascular flora of Forrestdale Lake Nature Reserve and identified 351 taxa, including 252 native and 99 introduced species (Appendix D: Flora). Previous flora surveys at Forrestdale Lake Nature Reserve identified two 'Declared Rare Flora' species listed under the *Wildlife Conservation Act 1950*: *Diuris purdiei* and *Drakaea elastica*; and seven Priority taxa: *Acacia lasiocarpa* var. *bracteolata*, *Eryngium pinnatifidum* subsp. *palustre* ms, *Stylidium mimeticum*, *Villarsia submersa*, *Drosera occidentalis*, *Verticordia lindleyi* subsp. *lindleyi*, *Anthotium junciforme* (State of Western Australia 2000). Keighery (2002b) identified a further two priority species *Schoenus benthamii* and *Jacksonia sericea* (*Jacksonia gracilis*).

There are two Threatened Ecological Communities at Forrestdale Lake Nature Reserve (State of Western Australia 2000): (1) 'herb-rich shrublands in clay pans' are listed as vulnerable in Western Australia and consist of clay pan communities that can be dominated by *Viminaria juncea*, *Melaleuca viminea*, *M. lateritia* or *M. uncinata* but occasionally by *Eucalyptus wandoo* and aquatic annuals are also common (Gibson *et al.* 1994) and; (2) 'shrublands on dry clay flats' are listed as endangered in Western Australia and form on the most rapidly drying of the clay flats. They contain aquatic annuals and geophytes such as *Schoenus natans*, *Crassula natans* and *Amphibromus neesii* (Gibson *et al.* 1994).

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

3.6 Wetland processes and ecological regime

Specific or critical processes may be identified by considering the ecological state or regime of the wetland (Davis and Brock 2008). The existence of two 'alternative states' occurring in eutrophic, shallow lakes where the components are the abundance of submerged macrophytes and phytoplankton, and the driver is nutrient loading (facilitated by changes in the light regime) was recognized by Moss (1990) and Scheffer (1990). This model was developed in Europe by researchers studying permanent, eutrophic shallow ecosystems (Moss 1990, Scheffer 1990).

The historic ecological regime in most of these wetlands is considered to be one of clear-water and submerged macrophyte-dominance. This parallels the situation in the Northern Hemisphere shallow lakes and supports, to some extent, Scheffer's (1998) assertion that '*the pristine state of the majority of shallow lakes is probably one of clear water and a rich aquatic vegetation*'.

The following five 'states' or ecological regimes have been recognized by Davis *et al.* (2003), Strehlow *et al.* (2005), and Sim *et al.* (2008) for southern Australian wetlands:

- I Clear, submerged macrophyte-dominated;
- II Clear, benthic microbial community-dominated;
- III Turbid, sediment-dominated;
- IV Turbid, phytoplankton-dominated; and
- V Free-floating plant dominated.

Regime I is defined as clear water with aquatic plants (submerged, floating and emergent species). Regimes I, II, and III all represent regimes found in undisturbed wetlands and may often be the baseline state. The first regime represents undisturbed wetlands of fresh or low salinities and low to moderate enrichment. The second regime represents naturally hypersaline or acidic lakes. The third occurs naturally in shallow waterbodies with clay substrates, for example, claypans, or under the low water levels associated with naturally occurring drying or wetting phases in seasonal wetlands. It is usually produced by wind driven re-suspension of bed sediments. The fourth and fifth regimes occur at high phosphorus levels, often >150 μg/L, and usually represent a shift from Regime I driven by eutrophication. The submerged macrophyte-dominated regime demonstrates some resilience to increased nutrient loading before reaching a threshold. Secondary salinisation or acidification can drive a shift from Regime I to II. Drawdown of water levels as a result of surface water or groundwater abstraction can result in a shift from Regime I to III.

Scheffer and van Nes (2007) recently extended the initial concept of two contrasting ecological regimes in shallow lakes affected by eutrophication, noting that nutrient enriched shallow lakes may be dominated by free-floating plants, submerged charophytes, submerged angiosperms, green algae or filamentous cyanobacteria at different points along a gradient of eutrophication. This 'gradient' and similarly, the 'phases' outlined in Moss (1990) suggest that gradual species replacements may occur across levels of a controlling variable that are interrupted at critical points by more dramatic shifts between ecological regimes, as exemplified by the clear water/turbid water contrast.

Forrestdale and Thomsons Lakes both usually exist in the state described by Regime I, which is largely driven by the annual drying process that the lakes currently experience. However, both lakes have occasionally transitioned to Regime IV as a result of eutrophication. If these wetlands were to become more permanent and did not dry completely on an annual basis, it is likely they would be driven towards Regime IV.

3.7 Ecosystem benefits and services

For the purposes of the Ramsar Convention, benefits and services are defined in accordance with the Millennium Ecosystem Assessment definition of ecosystem services as 'the benefits that people receive from ecosystems' (Ramsar Convention 2005a, Resolution IX.1 Annex A).
The Millennium Ecosystem Assessment (2005a and b) identifies four main categories of ecosystem benefits and services:

1. **Provisioning services** — the products obtained from the ecosystem such as food, fuel and fresh water
2. **Regulating services** — the benefits obtained from the regulation of ecosystem processes such as climate regulation, water regulation and natural hazard regulation
3. **Cultural services** — the benefits people obtain through spiritual enrichment, recreation, education and aesthetics
4. **Supporting services** — the services necessary for the production of all other ecosystem services such as water cycling, nutrient cycling and habitat for biota. These services will generally have an indirect benefit to humans or a direct benefit over a long period of time.

The key ecosystem benefits and services of the Forrestdale and Thomsons Lakes Ramsar site are outlined in Table 3.6 and a description of the cultural services is provided below. Ecological components and processes are described in depth in Sections 3.1–3.6.

3.7.1 Indigenous heritage

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

According to Noongar tradition, wetlands, waterways and lakes are said to be the home of the powerful water serpent figure, the Waugal. The Waugal is spiritually and mythologically important to Aboriginal people who believe that it created rivers and

lakes, and maintains the flow of waters that feed its resting places. According to Noongar beliefs, these places are described as winnatch, (an area that is avoided, usually for reasons of cultural or religious significance) and consequently require the highest respect and reverence in the way they are considered, used and valued.

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

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

Table 3.6: Wetland ecosystem benefits and services of the Forrestdale and Thomsons Lakes Ramsar site

Category	Description
Cultural Services: *Human uses and benefits obtained through spiritual and inspirational enrichment, recreation, education, and aesthetic experiences.*	
Recreation	Birdwatching, walking and horse riding.
Science and education	Educational activities and opportunities Scientific research site and long-term monitoring site for Murdoch University.
Aesthetic amenity	Provision of attractive natural landscapes. Representative example of a near-natural wetland, characteristic of those that were once widespread throughout the bioregion.
Cultural heritage	Indigenous and non-indigenous cultural heritage values.
Spiritual and inspirational	The sites have inspirational, spiritual and existence values that people can view, enjoy, or otherwise appreciate.
Supporting Services: *Wetland ecosystem services necessary for the production of all other ecosystem services, and include soil formation and nutrient cycling. These services often provide indirect human benefits by supporting other environmental services or benefits.*	
Hydrological processes	The wetland supports the seasonal expression of water, which is critical to the ecological values of the wetland.
Food webs	The wetland supports a network of flora and fauna that depend on each other for food e.g. aquatic and fringing plant communities provide food for invertebrates that, in turn, provide food for waterbirds and turtles.
Physical habitat	Supports biotic and abiotic features that are essential for the function of wetland ecosystems, including mudflats for migratory waders to feed, and riparian vegetation for habitat for aquatic macroinvertebrates and nesting birds.
Nutrient cycling	Supports primary production, and carbon, nitrogen and phosphorus cycles that are essential to the function of the wetland ecosystems.
Biodiversity	Supports a variety of wetland species, communities and habitats. Regularly supports 5,000 or more waterbirds.
Priority wetland species and ecosystems	Supports waterbird species listed under *JAMBA*, *CAMBA*, *ROKAMBA* and *Bonn Convention*.

Natural or near-natural wetland ecosystems	Representative example of natural or near-natural brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain.

3.7.2 Non-indigenous heritage

Thomsons Lake

In the late 1800s, during the goldrushes, market gardens were established on the land surrounding many of the wetlands of the Swan Coastal Plain. At Thomsons Lake, a proposed grazing lease was rejected in 1954 based on the area's value as habitat for native fauna, and in 1955 the reserve's purpose was changed from 'Drainage' to 'Drainage and Conservation of Fauna'. During this time, and into the 1960s, the as yet unvested reserve was being used by adjoining landholders for cattle grazing and the vegetation was being cut for firewood, with both practices having an impact on the reserve's vegetation (Crook and Evans 1981).

Land was excised from the reserve in 1962 for a prison site and again in 1969 for the University of Western Australia's Marsupial Breeding Station. The development of land around the reserve mainly occurred during the 1960s, and by 1968, most of the private land to the east and southwest had been subdivided (Crook and Evans 1981). The managing agency at the time, the Department of Fisheries and Fauna, sought vesting of the reserve. This was agreed to on the proviso that the lake could still be used as required for drainage purposes: consequently the reserve was vested in the then WA Wildlife Authority for its current purpose of 'Fauna Conservation and Research and Drainage' (Crook and Evans 1981). At the time the reserve was transferred to the Wildlife Authority, the lake was used for water skiing. Since then, the nature reserve has become increasingly popular with the local community as a place for nature appreciation, in particular birdwatching and bushwalking.

Forrestdale Lake

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

From the 1920s, intensive agriculture gave way to sheep and cattle grazing, which continued over the next 50 years. During the 1940s, the west side of Forrestdale Lake was heavily grazed by sheep and cattle, particularly during the drier summers when land owners used the fringing vegetation to supplement feed from their paddocks. In 1957 interest developed in creating a Class A reserve around and including Forrestdale Lake, with the intention that the reserve be used for recreation, particularly sailing. Thus the reserve was gazetted for the 'Protection of Flora and Fauna and Recreation' (Bartle *et*

al. 1987). Boating in hand-made canoes and catamarans was an important recreation activity at the lake. A Sailing Club was opened in the late 1950s to early 1960s when the lake rarely dried completely and regattas were held regularly (Giblett 2006). However, sailing could not continue as water levels declined and the lake dried more frequently. Recreation was removed from the purpose of the reserve in 1998, when it was changed to ‘Conservation of Flora and Fauna’.

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

3.7.3 Aesthetic, recreation, science and education values

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

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

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

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

4. Conceptual models

4.1 Annual deep-water and shallow-water phases

Davis and Brock (2008) developed a conceptual ecological model for Thomsons Lake, which is reproduced in Figure 4.1. The model is drawn as a two-dimensional cross-section and displays two temporal modes: a deep-water phase (present in winter and spring) and a shallow-water phase (present in summer and autumn). These phases conceptualise the intra-annual variation recorded at the wetland. Inter-annual variation also occurs, with the maximum water depth and the aerial extent to which the lake dries varying from year to year, depending on the combined effects of annual precipitation, height of the watertable and annual evaporation. However, additional models to describe inter-annual variation were not included as these are within the range encompassed by the deep-water and shallow-water phases illustrated.

Geomorphology and substrate type were used as the base layer in the model because these two factors exert considerable control over many wetland processes (following the model of Ryan *et al.* 2003 for estuaries) (Davis and Brock 2008). Due to the similarity of these factors (and others) at both Forrestdale and Thomsons Lakes, the conceptual model is also applicable to Forrestdale Lake. More detailed descriptions of the key physical, chemical and biological features, ecosystem processes and benefits/services are given in Section 3.

Davis and Brock (2008) compiled a unique set of identifiers for Thomsons Lake, which are also applicable to Forrestdale Lake, and include:

- Seasonal hydrological regime
- Inter-annual variability resulting in wet and dry cycles depending on annual rainfall and evaporation rates
- Shallow (<3 m)
- Fresh to brackish
- Alkaline
- Mesotrophic to eutrophic
- Weakly coloured
- Zoniform distribution of fringing vegetation
- Provision of habitat for aquatic biota, especially waterbirds
- Clear water, aquatic plant-dominated ecological regime

The loss of, or change to, any one of these identifiers flags the likely occurrence of unacceptable ecological change. Some changes will clearly be negative, for example, the change from a seasonal to permanent water regime, or from shallow to deep water, will result in the reduction or complete loss of shallow-water habitat for migratory waders. Major changes in water chemistry, for example, from fresh to saline or hypersaline conditions, from alkaline to acidic conditions or from mesotrophic to hypertrophic conditions, are also likely to lead to major changes in the floral and faunal assemblages currently present at the lake. The consequences of changes in the other identifiers listed may not be as predictable (without further investigation) as the preceding examples, but are still likely to serve as an early warning of potential negative impacts.

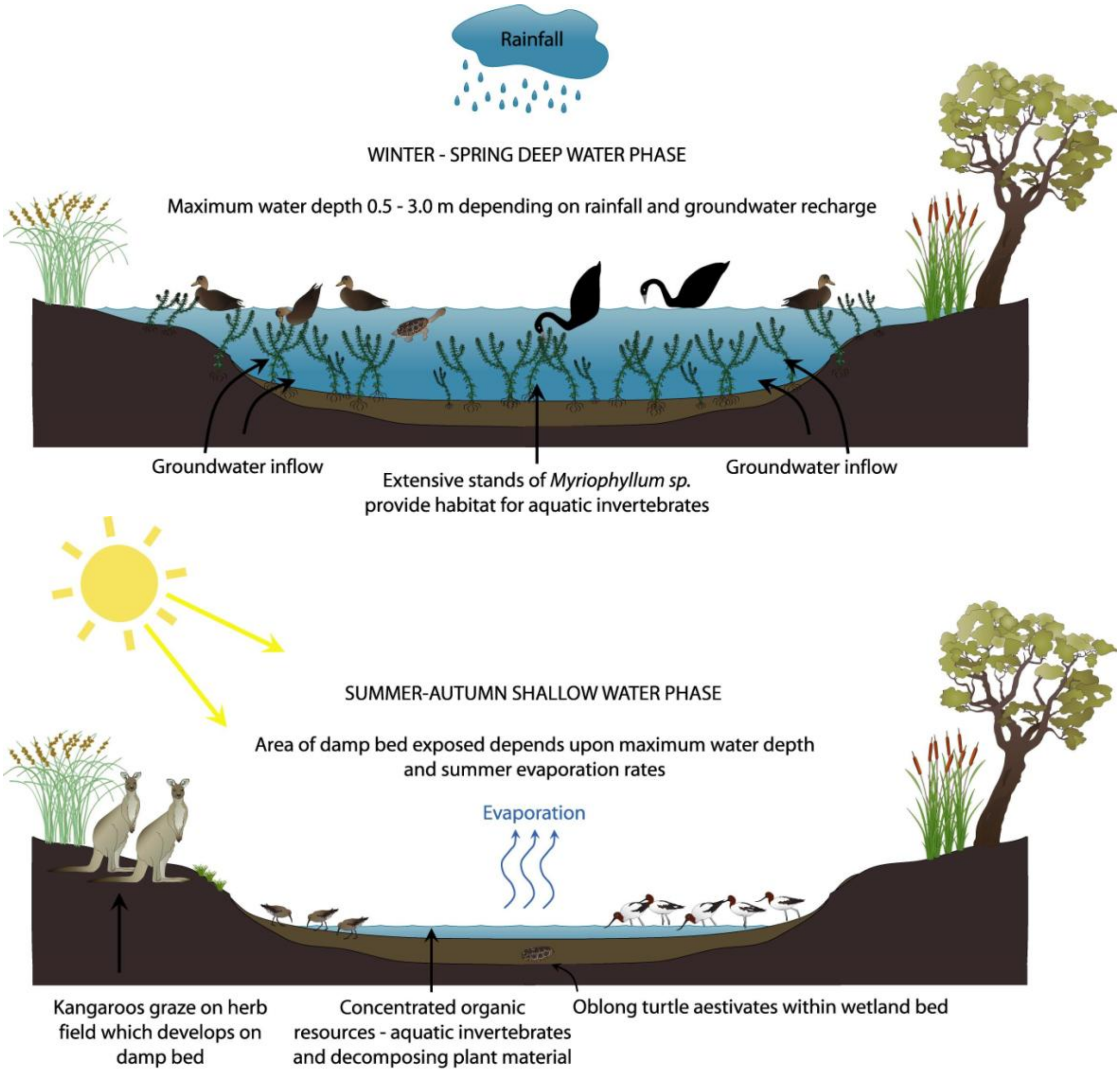

Figure 4.1: **Conceptual ecological models of Thomsons Lake showing deep-water and shallow-water phases.**

The two temporal modes: a deep-water phase (present in winter and spring) and a shallow-water phase (present in summer and autumn) illustrated in Figure 4.1 indicate the importance of a seasonal water regime in supporting the ecosystem components and processes at Forrestdale and Thomsons Lakes. Seasonal drying results in the concentration of organic resources which provide an important food source for waterbirds. Lower water levels in late spring and summer provide large expanses of shallow water habitat, which together with the concentrated organic resources particularly invertebrates, can be utilised by wading birds. Further drying during late summer and autumn results in a loss of aquatic habitats but provides extensive herb fields which are important feeding areas for grazing kangaroos. Waterbirds will move from the dry wetland to nearby estuarine mudflats (the Swan and Canning River estuaries) while the oblong turtle will avoid the dry phase by aestivating within the lake sediments.

The deep-water (winter and spring) phase provides suitable habitat for waterbirds such as diving ducks which require deeper water. The growth of extensive stands of

submerged macrophytes provides food for herbivores such as Black Swans. Submerged macrophytes also provide suitable habitats for macroinvertebrates, which, in turn, provide an abundant food source for ducks and turtles.

Although not illustrated here, it must also be noted that Forrestdale and Thomsons Lakes are important components of the larger Beeliar-Jandakot wetland system. There is faunal movement between wetlands within this larger system and, ideally, the entire coastal plain wetland system should be managed as an interdependent unit.

4.2 Drivers and effects of ecological change

In addition to conceptual models describing ecosystem components and processes, conceptual models can be also developed to illustrate the threats (and their impacts) to wetland ecosystems. Davis and Brock (2008) conceptualised the possible drivers and effects of ecological change for Thomsons Lake using a stressor/driver model (Figure 4.2), which is also applicable to Forrestdale Lake. Ecological stressors are the changes that occur in the wetland in response to the drivers. In the terminology of the Millennium Ecosystem Assessment (2005b) framework, these represent secondary direct drivers. These include altered hydrological regimes, elevated loadings of nutrients (phosphorus and nitrogen) and contaminants (including herbicides and pesticides) in drainage from surrounding urban areas. The drivers (both primary and secondary) result in a number of ecological effects many of which are linked. The naming of ecological effects can be viewed as the development of working hypotheses which recognize the critical linkages between drivers and components (attributes in the Everglades models). The latter represent the overall ecological state of the system. Typically they are the populations, communities or processes that are most readily identified with the wetland (Ogden *et al.* 2005).

The primary direct drivers are the major external forces that influence wetlands. These were identified at Thomsons Lake as:

- Climate change
- Water supply (mainly the abstraction of ground water for domestic, horticultural and industrial use); and
- Urbanization (and other land-use changes and impacts, including sub-surface drainage).

These direct drivers are illustrated in Figure 4.2. The effects of these drivers, as they apply to Forrestdale and Thomsons Lakes, are changes in water regime, an increase in nutrients and other pollutants, and an increase in the cover and biomass of invasive plants. The ecological effects of these stressors, and their influence on ecosystem components, are also summarised in Figure 4.2.

Recognising the links from drivers, through stressors, to ecological effects and wetland components, provides information in a format that can be very useful for developing management scenarios. This approach is developed further in the following section.

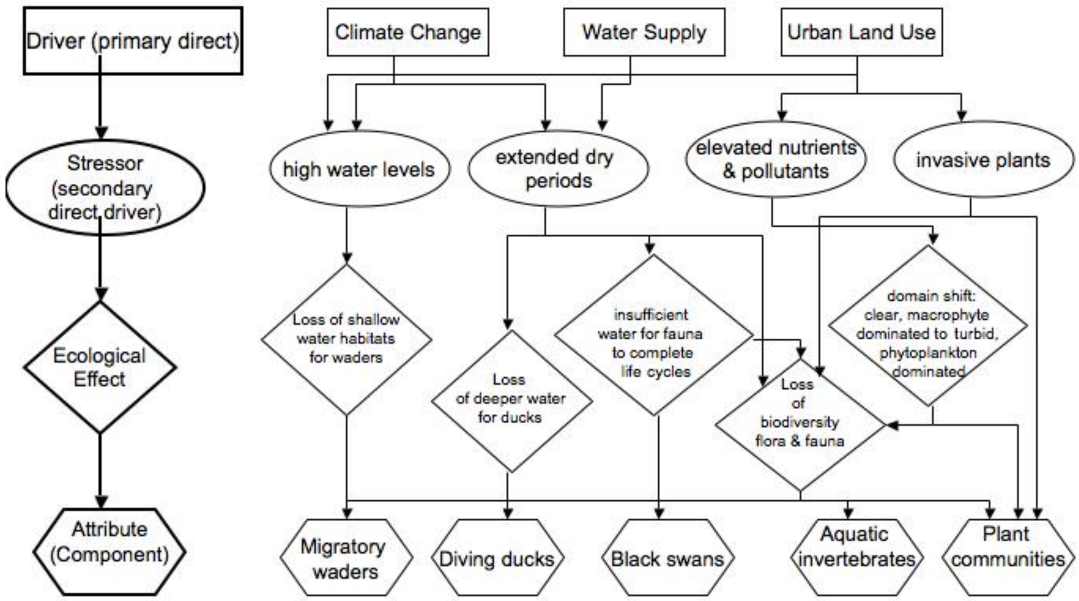

Figure 4.2: **Driver/stressor model for Forrestdale and Thomsons Lakes showing drivers, stressors, ecological effects and attribute (component) – after models developed for the Everglades restoration programme, Florida, USA, by Ogden *et al.* (2005). To avoid confusion, the Ramsar terms (see Ramsar resolution IX.1, Ramsar Convention 2005b) corresponding to the Ogden *et al.* (2005) terms are provided in brackets.**

4.3 Wetland response to altered water regime

Two of the stressors presented in Figure 4.2 – 'high water levels' and 'extended dry periods' – are examples of altered water regimes that may impact the site. Davis *et al.* (2001) developed a conceptual ecological model for Thomsons Lake under different water regimes (Figure 4.3), which is also applicable to Forrestdale Lake. Within the context of threats to the site (see section 6) and changes to the site since listing (see section 7), it is important to examine the potential impacts of changed water regimes. These potential impacts include changes to the composition and structure of the vegetation and thereby to the habitat values of the site. Three scenarios are presented below.

Scenario 1. Decreased water levels, seasonal water regime (Figure 4.3).
An overall decrease in water levels would result in a shift of the fringing vegetation communities down-gradient (Froend *et al.*, 1993). As the wetland has a relatively flat bed and steep sides, and the sedges and *Typha* occur where the land begins to rise out of the basin, reduction of water levels below a certain point could lead to a spread of the sedge and *Typha* vegetation across the bed of the lake. This would be associated with a loss of habitat for the aquatic *Myriophyllum* sp. (which supports a productive invertebrate fauna) and a loss of seasonally exposed mudflats, which are important for migratory wading waterbirds. Species that favour more permanent wetlands, including the threatened Australasian Bittern, would also be affected. Additionally, a reduction in water levels would be associated with recruitment of the wetland trees down-gradient of their present distributions (Froend *et al.*, 1993). If water levels decreased over time, sedges may take over the areas now characterised by open water and mud flats, leading

to a loss of habitat for waders. With a further loss, *Eucalyptus rudis* and *Melaleuca* sp. would take over the bottom of the basin.

Scenario 2. Seasonal or semi-permanent water regime: water levels intermediate between those of scenarios 1 and 3 (Figure 4.3).
Wader habitat will be optimal if water levels are between 0.3 m below the sediment and 0.7 m above) (Scenario 2). Migratory waders, which are protected by international agreements, occur at Forrestdale and Thomsons Lakes when mudflats become exposed in summer/ autumn. This would occur only seasonally in relatively dry years under scenario 2. Higher water levels would result in a reduction of both wader habitat and the extent of sedge beds (Scenario 3); while lower overall water levels may result in an invasion of the entire lake bed by sedges (Scenario 1).

Scenario 3. Deeper water levels, permanent water regime (Figure 4.3).
An increase in water levels could lead to loss of *Myriophyllum* sp. beds and possibly loss of the lower *E. rudis* and *Melaleuca* sp., although these could re-colonise at a higher gradient (Arnold, 1990; Froend *et al.*, 1993). A severe contraction of the sedge and *Typha* habitat could result. The most abundant waterbirds under this scenario are likely to be ducks and piscivorous birds. Waders would be less abundant, as exposed mudflats would cease to occur. The threatened Australasian Bittern, which requires sedge habitat, would also be affected. Diversity and abundance of invertebrates may be reduced by the loss of macrophyte habitat and the establishment of conditions suitable for the introduced predatory fish, *Gambusia holbrooki*. This may, in turn, reduce waterbird abundance although piscivorous birds would be favoured. Deeper water levels may satisfy a possible alternative management objective of providing landscape amenity in the form of year-round open water views. However, if the increase in water level was associated with algal blooms as a result of a shift from a macrophyte-dominated system to a phytoplankton-dominated system, the amenity value would be reduced.

The water regime of Scenario 2 best satisfies the current management objectives. Inter-annual variation in rainfall will mean that Scenarios 1 and 3 occur after successions of very wet or dry years. Forrestdale and Thomsons Lakes have primarily experienced conditions described by Scenario 2, particularly during the 1980s when migratory waders were abundant prior to the lakes being Ramsar listed. More recently, Forrestdale and Thomsons Lakes have been experiencing conditions described under scenario 1, with decreased water levels. This has resulted in the encroachment of riparian vegetation across the lake bed, which has removed the open muddy shallows utilised by migratory shorebirds and replaced it with flooded vegetation and pools (Bamford and Bancroft 2007).

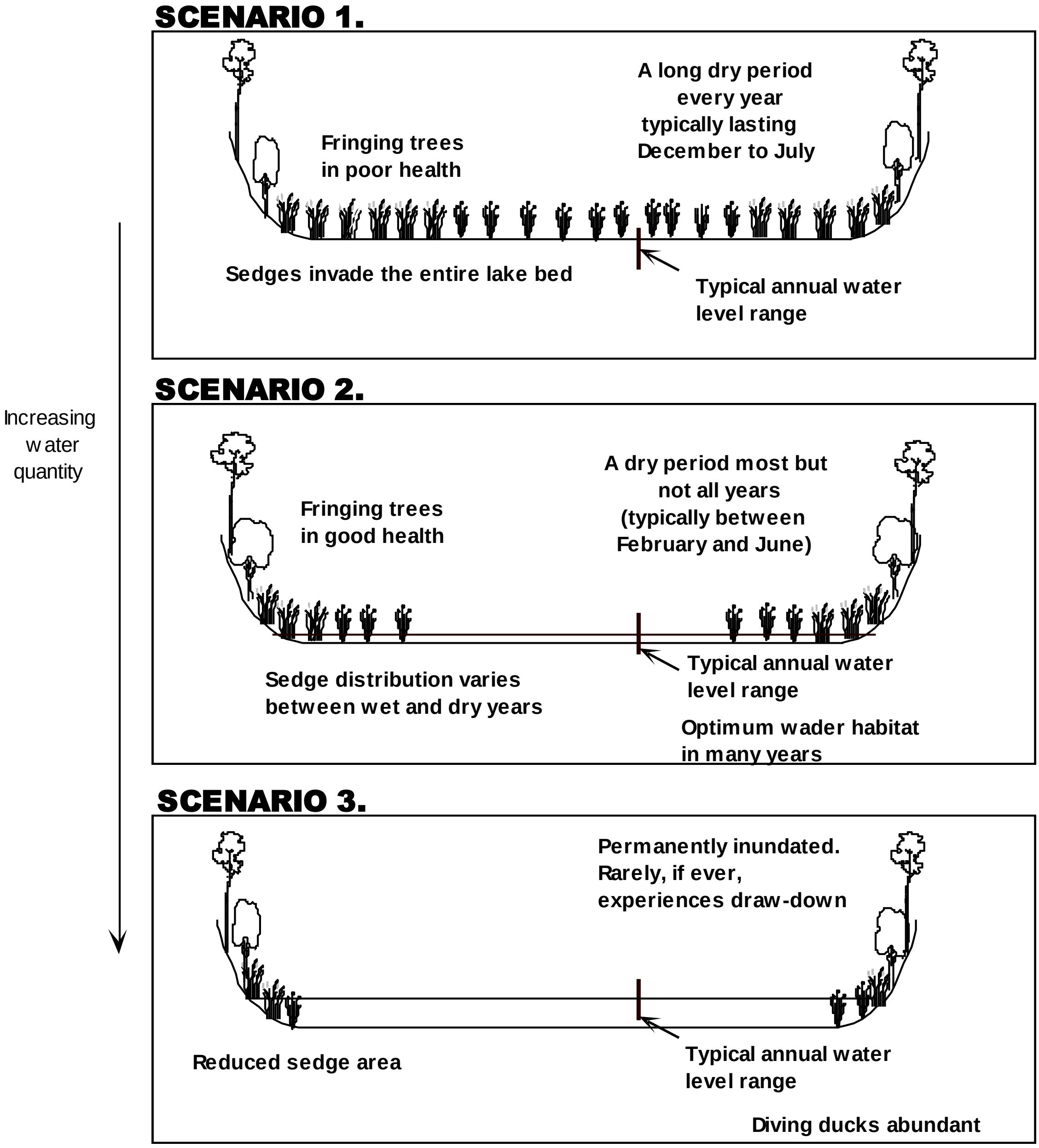

Figure 4.3: Conceptual model of scenarios describing wetland response to changing water regime (Thomsons Lake) (Davis *et al.* 2001).

5. Limits of acceptable change

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

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

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

Limits of acceptable change and the natural variability in the parameters for which limits are set are inextricably linked. Phillips (2006) suggested that limits of acceptable change should be beyond the levels of natural variability (Figure 5.1). However, setting limits in consideration with natural variability is complicated. Wetlands are complex systems and there is both spatial and temporal variability associated with all components and processes (Hale and Butcher 2007). Defining trends that are not within a "natural" range that can be detected with sufficient time to instigate management actions to prevent an irrevocable change in ecological character is therefore particularly difficult (Hale and Butcher 2007).

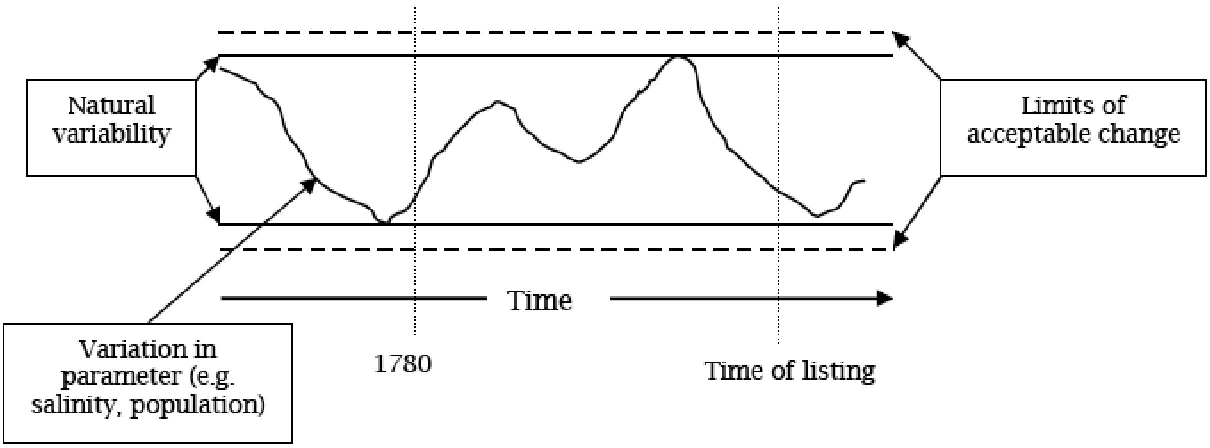

Figure 5.1: Example of natural variability and limits of ecological change (Source: Phillips 2006)

It is not sufficient to simply define the extreme measures of a given parameter and to set limits of acceptable change beyond those limits. There are many examples where a

parameter could change in ways that are detrimental to the ecological character of the site but do not result in a change in the maximum or minimum values. If the limits of acceptable change are set to be outside the extremes of natural variability then this will only capture a change in maximum or minimum values. Situations that involve a shift in the baseline values, an increase in the number of peak events or a seasonal shift will not be captured (Hale and Butcher 2007).

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

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

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

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

Limits of acceptable change for Forrestdale and Thomsons Lakes have been established for the key components and processes of ecological character identified in Section 3 (Table 5.1). The defined limit of acceptable change is the tolerance considered acceptable without indicating a change of ecological character is occurring (Phillips *et al.* 2006). Use of this concept requires good knowledge of natural variations, the boom-and-bust cycles that can occur naturally in these species or communities. Where this is lacking, the precautionary principle is applied.

Table 5.1: Limits of acceptable change for Forrestdale and Thomsons Lakes based on previous studies and natural variation documented in this report.

Components and processes	Baseline condition and range of natural variation where known (range with average in brackets)	Limits of acceptable change
Annual minimum water depth	Typically falls to around 0.5 m below the lake bed level. **Permanent water** (in most years): • Thomsons: 1972–1977 and 1989–1995 • Forrestdale: 1972–1982 and 1989–1993 **Annual drying** (in most years): • Thomsons: 1978–1988 and 1996–present • Forrestdale: 1983–1988 and 1994–present	• At the sediment surface (wet years), or up to 0.5 m below the lake bed levels (medium years), or 0.5–1.0 m below the lake bed surface (dry years) (DoE 2004) for 3–4 consecutive months annually. • Always < 1.0 m below the sediment surface (DoE 2004). • Not 0.5–1.0 m below the sediment surface for longer than 4 consecutive months more than once every ten years or for 2 consecutive years (Froend *et al.* 1993).
Annual maximum water depth	**1952–2005**: Thomsons Lake 38–371 cm (139 cm) Forrestdale Lake 45–266 cm (129 cm)	• > 0.9 m (DoE 2004) for 2 months during spring. • > 1.6 m at least once every 10 years (for invertebrates) • No less than 0.5 m more than once every 10 years (Froend *et al.* 1993). • No greater than 2.5 m for 2 consecutive years (Froend *et al.* 1993).
	1980–1999 (decades before and after Ramsar listing): Thomsons 38–206 cm (105 cm) Forrestdale 47–187 cm (103 cm)	
Period of inundation/ drying	**1972–2005**: Thomsons 5–12 months (9.6 months) Forrestdale 5–12 months (9.9 months)	• > 6 consecutive months annually (Balla and Davis 1993; Briggs and Thornton 1999). • Preferred earliest drying by April (wet year), Feb–Mar (medium year) or January (dry year) (DoE 2004). • Permanent water present for not more than 2 consecutive years in every ten years (Crome 1988; Halse *et al.* 1993; Davis *et al.* 2001).
	Drying phase 1 (1980s): Thomsons 7–10 months (8.6 months) Forrestdale 9–12 months (10.2 months)	
	Drying phase 2 (mid-1990s to 2005): Thomsons 5–9 months (7.3 months) Forrestdale 5–9 months (6.8 months)	
Colour	Colour typically 3.2–29.0 g 440 m^{-1} during spring.	< 30 g 440 m^{-1} at all times
Turbidity	Turbidity typically 0.4–38.0 NTU during spring.	< 40 NTU at all times
Salinity	Conductivity typically 1,500–7,000 µS cm^{-1} during spring.	< 2,475 µS cm-1 during winter
pH	pH typically 7.0–9.9 during spring.	> 7.0 (ANZECC 2000) < 9.0 (Davis *et al.* 1993)
Chlorophyll *a*	Chlorophyll *a* typically 0.5–23.3 µg L^{-1} during spring.	< 100 µg L^{-1} (Davis *et al.* 1993)
Nutrients	Total phosphorus typically 28–389 µg L^{-1} during spring.	< 100 µg L^{-1} (Davis *et al.* 1993)
	Total nitrogen typically 1,386–6,800 µg L^{-1} during spring.	< 1,500 µg L^{-1} (ANZECC 2000)
Aquatic plants	Systems dominated by submerged macrophytes but current extent and biomass of submerged and floating macrophytes unknown.	> 50 % cover of lake bed Strehlow *et al.* 2005).
Littoral vegetation	Current extent and biomass of native and exotic riparian vegetation unknown.	Baseline must be set before limits can be made.
	Current area of lake bed encroached by *Typha* and other riparian vegetation unknown.	Baseline must be set before limits can be made.

Aquatic invertebrates	Number of aquatic invertebrate families typically 14–39. Insufficient information to set a baseline for abundance.	> 14 families during spring
Waterbirds	Forrestdale and Thomsons Lakes regularly support > 5,000 waterbirds and breeding of 27 species (since 1988). However, waterbird numbers are highly variable and there has been no systematic, long term monitoring of these birds to enable a numerical baseline to be set.	Consideration should be given to climatic patterns and their potential effect on bird numbers. Generally each lake should support: • > 5,000 total waterbirds in 4 out of 5 years. • Breeding of 27 species a minimum of once every three years (lakes combined).

Note: The lake bed levels (m AHD) at both Forrestdale and Thomsons Lakes need to be agreed upon, as the reported levels have varied from <11.5 to 11.8 m AHD at Thomsons Lake and 21.1 to 21.6 m AHD at Forrestdale Lake. Levels currently used by the Department of Environment in setting EWPs are 11.8 m AHD at Thomsons Lake and 21.6 at Forrestdale Lake. However, measurements currently recorded at Thomsons Lake by the Water Corporation reads to a minimum level of 11.5 m AHD, which is considered to be located above the lake bed level. Agreement on these levels is critical to the management of both lakes for the purposes of maintaining ecological character.

Justification for the limits of acceptable change

The variability evident in some components and processes at Forrestdale and Thomsons Lakes have surpassed the limits of acceptable change specified in Table 5.1. Both lakes have experienced high total phosphorus concentrations (>300 µg L^{-1}), which has often resulted in problems with nuisance midges or algal blooms. These high levels of total phosphorus are greater than the 'natural' variability and are the consequence of anthropogenic impacts, such as urbanisation. Therefore, the limits of acceptable change specified in Table 5.1 are not necessarily set around the variability recorded at the lakes in the past. The limits specified are those, which if exceeded, are likely to result in a deleterious change in condition of the wetland. Justification for the specified limits is provided below.

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

Minimum water depth and period of inundation

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

- The declining watertable at Forrestdale Lake has reduced the health of fringing vegetation including *Eucalyptus rudis* and *Melaleuca preissiana* (Ladd 2001).
- Seasonal wetlands with a moderate (< 7 months) of shallow (< 0.5 m) inundation, support the largest areas and most diverse fringing plant communities. A lowering of the water regime would most likely result in a gradual shift of the vegetation down-gradient i.e. encroachment of the lake bed (Froend *et al.* 1993). Low counts of migratory wader species at Forrestdale and Thomsons Lakes in recent years has been attributed to encroachment of riparian vegetation, which has decreased the amount of mudflats available for wading birds (Bamford and Bancroft 2007).
- The minimum water levels should not fall below 0.5 m of the sediment surface more than once every ten years to protect the health and extent of the emergent vegetation, particularly sedge beds. The optimum water level for *Baumea articulata* is ± 0.1 m above the lake bed (Froend *et al.* 1993). This should in turn ensure the protection of fauna habitat, including waders and invertebrates (Davis *et al.* 2001).
- The richness of invertebrate families is greatly reduced if maximum annual depth is < 50 cm (Section 3.4.1).
- Adult insects with aquatic larvae require healthy vegetation for resting sites and some require submerged macrophytes, particularly damselflies (Odonata: Zygoptera), for egg-laying sites. Maintaining a water regime that supports submerged macrophytes is therefore also important for the maintenance of invertebrate habitat values. The requirements of aquatic invertebrates to complete their life cycles should be met if water is present for at least 4 months per year, seasonal wetlands do not dry out before December each year, and rates of wetland drying do not exceed 0.02 m day^{-1} (Balla and Davis 1993).
- Briggs and Thornton (1999) found that waterbirds (other than ducks) needed at least 5 to 8 months inundation to successfully complete breeding when flooding commences in winter/spring in River Red Gum *Eucalyptus camaldulensis* wetlands. This included time for egg laying, as well as for incubation and fledging of young. However, these times increased by one to three months (average of two months) following autumn flooding. Therefore, 7 to 10 months inundation under the nest trees is required when flooding commences in autumn.

Maximum water depth and period of inundation

- Prolonged flooding (>2 years) can lead to severe degradation and possibly local extinction of fringing tree populations, including *Eucalyptus rudis* and *Melaleuca preissiana* (Froend *et al.* 1993). The average annual evaporation in Perth is 2,056 mm (Bureau of Meteorology 2008), as a consequence, if the maximum water depth is >2.5 m it is unlikely that either lake would dry completely.
- The aquatic macrophyte, *Myriophyllum*, requires water that is relatively shallow. Excessive depth increases may lead to the death of macrophyte beds and favour cyanobacterial blooms (Balla and Davis 1993).
- Highest richness of aquatic invertebrates recorded at water depth >1.6 m indicating that high water levels may be preferred (Section 3.4.1), provided the regime does not change to permanent for >2 years.
- Inundation of *Baumea articulata* by 0.8 m each year will prevent downslope growth i.e. encroachment of the lake bed (Froend *et al.* 1993).

Seasonal drying requirements

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

Salinity

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

pH

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

Chlorophyll *a*

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

Nutrients

- Annual maximum concentrations of total phosphorus should not exceed 100 µg L^{-1} for prevention of problems with nuisance midges (*Polypedilum nubifer*) (Davis *et al.* 1993).
- A shift from clear water, submerged macrophyte-dominated regime to a turbid phytoplankton-dominated regime had been observed in wetlands on the Swan Coastal Plain with low colour (< 52 g440 m^{-1}) and levels of total phosphorus greater than 100 µg L^{-1} (Davis *et al.* 1993).

6. Threats

The major threatening activities that could impact on the ecological character of Forrestdale and Thomsons Lakes are summarised in Table 6.1 and described in more detail below.

Table 6.1: Likely threats to the ecological character of Forrestdale and Thomsons Lakes, potential impacts of the threats, and the likelihood and likely timing of the threats.

Threatening activities	Potential impact	Likelihood	Timing
Groundwater abstraction and/or climate change	• Altered hydrological regimes – wetlands drying earlier and for longer periods of time • Reduced water depth • Reduced habitat availability for waterbirds and invertebrates • Decline of fringing vegetation condition • Encroachment of vegetation (predominantly *Typha orientalis*) onto the lake bed • Reduced suitability of habitat for waterbirds to breed and rear young	Certain/ high	Immediate
Urban development	• Nutrient enrichment • Establishment of weeds • Altered water regimes • Reduced habitat quality • Disturbance of flora and fauna • Unplanned fire	Certain	Immediate –medium term (5 years)
Fire	• Reduced habitat • Domination of introduced species	High	Immediate
Problem species (native and introduced)	• Altered floristics of fringing vegetation • Reduced habitat • Competition with native flora and fauna • Reduced amount of open water • Increased fire frequency • Decline of native vegetation • Reduced survival of waterbirds, particularly hatchlings at Forrestdale Lake (Thomsons Lake is enclosed within a predator-proof fence).	Certain	Immediate
Disease	• Dieback (*Phytophthora cinnamomi*) infection leading to permanent changes to some native plant communities and their dependent fauna.	Certain/ high	Immediate –medium term
Acid sulfate soils	• Formation and release of sulphuric acid into the water column	Low	Medium term

Groundwater abstraction and/or climate change

Wetland water regimes have been under considerable pressure over recent years due to a combination of an increasingly dry climate, groundwater abstractions reaching management limits, and the influence of drainage (Water and Rivers Commission 2001). Other factors contributing to pressures on the groundwater include changes in vegetation cover and the increasing presence of impervious surfaces associated with urbanisation. It seems likely that similar dry phases have occurred on the Swan Coastal Plain in the past; however, the current capacity to extract large volumes of groundwater is unprecedented (Davis *et al.* 2008). As urban development increases in the catchment of the reserves, so do the threats to the wetlands. Such changes may see the wetlands

change from being groundwater dominated to surface water dominated, as surface runoff from urban areas increases and groundwater levels decrease.

Declining water levels at Forrestdale and Thomsons Lakes have become a significant management issue for the protection of the wetland ecosystems and waterbird habitat. Impacts of declining water levels include:

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

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

- Lower peak water levels and shorter periods of inundation has resulted in poor breeding of waterbirds, especially swans, across the wetlands on the Jandakot Mound (Bamford and Bancroft 2007). Breeding typically occurs when water levels are high in late winter/early spring and a high winter/spring peak water level appears to be required to trigger breeding or allow breeding to be successful.

- The premature drying of Thomsons Lake has resulted in cygnets, which have not matured to a stage where they can fly, being trapped inside the predator-proof fence whilst trying to find an alternative water source. Water supplementation (see below) should help to alleviate this problem by diverting stormwater into the lake during winter so that water is present in November and December. This would allow the cygnets to mature to a stage where they can fly to other water bodies (such as the Swan River Estuary) as Thomsons Lake dries up.

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

In 1992, Environmental Water Provisions were set for both lakes and included a preferred minimum water level and an absolute minimum level. These values were set to ensure the maintenance of the lakes' habitat value for migratory birds and rare, threatened and priority flora and fauna. These levels have been breached a number of times at Forrestdale Lake but not at Thomsons Lake (CALM 2005a, b). The breaches mainly occurred as a result of water extractions being excessive given the declining groundwater levels resulting from drier climatic conditions (CALM 2005a).

A water supplementation trial has been initiated at Thomsons Lake to help ensure that water levels remain adequate for the protection of the reserve's Ramsar values and waterbird habitat, and to enable fledgling cygnets to survive until they are able to fly. Continued monitoring of water levels is important, and where practicable suitable water levels maintained, to ensure that waterbird habitats are protected at both lakes. Monitoring of other potential impacts of replenishment of Thomsons Lake with drainage water, e.g. nutrient enrichment, is also important.

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

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

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

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

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

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

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

Foxes and cats are considered to be a threat to wildlife at both lakes; however, the extent of their impact is currently unknown. Predation by foxes has, in the past, been identified as a threatening process for breeding waterbirds and other native fauna (Mawson 2002). In recent drier years, foxes have been seen preying on young cygnets at Forrestdale Lake (CALM 2005a). The potential of cats to prey on waterbirds, particularly hatchlings, is also a significant concern. In 1993, a predator-proof fence was constructed around Thomsons Lake to protect native fauna by preventing feral animals from entering the reserve. A fox eradication program was also implemented. The fence does inhibit the movement of some native fauna (e.g. kangaroos, turtles and cygnets). However, the benefits of the fence in protecting migratory waders, other fauna and their habitats, are considered to outweigh the negative impacts.

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

as necessary, with culling initiated whenever the population reaches approximately 50 animals.

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

Disease

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

Acid sulfate soils

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

Recreation

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

7. Changes to ecological character

Forrestdale and Thomsons Lakes were first listed under the Ramsar Convention in 1990. Since this time, many of the components, processes, benefits and services critical to the ecological character of the site have been maintained, however, there have also been a number of changes to the wetlands. Section 3 documents the critical aspects of the ecology of Forrestdale and Thomsons Lakes, the driving forces behind them, and relationships between them. A summary of the critical ecosystem components and processes is provided in Table 3.1, and the benefits and services in Table 3.6. This section will explore changes in the ecological character of the site, the magnitude of the changes and the factors causing these changes to occur.

7.1 Hydrology

Maximum water depth

Average maximum water depths have decreased by approximately 40 cm at Thomsons Lake and 44 cm at Forrestdale Lake in the decades before and after the lakes were designated as a Ramsar site (1980–1999). The average maximum water depth at Thomsons Lake has decreased from 105 cm (± SE 9.0) over the period 1980–1999, to 65 cm (± SE 9.2) over the period 2000–2007. The average maximum water depth at Forrestdale Lake has decreased from 103 cm (± SE 7.5) over the period 1980–1999, to 59 cm (± SE 8.7) over the period 2000–2007.

Annual period of inundation/drying

Forrestdale and Thomsons Lakes did not dry in 1990 when they were designated as a Ramsar site, but have dried completely in most years since that time. The lakes are now drying for increasingly longer periods of time and the duration of time that water is present in Forrestdale and Thomsons Lakes is currently less than any time in the past.

In the dry phase during the 1980s, the average annual period of inundation was 8.6 months (± SE 0.44) at Thomsons Lake and 10.2 months (± SE 0.73) at Forrestdale Lake. The annual period of inundation has declined by around 2 months at Thomsons Lake and almost 4 months at Forrestdale Lake. In the present annual drying phase, the average annual period of inundation is 6.7 months per year (± SE 0.56) at Thomsons Lake and 6.4 (± SE 0.45) months at Forrestdale Lake. Most recently (2006–2007), water has been present in both lakes for only 3 to 4 months. Such long periods of drying exceed the limits of acceptable change and are resulting in deleterious changes to the condition of the lakes (see Section 5).

Timing of water presence/absence in dry phases

Forrestdale and Thomsons Lakes are drying out earlier than in previous years. Both lakes have tended to dry completely from January to March during both annual drying phases until around 2000. In the 6 years since 2002, Thomsons Lake has been completely dry in December in 3 years and Forrestdale Lake in 2 years. Such frequent drying prior to December exceeds the limits of acceptable change and is resulting in deleterious changes to the condition of the lakes (see Section 5).

Wetland water levels have been under considerable pressure over recent years due to a combination of an increasingly dry climate, groundwater abstractions reaching management limits, and the influence of drainage (Water and Rivers Commission 2001). Other factors contributing to pressures on the groundwater include changes in vegetation cover and the increasing presence of impervious surfaces associated with urbanisation (CALM 2005a, b). Average annual rainfall has declined from 757 mm during the period from 1980 to 1999 to 674 mm from 2000 to 2007 (Bureau of Meteorology 2008). Although similar dry phases may have occurred on the Swan Coastal Plain in the past, Davis *et al.* (2008) noted that the current capacity to extract large volumes of groundwater is unprecedented.

The adverse impacts of an annual drying regime and reduced water depth include:

- Reduced amount of time for flora and fauna dependent on water e.g. aquatic plants, macroinvertebrates and waterbirds, to complete their lifecycle.
- Encroachment of vegetation (*Typha orientalis*) onto the lakebed, subsequently altering waterbird habitat.
- Reduced health of fringing vegetation around the lake.
- Reduced richness of macroinvertebrates.

The beneficial impacts of an annual drying regime include:

- There have been few problems from midges over the past few years as a result of Forrestdale Lake drying out early in summer before major midge swarms develop.
- The introduced fish, *Gambusia holbrooki*, which is an aggressive predator, was present at Thomsons Lake under a permanent water regime in the early 1990s, but disappeared when the lake reverted to a seasonal drying regime.

7.2 Physico-chemistry

The water in both Forrestdale and Thomsons Lakes continues to have a neutral to alkaline pH, weakly coloured, generally clear, and fresh to brackish with higher salinities occurring as the lakes dry out. Conductivity was much higher than usual in spring 2006 (15,900 $\mu S\ cm^{-1}$) at Forrestdale Lake because it was drying out and water depth was only 10 cm and therefore contained a high concentration of salts. However, conductivity returned to normal levels in spring 2007.

Forrestdale and Thomsons Lakes are moderately enriched. Total phosphorus levels have been below 140 µg/L at both lakes since 2004, which is lower than around the time the site was Ramsar listed, largely due to the more frequent and extended duration of complete drying. Total nitrogen levels are similar to those at the time that the lakes were listed as a Ramsar site. The level of nitrogen in Forrestdale Lake was higher than usual in spring 2006 (9,500 $\mu g\ L^{-1}$), most likely due to evapoconcentration effects as the lake was drying out at the time of sampling and water depth was only 10 cm. However, nitrogen levels were within the normal range at Forrestdale Lake in spring 2007.

The decline in nutrient enrichment has meant that blue-green algal blooms (cyanobacteria) have not occurred in recent years. Such blooms can result in the loss of submerged macrophytes, foul odours, low oxygen levels, toxic effects on invertebrates and birds, and provides an extensive food source for larval midges (Balla 1994; Pinder

et al. 1991). Therefore, aerial spraying for midges has not been required at Forrestdale Lake.

7.3 Invertebrates

Invertebrate species richness at Forrestdale and Thomsons Lakes has remained relatively stable since being listed as a Ramsar site. High numbers of invertebrate families were recorded in 1992 and 1993 at Thomsons Lake (Forrestdale Lake was not sampled at this time), when maximum water depths were the highest recorded since 1985. Forrestdale Lake was very poor in invertebrate families in spring 2006, which indicates that this lake had not filled sufficiently to support the macroinvertebrate community previously recorded at the lake. However, species richness returned to normal levels in spring 2007. An increase in frequency and duration of prolonged drying phases may result in a loss of resilience in the invertebrate biota.

7.4 Waterbirds

The number of waterbirds and number of species recorded at Forrestdale and Thomsons Lakes have been variable, but overall have declined in recent years. Over 10,000 individual birds were recorded in 40% of the years from 1982 to 1999 at Thomsons Lake, and 53% of years at Forrestdale Lake, and over 5,000 individual birds were recorded in most years (80% at Thomsons Lake and 67% at Forrestdale Lake).

Since 2000, 10,000 individual birds have not been recorded at Thomsons Lake and have been recorded on one occasion at Forrestdale Lake in 2005 (14% of years from 2000–2007). Over 5,000 individual birds have been recorded in only two years (14%) at Thomsons Lake and in 4 years (57%) at Forrestdale Lake. The recent reduction in waterbird numbers to < 5,000 individual birds exceeds the limits of acceptable change (see Section 5); however, more frequent surveys need to be conducted to ensure that these low numbers are not a consequence of reduced sample effort. In a study of 12 wetlands on the Jandakot Mound from 1996 to 2006, Bamford and Bancroft (2007) noted that low counts of many species and low total counts occurred in years of low water levels, while the generally high numbers of 2005 occurred at the highest water levels since 1996.

Two groups of waterbirds in particular have experienced substantial decline at Forrestdale and Thomsons Lakes – diving waterbirds that do not use inland wetlands, (notably the Blue-billed and Musk Ducks) and migratory shorebirds (Bamford and Bancroft 2007). They attributed the decline in abundance of diving waterbirds in Jandakot Wetlands to poor breeding success, and the ‘virtual disappearance’ of migratory waders to the encroachment of riparian vegetation; both factors are due to low water levels. The Eurasian Coot has also decreased, which suggests that the submerged aquatic plants it forages on have decreased in abundance (Bamford and Bancroft 2007).

Breeding of most waterbirds has been relatively poor across the wetlands on the Jandakot Mound since 1997, and was especially poor in 2006 (Bamford and Bancroft 2007). They attributed such poor breeding in part to low peak water levels and short

periods of inundation. Although Thomsons Lake was one of few known breeding localities for Baillon's Crake, and the last wetland within the Perth metropolitan area where Swamp Harrier was recorded breeding, these species have not been recorded breeding at this lake since the mid-1980s. As noted previously, however, differences in the number of surveys conducted each year and monitoring methods may have had an impact on breeding records for some species.

7.5 Aquatic plants

Anecdotal observations suggest that aquatic plants remain similar at both lakes, with *Myriophyllum* an important species at Thomson Lake, and *Ruppia* and *Chara* at Forrestdale Lake (J. Davis pers. obs.). However, the extent of macrophytes has not been mapped at the lakes and therefore any changes in these communities have not been fully documented.

7.6 Littoral vegetation

The introduced Bulrush *Typha orientalis* has increased in abundance since Forrestdale and Thomsons Lakes were listed as a Ramsar site. *Typha*, along with other exotic and native emergent rushes and sedges, now covers expansive areas of the waters edge and is encroaching across the dry lake beds. The extent of *Typha* at Thomsons Lake has recently been mapped and results indicate an increase in Typha extent of 2.7 ha from 2006 to 2009 (SCP Conservation 2009). While the extent of *Typha* has increased, the spatial distribution has also changed over the three years, that is, *Typha* expanded in some areas and contracted in others (SCP Conservation 2009). The invasion and expansion of *Typha* and other emergent rushes and sedges appears largely due to the prolonged drying phase in recent times, and this seems likely to continue while drier conditions persist (Davis *et al.* 2008). *Typha* is displacing and changing riparian vegetation, which appears to be altering waterbird habitat. Low counts of migratory wader species at Forrestdale and Thomsons Lakes in recent years has been attributed to encroachment of riparian vegetation, which has decreased the amount of mudflats available for wading birds (Bamford and Bancroft 2007).

Ladd (2001) reported that the declining water table at Forrestdale Lake had affected fringing vegetation including *Melaleuca rhaphiophylla* and *Eucalyptus rudis*, which were generally in poorer health than at other wetlands assessed in the Jandakot area.

A summary of the major changes to the ecological character of the Forrestdale and Thomsons Lakes Ramsar site since the time of listing, which are identified in sections 7.1–7.6, includes:

- Maximum water depths at both lakes are substantially lower, the period of inundation substantially less, and annual drying is occurring earlier than at any time in the past.
- The introduced Bulrush *Typha orientalis* now covers expansive areas of the waters edge and is encroaching across the dry lake beds at both lakes.
- The number of waterbirds and number of species recorded at Forrestdale and Thomsons Lakes have been variable, but overall have declined in recent years.
- Total phosphorus levels have declined and subsequently associated blue-green algal blooms (cyanobacteria) and midge swarms have also declined.

These major changes highlight the common theme of drier conditions causing change to the ecological character of Forrestdale and Thomsons Lakes.

7.7 Wetland processes and ecological regime

Forrestdale and Thomsons Lakes are clear, submerged macrophyte-dominated systems, which is largely driven by the annual drying process that the lakes currently experience. Both lakes have occasionally transitioned to turbid, phytoplankton-dominated regimes as a result of eutrophication.

7.8 Ramsar Criteria

7.8.1 Ramsar Criteria currently met

Forrestdale and Thomsons Lakes continues to meet the following Ramsar Criteria the site was listed for:

Criterion 1: The site contains a representative example of a natural or near-natural wetland type found within the appropriate biogeographic region.

Forrestdale and Thomsons Lakes are the best remaining examples of large brackish, seasonal lakes with extensive fringing sedgeland typical of the Swan Coastal Plain. While these types of wetland were formerly common, extensive development of the Swan Coastal Plain has resulted in the loss of many of these wetlands, and most of the remaining wetlands of this type have been degraded through drainage, eutrophication and the loss of fringing vegetation.

Criterion 3: The site supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.

Forrestdale and Thomsons Lakes provide important habitat for waterbirds on the Swan Coastal Plain with 85 species of waterbird occurring at the two lakes, including 23 migratory species, and 27 species have been recorded breeding. Forrestdale and Thomsons Lake contain rich and diverse communities of aquatic invertebrates that are representative of relatively undisturbed, large, shallow Swan Coastal Plain wetlands dominated by submerged macrophytes. Macroinvertebrates are an important component of wetland food webs, comprising much of the diet of many faunal species, including migratory waders and other waterbirds, and turtles. There are two Threatened Ecological Communities at Forrestdale Lake Nature Reserve, two ‘Declared Rare Flora’ species and nine Priority taxa. Thomsons Lake Nature Reserve contains one ‘Declared Rare Flora’ species and three Priority taxa.

7.8.2 Ramsar Criteria no longer met

Forrestdale and Thomsons Lakes no longer meet the following Ramsar Criteria the site was listed for:

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

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

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

Criterion 6: The site regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.

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

Forrestdale and Thomsons Lakes have supported more than 1% of the population of 4 waterbirds in several years: Australasian Shoveler, Black-winged Stilt, Blue-billed Duck, and Red-capped Plover (section 3.4.2). However, the wetlands have not "regularly" supported 1% of the population, particularly in recent years. Therefore Forrestdale and Thomsons Lakes do not meet the current requirements for listing under Criterion 6.

8. Knowledge gaps

Knowledge gaps and data deficiencies of ecosystem components and processes at Forrestdale and Thomsons Lakes have been identified throughout this Ecological Character Description. This knowledge is required to better understand these complex systems in order to appropriately manage them for conservation purposes and to maintain their ecological character. The key knowledge gaps are summarised below, including issues associated with data availability and accessibility, and corresponding recommended actions are listed.

Table 8.1: Knowledge gaps and recommended actions.

Component/ Process	Knowledge gap	Recommended action
Water Depth and Period of Inundation	The impact of climate change, groundwater abstraction and drainage as separate factors on wetland water levels is not known.	Comprehensive investigation.
	The minimum period of inundation required for aquatic fauna to complete life cycles. Although estimated in this ECD, requires refinement to ensure that dominant, iconic, keystone and rare species are fully considered. This is particularly important for breeding waterbirds at Thomsons Lake where the predator-proof fence prevents movement to alternative water sources.	Comprehensive investigation of water requirements for breeding waterbirds and turtles.
Water Quality	Although a reasonable baseline dataset exists it does not provide information on seasonal variation (the lakes are currently only monitored in spring). Several agencies (e.g. DEC, DoW, Water Corporation and Murdoch University) undertake monitoring but greater sharing and interpretation of information is needed.	Monthly monitoring of water quality parameters and improved data sharing and interpretation.
Phytoplankton	Species composition and abundance has not been monitored regularly.	Increased monitoring.
Aquatic Plants	There is little information on the species composition, distribution biomass and condition of submerged aquatic plants.	Mapping of extent and distribution.
Littoral Vegetation	Extent and distribution of emergent macrophytes has not been regularly mapped.	Mapping of extent and condition assessment.
	Extent, distribution and health of littoral vegetation have not been regularly mapped or monitored, including areas affected by 'dieback' (*Phytophthora cinnamomi*).	Mapping and condition assessments, particularly of fringing tree species.
Waterbirds	There has been no systematic survey and reporting of abundance, species composition or breeding. Currently surveys are conducted 3 times per year; however this may be insufficient to determine changes to species assemblages and abundance.	More frequent waterbird surveys, especially during the late spring and summer months when migratory waders are present.
	The effects of fox predation on waterbird breeding success and the interactive effects of predation and water level decline at Forrestdale Lake have been observed but not quantified.	Comprehensive investigation.
Ecosystem components, processes and services review	Although there has been substantial monitoring and reporting of individual components and processes, data have not been compiled to assess ecosystem change, causes and relationships.	Improved data sharing, annual review of ecosystem change using combined monitoring data.

9. Monitoring needs

While monitoring programs are in place for components within Forrestdale and Thomsons Lakes, there is no comprehensive monitoring program designed to detect and manage changes to the ecological character of the wetlands. This section provides a brief summary of existing monitoring and an identification of monitoring needs required to both set baselines for key components and processes and to assess against limits of acceptable change.

9.1 Current monitoring

Water depth
DoW has monitored surface water levels at Forrestdale and Thomsons Lakes on a monthly basis since the early 1970s and groundwater levels at Forrestdale Lake. Monitoring of Thomsons Lake has been taken over by the Water Corporation as part of the monitoring program for the operation of the Southern Lakes Drainage Scheme.

Water quality
Water quality parameters have been measured at Thomsons Lake since 1996 and Forrestdale Lake since 2001 by Murdoch University on behalf of DoW as part of the Environmental Investigations for the Jandakot Groundwater Scheme Stage 2. The parameters measured include: chlorophyll-*a*, nitrate/nitrite, orthophosphate, total nitrogen, total phosphorus, colour (gilvin or soluble humic colour) and formazin turbidity (NTU). Monitoring occurs once each year during spring. The objective of the monitoring program is to provide an indication of whether existing and proposed groundwater abstraction schemes together with private groundwater abstraction, are having an impact on the identified ecological values of wetlands (Wild and Davis 2004).

Data on water quality and aquatic invertebrates has been collected as part of various studies undertaken by Murdoch University at Thomsons Lake (since 1985) and Forrestdale Lake (since 1989). These datasets extend the baselines back in time from the 1996 programs.

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

Vegetation
Wetland associated terrestrial vegetation has been monitored at Thomsons Lake since 1996 and Forrestdale Lake since 2001 by Murdoch University on behalf of DoW as part of the Environmental Investigations for the Jandakot Groundwater Scheme Stage 2. Monitoring is undertaken annually in spring/summer and the parameters measured include: tree position and diameter; species richness; crown health; cover and abundance for all species; weediness index; and a regeneration index. The objectives of monitoring are to determine if there have been any changes in the condition of the vegetation over time, and if this is related to alterations of the groundwater regime or to other factors affecting the wetlands (Ladd 1999).

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

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

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

9.2 Monitoring of ecological character

A detailed monitoring program is required to detect actual or potential changes in ecological character and ensure that data collected can be used to implement required management interventions. A detailed monitoring program is beyond the scope of an ecological character description (DEWHA 2008); however, Ramsar recommends the following framework for designing an effective wetland monitoring programme (Ramsar Convention Secretariat 2007). The framework is not a prescriptive recipe for any particular monitoring programme. It provides a series of steps that can be used by wetland managers and planners, working in partnership with local users and managers, to design a monitoring programme based on their particular circumstances and needs (Ramsar Convention Secretariat 2007).

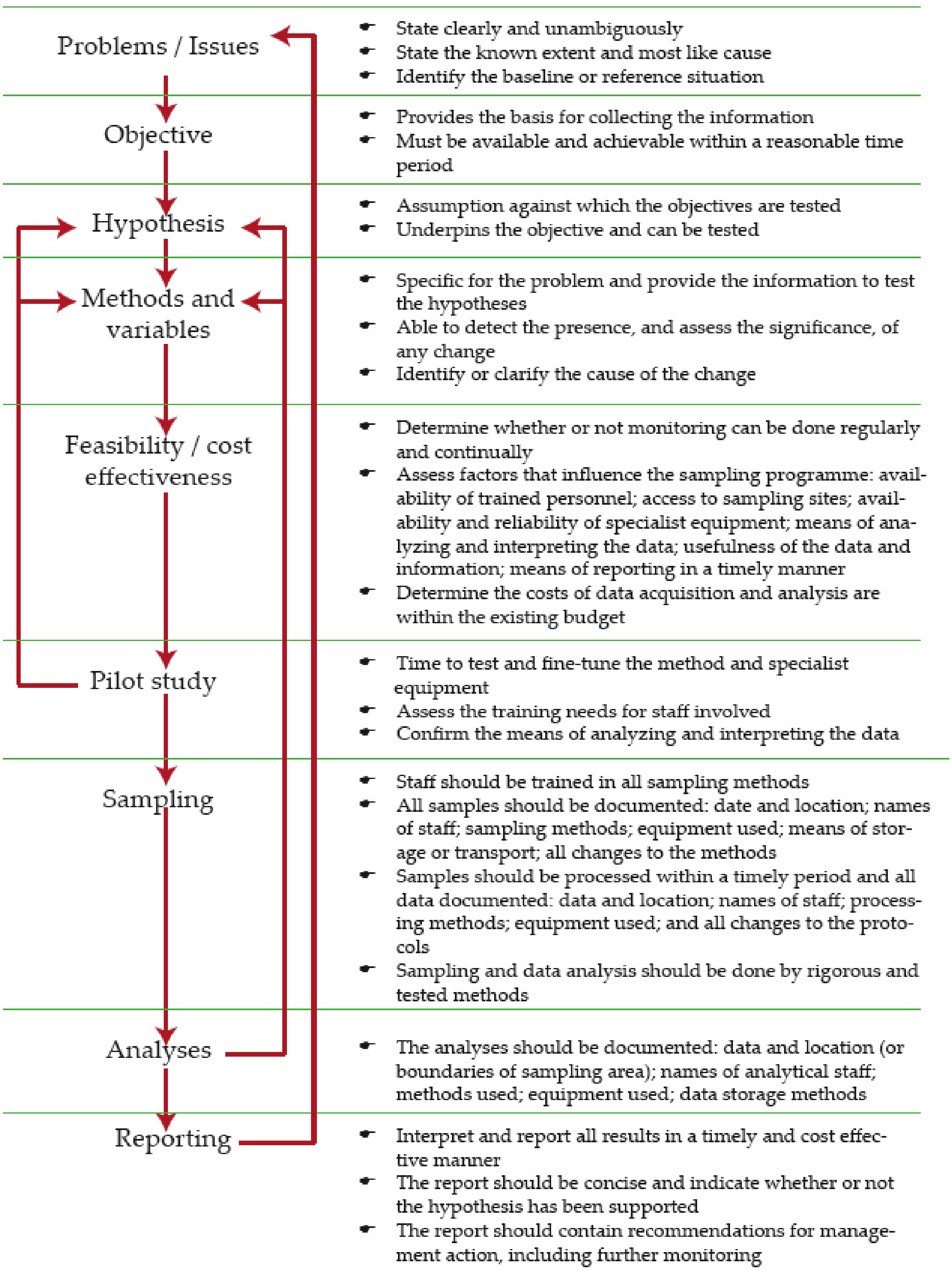

Figure 9.1: Framework for designing a wetland monitoring programme (Source: Ramsar Convention Secretariat, 2007). The arrows illustrate the feedback which enables assessment of the effectiveness of the monitoring programme in achieving its objective(s).

Monitoring needs for the Forrestdale and Thomsons Lakes site in relation to determining or maintaining the site's ecological character are summarised and include components, processes or threats (e.g. to fill a knowledge gap, to set limits of acceptable change, to detect changes in ecological character).

Table 9.1: Monitoring needs for the Forrestdale and Thomsons Lakes Ramsar Site

Component/ Process	Purpose	Indicator	Frequency	Priority
Water depth and inundation	Detection of change	• Depth gauges • Monitoring wells	Monthly	High
Physicochemical parameters	Establishment of intra-annual limits of change and detection of inter-annual change.	• Colour • Turbidity • Conductivity • pH • Chlorophyll *a* • Nutrients	Monthly	High
Aquatic plants	Assessment of limits of change, detection of change.	• Mapping of species distribution and biomass	Annual mapping	High
Littoral vegetation (emergent sedges and rushes)	Establishment of benchmarks and limits of change.	• Mapping of species distribution, condition and recruitment. • Targeted mapping of *Typha orientalis*.	Every 2-5 years	High
Wetland-associated and phreatophytic vegetation	Detection of change	• Cover and abundance of trees, understorey species, and weeds. • Tree growth, condition, and regeneration. • Areas infected with dieback (*P. cinnamomi*).	Annual assessment	High
Invertebrates	Assessment of limits of change, establishment of intra-annual change, and detection of inter-annual change.	• Richness and abundance of invertebrate families	Bi-annual (spring and summer)	High
Waterbirds	Establishment of benchmarks and limits of change.	• Surveys of waterbird species and abundance • Targeted surveys of migratory wader species and abundance • Targeted surveys of breeding and nesting	Quarterly surveys; fortnightly from the time migratory waders arrive until lakes dry	High

In addition to the required monitoring there are a number of areas where there is incomplete understanding of processes and threats. While these may not require the establishment for monitoring programs, there is a need for research or investigations to enable the site to be managed to maintain ecological character. These are outlined in Table 8.1 where the recommended action indicates a comprehensive investigation.

10. Communication and education

Communication and public awareness activities can play an important role in wetland conservation, wise use and management (DEWHA 2008). Under the Ramsar Convention a Program of Communication, Education and Public Awareness 2003-2008 was established to help raise awareness of wetland values and functions. The program calls for coordinated international and national wetland education, public awareness and communication. In response to this, Australia has established the Wetland Communication, Education and Public Awareness (CEPA) National Action Plan 2001-2005. Australia's National Action Plan provides an umbrella for coordinated activities across Australia. It is an evolving plan that will document and provide guidance towards the collaboration of effectively delivered CEPA activities.

A Communication Strategy has been prepared for Perth's network of regional parks, including Beeliar Regional Park. The aim of the strategy is to promote the conservation and enjoyment of regional parks. It outlines interpretive themes (messages) for the regional park network, including park specific themes and management messages. Interpretive themes for Beeliar Regional Park are based on the following values:

- Wetlands as corridors for wildlife and people;
- Waterbirds;
- Groundwater – catchment interactions; and
- The role of environment centres.

An Interpretation Plan for Beeliar Regional Park will be prepared to guide the development and implementation of interpretation facilities for specific areas within the park, including Thomsons Lake. Existing interpretation facilities within Thomsons Lake are limited and will be upgraded as part of the Interpretation Plan for Beeliar Regional Park (CALM 2005b).

An Interpretation Plan will be prepared for Forrestdale Lake to guide the development and implementation of interpretation facilities. Existing interpretation facilities at Forrestdale Lake are limited and will be upgraded in accordance with the proposed interpretation plan (CALM 2005a).

Following on from the identified threats to the ecological character of Forrestdale and Thomsons Lakes (Section 6), there are a number of communication and education messages that could be given priority to increase community awareness, appreciation and understanding of Forrestdale and Thomsons Lakes listing as a Ramsar site, and the significance of Ramsar listed wetlands, and to gain support for management practices. These include:

- Human disturbance can have a negative impact on vegetation, waterbirds, and nesting birds;
- Domestic cats and dogs may predate upon and disturb waterbirds and other fauna;
- Garden activities, such as application of fertiliser, can have negative effects on the water quality of the lakes.

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Appendix A: Waterbirds

Table A1: Native waterbirds present in the Ramsar site.
Species recorded at: X = both lakes; TL = Thomsons Lake only, FL = Forrestdale Lake only; U = uncommon, recorded on 5 occasions or less. Species listed under the Bonn, CAMBA, JAMBA and ROKAMBA Conventions are also listed as migratory under the EPBC Act.

			Listed species
Ducks, Geese, Swans			
Australasian Shoveler	*Anas rhynchotis*	X	
Australian Shelduck	*Tadorna tadornoides*	X	
Australian Wood Duck	*Chenonetta jubata*	X	
Black Swan	*Cygnus atratus*	X	
Blue-billed Duck	*Oxyura australis*	X	
Chestnut Teal	*Anas castanea*	X	
Freckled Duck (U)	*Stictonetta naevosa*	FL	
Grey Teal	*Anas gracilis*	X	
Hardhead	*Aythya australis*	X	
Musk Duck	*Biziura lobata*	X	
Pacific Black Duck	*Anas superciliosa*	X	
Pink-eared Duck	*Malacorhynchus membranaceus*	X	
Grebes			
Australasian Grebe	*Tachybaptus novaehollandiae*	X	
Great Crested Grebe (U)	*Podiceps cristatus*	X	
Hoary-headed Grebe	*Poliocephalus poliocephalus*	X	
Pelicans, Cormorants, Darters			
Australian Pelican	*Pelecanus conspicillatus*	X	
Darter	*Anhinga melanogaster*	X	
Great Cormorant	*Phalacrocorax carbo*	X	
Little Black Cormorant	*Phalacrocorax sulcirostris*	X	
Little Pied Cormorant	*Phalacrocorax melanoleucos*	X	
Pied Cormorant	*Phalacrocorax varius*	X	
Herons, Ibis, Egrets, Spoonbills			
Australasian Bittern	*Botaurus poiciloptilus*	TL	
Australian Little Bittern	*Ixobrychus dubius*	X	
Australian White Ibis	*Threskiornis molucca*	X	
Black Bittern (U; last record 1950s)	*Ixobrychus flavicollis*	TL	
Cattle Egret (U)	*Ardea ibis*	FL	CAMBA, JAMBA
Glossy Ibis	*Plegadis falcinellus*	X	Bonn, CAMBA
Great Egret	*Ardea modesta*	X	CAMBA, JAMBA
Little Egret	*Egretta garzetta*		
Nankeen Night Heron	*Nycticorax caledonicus*	X	
Royal Spoonbill (U)	*Platalea regia*	TL	
Straw-necked Ibis	*Threskiornis spinicollis*	X	
White-faced Heron	*Egretta novaehollandiae*	X	
White-necked Heron	*Ardea pacifica*	X	
Yellow-billed Spoonbill	*Platalea flavipes*	X	
Hawks, Eagles, Falcons			
Osprey (U)	*Pandion haliaetus*	TL	Bonn
Swamp Harrier	*Circus approximans*	X	
Whistling Kite (U)	*Haliastur sphenurus*	X	
White-bellied Sea-eagle	*Haliaeetus leucogaster*	TL	CAMBA
Crakes, Rails, Water Hens, Coots			
Australian Spotted Crake	*Porzana fluminea*	X	
Baillon's Crake	*Porzana pusilla*	X	
Black-tailed Native-hen	*Gallinula ventralis*	X	

Buff-banded Rail	*Gallirallus philippensis*	X	
Dusky Moorhen	*Gallinula tenebrosa*	X	
Eurasian Coot	*Fulica atra*	X	
Purple Swamphen	*Porphyrio porphyrio*	X	
Spotless Crake	*Porzana tabuensis*	X	
Shorebirds			
Sharp-tailed Sandpiper	*Calidris acuminata*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Banded Lapwing	*Vanellus tricolor*	X	
Banded Stilt	*Cladorhynchus leucocephalus*	X	
Bar-tailed Godwit (U)	*Limosa lapponica*	TL	Bonn, CAMBA, JAMBA, ROKAMBA
Black-fronted Dotterel	*Elseyornis melanops*	X	
Black-tailed Godwit	*Limosa limosa*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Black-winged Stilt	*Himantopus himantopus*	X	
Broad-billed Sandpiper (U)	*Limicola falcinellus*	FL	Bonn, CAMBA, JAMBA, ROKAMBA
Common Greenshank	*Tringa nebularia*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Common Sandpiper (U)	*Actitis hypoleucos*	FL	Bonn, CAMBA, JAMBA, ROKAMBA
Curlew Sandpiper	*Calidris ferruginea*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Double Banded Plover (U, last record 1970s)	*Charadrius bicinctus*	TL	Bonn
Great Knot (U)	*Calidris tenuirostris*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Greater Sand Plover (U)	*Charadrius leschenaultii*	FL	Bonn, CAMBA, JAMBA, ROKAMBA
Grey Plover (U)	*Pluvialis squatarola*	FL	Bonn, CAMBA, JAMBA, ROKAMBA
Hooded Plover (U)	*Thinornis rubricolli*	X	
Inland Dotterel (U)	*Charadrius australis*	FL	
Little Ringed Plover (U)	*Charadrius dubius*	FL	CAMBA, ROKAMBA
Little Stint (U)	*Calidris minuta*	FL	ROKAMBA
Long-toed Stint	*Calidris subminuta*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Marsh Sandpiper	*Tringa stagnatilis*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Oriental Pratincole (U)	*Glareola maldivarum*	TL	CAMBA, JAMBA, ROKAMBA
Pacific Golden Plover (U)	*Pluvialis fulva*	FL	Bonn, CAMBA, JAMBA, ROKAMBA
Pectoral Sandpiper	*Calidris melanotos*	X	Bonn, JAMBA, ROKAMBA
Red Knot (U)	*Calidris canutus*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Red-capped Plover	*Charadrius ruficapillus*	X	
Red-kneed Dotterel	*Erythrogonys cinctus*	X	
Red-necked Avocet	*Recurvirostra novaehollandiae*	X	
Red-necked Stint	*Calidris ruficollis*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Ruddy Turnstone (U)	*Arenaria interpres*	FL	Bonn, CAMBA, JAMBA, ROKAMBA
Ruff (U)	*Philomachus pugnax*	X	Bonn, CAMBA, JAMBA, ROKAMBA
White−rumped Sandpiper (U)	*Calidris fuscicollis*	FL	
Wood Sandpiper	*Tringa glareola*	X	Bonn, CAMBA, JAMBA, ROKAMBA
Gulls, Terns			
Silver Gull	*Larus novaehollandiae*	X	

Whiskered Tern	*Chlidonias hybridus*	X	
White-winged Tern	*Chlidonias leucopterus*	TL	JAMBA
Old World Warblers			
Australian Reed-Warbler	*Acrocephalus australis*	X	
Little Grassbird	*Megalurus gramineus*	X	

Table A2: Waterbird feeding habitat guilds.
Data refer to principal or commonly used habitats for feeding. Birds may roost or loaf in certain habitats but not feed there.

	Dense inundated vegetation	Shallows (<0.5m) &/or mud	Deep water (>1m)	Away from wetland	Saline water	Fresh water
Ducks, Geese, Swans						
Australasian Shoveler		X	X			X
Australian Shelduck		X		X		
Australian Wood Duck				X		
Black Swan		X	X	X	X	X
Blue-billed Duck			X			X
Chestnut Teal		X	X		X	X
Freckled Duck		X	X		X	X
Grey Teal		X	X		X	X
Hardhead		X	X			X
Musk Duck			X		X	X
Pacific Black Duck		X	X	X	X	X
Pink-eared Duck		X	X		X	X
Grebes						
Australasian Grebe		X	X		X	X
Great Crested Grebe			X		X	X
Hoary-headed Grebe		X	X		X	X
Pelicans, Cormorants, Darters						
Australian Pelican			X		X	X
Darter			X		X	X
Great Cormorant			X		X	X
Little Black Cormorant			X		X	X
Little Pied Cormorant		X	X		X	X
Pied Cormorant			X		X	X
Herons, Ibis, Egrets, Spoonbills						
Australasian Bittern	X	X				X
Australian Little Bittern	X	X				X
Australian White Ibis		X		X	X	X
Black Bittern	X	X			X	X
Cattle Egret		X		X		
Glossy Ibis		X				X
Great Egret		X		X	X	X
Little Egret		X			X	X
Nankeen Night Heron	X	X		X		X
Royal Spoonbill		X			X	X
Straw-necked Ibis		X		X		X
White-faced Heron		X		X	X	X
White-necked Heron		X				X
Yellow-billed Spoonbill		X			X	X
Hawks, Eagles, Falcons						
Osprey			X		X	
Swamp Harrier	X	X		X		X
Whistling Kite		X	X	X	X	X
White-bellied Sea-eagle		X	X	X	X	X
Crakes, Rails, Water Hens, Coots						
Australian Spotted Crake	X	X			X	X
Baillon's Crake	X	X	X			X
Black-tailed Native-hen	X	X		X		X
Buff-banded Rail	X	X		X	X	X

Dusky Moorhen	X	X		X		X
Eurasian Coot		X	X		X	X
Purple Swamphen	X	X		X		X
Spotless Crake	X	X		X		X
Shorebirds						
Banded Lapwing				X		
Banded Stilt		X	X		X	
Bar-tailed Godwit		X			X	X
Black-fronted Dotterel		X		X		X
Black-tailed Godwit		X			X	X
Black-winged Stilt		X			X	X
Broad-billed Sandpiper		X			X	
Common Greenshank		X			X	X
Common Sandpiper		X			X	X
Curlew Sandpiper		X			X	X
Double Banded Plover		X			X	
Great Knot		X			X	
Greater Sand Plover		X			X	
Grey Plover		X			X	
Hooded Plover		X			X	
Inland Dotterel				X		
Little Ringed Plover		X				X
Little Stint		X			X	
Long-toed Stint		X			X	X
Marsh Sandpiper		X			X	X
Oriental Pratincole				In-flight		
Pacific Golden Plover		X		X	X	X
Pectoral Sandpiper		X			X	X
Red Knot		X			X	
Red-capped Plover		X		X	X	X
Red-kneed Dotterel		X				X
Red-necked Avocet		X			X	X
Red-necked Stint		X			X	X
Ruddy Turnstone		X			X	
Ruff		X			X	X
Sharp-tailed Sandpiper		X			X	X
White-rumped Sandpiper		X			X	X
Wood Sandpiper		X				X
Gulls, Terns						
Silver Gull		X	X	X	X	X
Whiskered Tern		X	X		X	X
White-winged Tern		Skim/in-flight	Skim/in-flight		X	X
Old World Warblers						
Australian Reed-Warbler	X	X		X		
Little Grassbird	X	X		X		

Table A3: Waterbird dietary guilds.
O = occasionally may eat item (some records from gut analyses). Note that information on diets of waterbirds is incomplete, best known for certain groups, poorly known for others, and not necessarily based on studies from this Ramsar site.

	Plants and Animals	Mainly Plants	Mainly Animals	Fish	Freshwater crayfish
Ducks, Geese, Swans					
Australasian Shoveler	X				
Australian Shelduck	X				
Australian Wood Duck	X				
Black Swan		X			
Blue-billed Duck	X				
Chestnut Teal	X				X
Freckled Duck	X				
Grey Teal	X				X
Hardhead	X			O	X
Musk Duck	X			O	X
Pacific Black Duck	X				X
Pink-eared Duck	X				X
Grebes					
Australasian Grebe			X	X	
Great Crested Grebe		O	X	X	
Hoary-headed Grebe			X	X	
Pelicans, Cormorants, Darters					
Australian Pelican			X	X	X
Darter	X			X	
Great Cormorant			X	X	X
Little Black Cormorant			X	X	X
Little Pied Cormorant			X	X	X
Pied Cormorant			X	X	X
Herons, Ibis, Egrets, Spoonbills					
Australasian Bittern			X	X	X
Australian Little Bittern			X	X	X
Australian White Ibis			X	X	X
Black Bittern			X	X	X
Cattle Egret			X	X	X
Glossy Ibis			X	O	X
Great Egret			X	X	X
Little Egret			X	X	X
Nankeen Night Heron			X	X	X
Royal Spoonbill		O	X	X	X
Straw-necked Ibis			X		X
White-faced Heron			X	X	X
White-necked Heron			X	X	X
Yellow-billed Spoonbill			X	X	X
Hawks, Eagles, Falcons					
Osprey			X	X	
Swamp Harrier			X	X	
Whistling Kite			X	X	
White-bellied Sea-eagle			X	X	
Crakes, Rails, Water Hens, Coots					
Australian Spotted Crake	X				
Baillon's Crake	X				
Black-tailed Native-hen	X				
Buff-banded Rail	X				

Dusky Moorhen	X				
Eurasian Coot	X				
Purple Swamphen	X			X	Possibly
Spotless Crake	X				
Shorebirds					
Banded Lapwing	X				
Banded Stilt	X			O	
Bar-tailed Godwit	X		X		
Black-fronted Dotterel	X				
Black-tailed Godwit		O	X		
Black-winged Stilt		O	X	O	
Broad-billed Sandpiper			X		X
Common Greenshank	X				
Common Sandpiper	X				
Curlew Sandpiper			X		X
Double Banded Plover			X		
Great Knot			X		
Greater Sand Plover			X		
Grey Plover			X		
Hooded Plover			X		X
Inland Dotterel	X				
Little Ringed Plover			X		
Little Stint			X		
Long-toed Stint			X		
Marsh Sandpiper			X		
Oriental Pratincole			X		
Pacific Golden Plover	X		X		
Pectoral Sandpiper	X				
Red Knot			X		
Red-capped Plover	X				
Red-kneed Dotterel	X				
Red-necked Avocet		O	X	O	
Red-necked Stint	X				
Ruddy Turnstone			X		
Ruff			X		
Sharp-tailed Sandpiper	X				
White-rumped Sandpiper			X		
Wood Sandpiper			X		
Gulls, Terns					
Silver Gull	X			X	X
Whiskered Tern			X	X	
White-winged Tern			X		
Old World Warblers					
Australian Reed-Warbler			X		
Little Grassbird	O		X		

Table A4: Waterbird nesting guilds

	Inundated dead trees	Inundated live trees	In/under inundated shrubs or low vegetation	Ground next to water or on island/ islet	Away from wetlands	Mainly in colonies (in Australia)
Ducks, Geese and Swans						
Australasian Shoveler	X	X	X			
Australian Shelduck	X					
Australian Wood Duck	X	X			X	
Black Swan	X		X	X		O
Blue-billed Duck			X			
Grey Teal	X	X	X	X		
Hardhead			X			
Musk Duck			X			
Pacific Black Duck	X	X	X	X	X	
Pink-eared Duck	X	X	X	X		
Grebes						
Australasian Grebe			X	X		
Hoary-headed Grebe			X			X
Pelicans, Cormorants, Darters						
Little Pied Cormorant	X	X				X
Herons, Ibis, Egrets, Spoonbills						
Australian Little Bittern			X			
Australian White Ibis			X			X
White-faced Heron		X			X	
Hawks, Eagles, Falcons						
Swamp Harrier			X		X	
Crakes, Rails, Water Hens, Coots						
Baillon's Crake			X	X		
Dusky Moorhen			X	X		
Eurasian Coot	X	X	X	X		O
Purple Swamphen			X			
Spotless Crake			X			
Shorebirds						
Banded Lapwing					X	
Black-winged Stilt			X	X		
Red-capped Plover				X		
Old World Warblers						
Australian Reed-Warbler			X			
Little Grassbird			X			

Table A5: Waterbird guilds: other critical life stages or habits

	Flightless at times, each year, due to moulting	Uses daily communal roost or loafing sites
Ducks, Geese, Swans		
Australasian Shoveler	X	Seasonal aggregations on open water
Australian Shelduck	X	X
Australian Wood Duck	X	X
Black Swan	X	Seasonal aggregations on open water
Blue-billed Duck	X	
Chestnut Teal	X	X
Freckled Duck	X	X
Grey Teal	X	X
Hardhead	X	Seasonal aggregations on open water
Musk Duck	X	Seasonal aggregations on open water
Pacific Black Duck	X	X
Pink-eared Duck	X	X
Grebes		
Australasian Grebe	X	Seasonal aggregations on open water
Great Crested Grebe	X	Seasonal aggregations on open water
Hoary-headed Grebe	X	Seasonal aggregations on open water
Pelicans, Cormorants, Darters		
Australian Pelican		X
Darter		X
Great Cormorant		X
Little Black Cormorant		X
Little Pied Cormorant		X
Pied Cormorant		X
Herons, Ibis, Egrets, Spoonbills		
Australasian Bittern		
Australian Little Bittern		
Australian White Ibis		X
Black Bittern		
Cattle Egret		X
Glossy Ibis		
Great Egret		X
Little Egret		X
Nankeen Night Heron		X
Royal Spoonbill		X
Straw-necked Ibis		X
White-faced Heron		X
White-necked Heron		X
Yellow-billed Spoonbill		X
Hawks, Eagles, Falcons		
Osprey		
Swamp Harrier		
Whistling Kite		
White-bellied Sea-eagle		
Crakes, Rails, Water Hens, Coots		
Australian Spotted Crake	X	
Baillon's Crake	X	
Black-tailed Native-hen	X	
Buff-banded Rail	X	
Dusky Moorhen	X	X
Eurasian Coot	X	Seasonal aggregations on open water
Purple Swamphen	X	X

Spotless Crake	X	
Shorebirds		
Banded Lapwing		
Banded Stilt		X
Bar-tailed Godwit		X
Black-fronted Dotterel		
Black-tailed Godwit		X
Black-winged Stilt		X
Broad-billed Sandpiper		X
Common Greenshank		X
Common Sandpiper		X
Curlew Sandpiper		X
Double Banded Plover		X
Great Knot		X
Greater Sand Plover		X
Grey Plover		X
Hooded Plover		X
Inland Dotterel		
Little Ringed Plover		
Little Stint		X
Long-toed Stint		
Marsh Sandpiper		X
Oriental Pratincole		
Pacific Golden Plover		X
Pectoral Sandpiper		X
Red Knot		X
Red-capped Plover		X
Red-kneed Dotterel		
Red-necked Avocet		X
Red-necked Stint		X
Ruddy Turnstone		X
Ruff		X
Sharp-tailed Sandpiper		X
White-rumped Sandpiper		X
Wood Sandpiper		
Gulls, Terns		
Silver Gull		X
Whiskered Tern		X
White-winged Tern		X
Old World Warblers		
Australian Reed-Warbler		
Little Grassbird		

Appendix B: Macroinvertebrates

Table B1: Macroinvertebrate families recorded in Forrestdale and Thomsons Lakes.

	Family	Thomsons Lake	Forrestdale Lake
Annelida	Glossiphoniidae	+	
	Tubificidae	+	
Mollusca	Ancylidae	+	
	Lymnaeidae	+	+
	Physidae	+	+
	Planorbidae	+	
Arachnida	Arrenuridae	+	
	Eylaidae	+	+
	Hydrachnidae	+	+
	Hydryphantidae	+	+
	Limnesiidae	+	+
	Limnocharidae		+
	Oribatidae	+	+
	Pionidae	+	+
	Unionicolidae	+	
Crustacea	Amphisopidae	+	+
	Calanoida	+	+
	Candonidae	+	
	Ceinidae	+	+
	Centropagidae	+	+
	Chydoridae	+	+
	Cyclopoida	+	+
	Cyprididae	+	+
	Cypridopsidae	+	
	Daphniidae	+	+
	Harpacticoida	+	+
	Ilyocryptidae	+	
	Limnocytheridae	+	+
	Macrothricidae		+
	Moinidae	+	+
	Notodromadidae	+	
Insecta	Aeshnidae	+	+
	Caenidae		+
	Ceratopogonidae	+	+
	Chironomidae	+	+
	Chrysomelidae	+	
	Coenagrionidae	+	+
	Corduliidae	+	
	Corixidae	+	+
	Crambidae	+	
	Culicidae	+	+
	Curculionidae	+	
	Dytiscidae	+	+
	Ecnomidae	+	
	Ephydridae	+	+
	Haliplidae	+	+
	Helodidae	+	
	Hydrophilidae	+	+
	Hydroptilidae	+	
	Leptoceridae	+	+
	Lestidae	+	+
	Libellulidae	+	+
	Mesoveliidae	+	
	Nepidae	+	+
	Noteridae	+	
	Notonectidae	+	+
	Pleidae	+	
	Pyralidae	+	+
	Saldidae	+	

	Sciomyzidae	+	
	Scirtidae	+	+
	Stratiomyidae	+	+
	Tabanidae	+	+
	Tipulidae	+	+
	Veliidae	+	+

Appendix C: Amphibians, Reptiles and Mammals

Table C1: Native fauna recorded in Forrestdale and Thomsons Lakes.
Species recorded at: X = both lakes; TL = Thomsons Lake only, FL = Forrestdale Lake only.

Frogs		
Tschudi's Froglet	*Crinia georgiana*	X
Western Sign-bearing Froglet	*Crinia insignifera* (prev. *Ranidella insignifera*)[AB]	X
Moaning Frog	*Heleioporus eyrei*	X
Bullfrog, Western Banjo Frog	*Limnodynastes dorsalis*	X
Slender Tree Frog	*Litoria adelaidensis*	X
Motorbike Frog	*Litoria moorei*	X
Turtle Frog[C]	*Myobatrachus gouldii*	TL
Gunther's Toadlet	*Pseudophryne guentheri*	FL
Turtles		
Long-necked turtle, Oblong Turtle	*Chelodina oblonga*	X
Lizards and Snakes		
Marbled Gecko	*Christinus marmoratus* (prev. *Phyllodactytus marmoratus*)[A]	FL
	Delma Gray	FL
Burton's Snake-lizard	*Lialis burtonis*	X
Keeled Legless Lizard	*Pletholax gracilis*	TL
Southwestern Cool Skink, Swamp Skink	*Acritoscincus trilineatum* (prev. *Leiolopisma trilineatum*)[AB]	X
	Cryptoblepharus plagiocephalus	FL
	Ctenotus lesueurii	TL
Elegant Slider	*Lerista elegans*	TL
Lined Skink, Perth Slider	*Lerista lineata*	X
Common Dwarf Skink	*Menetia greyii*	X
West Coast Morethia Skink	*Morethia lineoocellata*	TL
Dwarf Bearded Dragon	*Pogona minor* (prev. *Amphibolurus minor*)[B]	TL
Western Blue-tongue	*Tiliqua occipitalis*	TL
Bobtail, Shingle-back	*Tiliqua rugosa*	X
Gould's Goanna, Racehorse Goanna	*Varanus gouldii*	X
	Demansia reticulata	FL
Little whip-snake	*Denisonia gouldii*	TL
Crowned Snake	*Elapognathus coronatus* (prev. *Notechis coronatus*)[A]	FL
Tiger Snake	*Notechis scutatus*	X
Dugite	*Pseudonaja affinis*	X
Gould's snake, Gould's Hooded Snake	*Parasuta gouldii* (prev. *Rhinoplocephalus gouldii*)[A]	FL
Mammals		
Water rat	*Hydromys chrysogaster*	TL
Quenda	*Isoodon obesulus fusciventer*	X
Western Grey Kangaroo	*Macropus fuliginosus*	X
Western Brush Wallaby[D]	*Macropus irma*	X
Numbat[E]	*Myrmecobius fasciatus*	TL
White-striped Mastiff Bat	*Tadarida australis*	FL
Brush-tailed Possum	*Trichosurus vulpecula*	TL
Terrestrial birds		
Carnaby's Black-cockatoo	*Calyptorhynchus latirostris*	X

[A] Bartle *et al.* 1987
[B] Crook and Evans 1981
[C] Recorded at Thomsons Lake in the 1970s (Crook and Evans 1981), but has not been recorded since (CALM 2005b).
[D] At Forrestdale Lake, few have been recorded since the 1960s and are believed to no longer inhabit the area (CALM 2005a).
[E] Not recorded in the reserve since 1984 (CALM 2005b).

Appendix D: Flora

Table D1: Flora recorded at Forrestdale and Thomsons Lakes.
TL = Thomsons Lake, FL = Forrestdale Lake; ***** weed species; species names in brackets are no longer current.

Family	Species	TL	FL
Aizoaceae			
*	*Carpobrotus aequilaterus*	X	
*	*Carpobrotus edulis*	X	X
Amaryllidaceae			
*	*Amaryllis belladonna*	X	X
*	*Narcissus tazetta*	X	
Anacardiaceae			
*	*Schinus terebinthifolius*		X
Anthericaceae			
	Caesia micrantha	X	
	Caesia occidentalis	X	
	Chamaescilla corymbosa	X	
	Corynotheca micrantha	X	X
	Dichopogon capillipes (*Arthropodium capillipes*)	X	X
	Dichopogon preissii (*Arthropodium preissii*)	X	X
	Laxmannia squarrosa	X	X
	Sowerbaea laxiflora	X	X
	Thysanotus arbuscula		X
	Thysanotus manglesianus	X	X
	Thysanotus multiflorus	X	
	Thysanotus patersonii	X	X
	Thysanotus sparteus	X	
	Thysanotus triandrus		X
	Tricoryne elatior	X	
	Tricoryne tenella	X	
Apiaceae			
	Apium prostratum	X	
	Centella asiatica (*Centella cordifolia*)	X	X
	Daucus glochidiatus	X	X
	Eryngium pinnatifidum subsp. *palustre* ms	X	
	Eryngium pinnatifidum subsp. *pinnatifidum*	X	
*	*Foeniculum vulgare*	X	
	Homalosciadium homalocarpum	X	X
	Hydrocotyle alata	X	
	Hydrocotyle callicarpa	X	X
	Hydrocotyle diantha	X	
	Hydrocotyle sp.		X
	Platysace compressa	X	
	Schoenolaena juncea		X
	Trachymene pilosa	X	X
	Xanthosia huegelii	X	
Araceae			
*	*Zantedeschia aethiopica*	X	X
Ascelpidaceae			
*	*Asclepias curassavica*		X
*	*Gomphocarpus fruticosus*	X	X
Asparagaceae			
*	*Asparagus asparagoides*	X	X
Asphodelaceae			
*	*Asphodelus fistulosus*	X	X

	Bulbine semibarbata	X	
*	*Trachyandra divaricata*		X
Asteraceae			
	Angianthus preissianus	X	X
*	*Arctotheca calendula*	X	X
	Asteridea pulverulenta	X	X
	Brachyscome bellidioides	X	X
*	*Carduus pycnocephalus*	X	X
*	*Cirsium vulgare*	X	X
*	*Conyza bonariensis*		X
*	*Conyza parva*		X
*	*Conyza sumatrensis* (*Conyza albida*)	X	X
*	*Cotula coronopifolia*	X	X
*	*Dittrichia graveolens*	X	X
	Euchiton collinus (*Gnaphalium gymnocephalum*)	X	
	Gnephosis angianthoides		X
*	*Helichrysum luteoalbum* (*Pseudognaphalium luteoalbum*)	X	X
	Hyalosperma cotula	X	
*	*Hypochaeris glabra*	X	X
	Ixiolaena viscosa	X	
*	*Lactuca saligna*		X
*	*Lactuca serriola*		X
	Lagenophora huegelii (*Lagenifera huegelii*)	X	X
	Millotia myosotidifolia	X	
	Millotia tenuifolia		X
	Myriocephalus occidentalis (*Myriocephalus rhizocephalus*)		X
	Olearia axillaris	X	
	Ozothamnus cordatus		X
	Podolepis gracilis (Swamp form) (GJ Keighery 13126)	X	X
	Podotheca angustifolia	X	X
	Podotheca chrysantha	X	X
	Podotheca gnaphalioides		X
	Pogonolepis stricta	X	
	Pterochaeta paniculata		X
	Quinetia urvillei	X	X
	Rhodanthe citrina	X	
	Senecio hispidulus	X	
	Senecio pinnatifolius (*Senecio lautus*)	X	
	Senecio pinnatifolius var. *maritimus* (*Senecio lautus* subsp. *maritimus*)		X
	Senecio quadridentatus	X	
	Siloxerus humifusus	X	X
	Siloxerus multiflorus (*Rutidosis multiflora*)	X	X
*	*Sonchus asper*	X	
	Sonchus hydrophilus	X	X
*	*Sonchus oleraceus*	X	X
*	*Symphyotrichum subulatum* (*Aster subulatus*)	X	X
*	*Ursinia anthemoides*	X	X
*	*Vellereophyton dealbatum*	X	X
	Waitzia suaveolens	X	X
Brassicaceae			
*	*Brassica tournefortii*	X	X
	Cardamine paucijuga	X	
*	*Heliophila pusilla*	X	X
*	*Raphanus raphanistrum*	X	
*	*Rorippa nasturtium-aquaticum* (*Nasturtium officinale*)	X	X
Campanulaceae			
*	*Wahlenbergia capensis*	X	X
	Wahlenbergia preissii	X	X

Callitrichaceae			
*	*Callitriche stagnalis*	X	
Caryophyllaceae			
*	*Cerastium glomeratum*	X	X
*	*Corrigiola litoralis*	X	X
*	*Petrorhagia dubia* (*Petrorhagia velutina*)	X	X
*	*Silene gallica* var. *quinquevulnera*	X	
*	*Spergula arvensis*	X	
*	*Stellaria media*	X	
Casuarinaceae			
	Allocasuarina fraseriana	X	X
	Allocasuarina humilis	X	
Centrolepidaceae			
	Aphelia cyperoides	X	X
	Centrolepis aristata	X	X
	Centrolepis drummondiana	X	X
	Centrolepis glabra		X
	Centrolepis polygyna		X
Chenopodiaceae			
*	*Atriplex prostrata*	X	X
*	*Chenopodium glaucum*	X	X
*	*Chenopodium macrospermum*		X
*	*Dysphania multifida* (*Chenopodium multifidum*)	X	
	Rhagodia baccata	X	
	Suaeda australis		X
	Tecticornia indica (*Halosarcia indica*)		X
Colchicaceae			
	Burchardia bairdiae		X
	Burchardia congesta (*Burchardia umbellata*)	X	X
	Burchardia multiflora	X	X
Commelinaceae			
	Cartonema philydroides	X	X
Convolvulaceae			
	Wilsonia backhousei		X
Crassulaceae			
*	*Crassula alata*	X	
	Crassula colorata	X	X
	Crassula exserta	X	
*	*Crassula glomerata*	X	X
*	*Crassula natans*	X	X
	Crassula peduncularis	X	
	Crassula thunbergiana	X	
Cuscutaceae			
*	*Cuscuta epithymum*	X	X
Cupressaceae			
	Actinostrobus pyramidalis		X
Cyperaceae			
	Baumea articulata	X	X
	Baumea juncea	X	X
	Baumea preissii subsp. *laxa* (*Baumea laxa*)	X	
	Baumea rubiginosa	X	X
	Bolboschoenus caldwellii	X	X
	Carex preissii	X	
	Chorizandra enodis		X
	Cyathochaeta avenacea	X	X
*	*Cyperus congestus*	X	X

*	*Cyperus eragrostis*	X	
*	*Cyperus tenellus*	X	X
*	*Cyperus tenuiflorus*		X
	Eleocharis acuta		X
	Ficinia nodosa (*Isolepis nodosa*)	X	X
	Gahnia trifida		X
	Isolepis cernua	X	
	Isolepis cernua var. *setiformis* (*Isolepis setiformis*)		X
*	*Isolepis marginata*	X	X
	Isolepis oldfieldiana	X	X
*	*Isolepis prolifera*	X	
	Isolepis stellata	X	
	Lepidosperma longitudinale	X	X
	Lepidosperma pubisquameum	X	
	Lepidosperma scabrum	X	
	Lepidosperma squamatum	X	X
	Lepidosperma striatum	X	
	Mesomelaena stygia	X	X
	Schoenoplectus validus	X	
	Schoenus benthamii		X
	Schoenus brevisetis	X	
	Schoenus clandestinus	X	
	Schoenus curvifolius	X	X
	Schoenus efoliatus	X	
	Schoenus elegans	X	
	Schoenus grandiflorus	X	X
	Schoenus odontocarpus	X	
	Schoenus rigens		X
	Schoenus subbulbosus	X	
	Schoenus tenellus		X
	Tricostularia neesii		X
Dasypogonaceae			
	Acanthocarpus preissii	X	X
	Calectasia narragara	X	X
	Dasypogon bromeliifolius	X	X
	Lomandra caespitosa	X	
	Lomandra hermaphrodita	X	X
	Lomandra nigricans	X	
	Lomandra suaveolens	X	
Dennstaedtiaceae			
	Pteridium esculentum	X	
Dilleniaceae			
	Hibbertia huegelii	X	
	Hibbertia hypericoides	X	X
	Hibbertia racemosa	X	
	Hibbertia subvaginata	X	X
Droseraceae			
	Drosera erythrorhiza	X	
	Drosera gigantea		X
	Drosera glanduligera	X	X
	Drosera macrantha subsp. *macrantha*	X	X
	Drosera menziesii subsp. *penicillaris*	X	X
	Drosera occidentalis		X
	Drosera paleacea	X	
Epacridaceae			
	Astroloma pallidum	X	
	Brachyloma preissii		X

	Conostephium pendulum	X	X
	Conostephium preissii	X	
	Leucopogon conostephioides	X	X
	Leucopogon propinquus	X	X
	Lysinema ciliatum	X	
	Lysinema elegans	X	
Euphorbiaceae			
*	*Euphorbia peplus*	X	X
*	*Euphorbia terracina*	X	X
	Phyllanthus calycinus	X	
	Poranthera microphylla		X
*	*Ricinus communis*		X
Furmariaceae			
*	*Fumaria capreolata*	X	X
*	*Fumaria muralis*	X	
Gentianaceae			
*	*Centaurium erythraea*	X	X
*	*Centaurium tenuiflorum*		X
*	*Cicendia filiformis*	X	
Geraniaceae			
*	*Erodium botrys*	X	
	Erodium cygnorum		X
*	*Geranium molle*	X	X
	Geranium solanderi	X	
	Pelargonium australe		X
*	*Pelargonium capitatum*	X	X
	Pelargonium littorale	X	
Goodeniaceae			
	Anthotium junciforme		X
	Dampiera linearis	X	X
	Goodenia micrantha	X	X
	Goodenia pulchella	X	X
	Lechenaultia expansa	X	
	Lechenaultia floribunda		X
	Scaevola aemula		X
	Scaevola canescens	X	X
Haemodoraceae			
	Anigozanthos humilis	X	X
	Anigozanthos manglesii	X	X
	Anigozanthos viridis	X	X
	Conostylis aculeata	X	X
	Conostylis candicans	X	
	Conostylis juncea	X	X
	Conostylis setigera	X	
	Haemodorum paniculatum	X	
	Haemodorum sparsiflorum	X	X
	Haemodorum spicatum	X	X
	Phlebocarya ciliata	X	X
	Tribonanthes australis	X	X
	Tribonanthes violacea		X
Haloragaceae			
	Haloragis brownii	X	
	Myriophyllum salsugineum	X	
Hypoxidaceae			
	Hypoxis occidentalis	X	
Iridaceae			
*	*Chasmanthe floribunda*	X	

*	*Ferraria crispa*	X	
*	*Freesia alba* x *leichtlinii* (*Freesia* x *refracta*)	X	
*	*Gladiolus caryophyllaceus*	X	X
*	*Gladiolus undulatus*	X	
	Orthrosanthus laxus	X	
	Patersonia juncea	X	
	Patersonia occidentalis	X	X
	Patersonia occidentalis (Swamp Form)	X	
*	*Romulea flava*		X
*	*Romulea rosea*	X	X
*	*Watsonia meriana* var. *bulbillifera* (*Watsonia bulbillifera*)	X	
Juncaceae			
*	*Juncus articulatus*	X	
*	*Juncus bufonius*	X	X
*	*Juncus capitatus*	X	X
	Juncus kraussii		X
*	*Juncus microcephalus*	X	X
	Juncus pallidus	X	X
	Juncus planifolius		X
	Luzula meridionalis	X	X
Juncaginaceae			
	Triglochin centrocarpa		X
	Triglochin huegelii	X	
	Triglochin linearis	X	
	Triglochin mucronata		X
	Triglochin muelleri (*Triglochin calcitrapum* subsp. *recurvum*)	X	
Lamiaceae			
	Hemiandra pungens	X	X
*	*Mentha* x *piperita*	X	
*	*Stachys arvensis*	X	
Lauraceae			
	Cassytha aurea (*Cassytha pubescens*)		X
	Cassytha racemosa	X	X
Lemnaceae			
	Lemna disperma	X	
Linaceae			
	Linum marginale	X	X
Lobeliaceae			
	Grammatotheca bergiana	X	
	Lobelia anceps (*Lobelia alata*)	X	
	Lobelia tenuior	X	X
*	*Monopsis debilis*	X	X
Loganiaceae			
	Logania vaginalis	X	
	Phyllangium paradoxum	X	
Loranthaceae			
	Amyema miquelii		X
	Nuytsia floribunda	X	X
Lythraceae			
*	*Lythrum hyssopifolia*	X	X
Menyanthaceae			
	Villarsia albiflora	X	X
	Villarsia capitata	X	
	Villarsia submersa		X
	Villarsia violifolia	X	
Mimosaceae			

	Acacia cochlearis	X	
	Acacia cyclops	X	
	Acacia huegelii	X	X
	Acacia lasiocarpa var. *bracteolata*		X
	Acacia pulchella	X	X
	Acacia saligna	X	X
	Acacia stenoptera	X	X
	Acacia willdenowiana	X	
Molluginaceae			
	Macarthuria australis	X	X
Moraceae			
*	*Ficus carica*		X
Myoporaceae			
	Eremophila glabra		X
	Myoporum caprarioides	X	X
Myrtaceae			
	Astartea affinis (*Astartea* sp. Brixton)		X
	Astartea fascicularis	X	X
	Baeckea camphorosmae	X	
	Beaufortia elegans	X	
	Calothamnus hirsutus		X
	Calothamnus lateralis	X	X
	Calothamnus quadrifidus	X	
	Calytrix angulata	X	X
	Calytrix flavescens	X	
	Calytrix fraseri	X	X
	Eremaea pauciflora var. pauciflora	X	
	Eucalyptus gomphocephala	X	
	Eucalyptus marginata	X	X
	Eucalyptus rudis subsp. *rudis*	X	X
	Eucalyptus todtiana	X	
	Hakea sulcata		X
	Hypocalymma angustifolium	X	X
	Hypocalymma robustum	X	
	Kunzea glabrescens	X	X
	Kunzea micrantha		X
*	*Leptospermum laevigatum*		X
	Melaleuca cuticularis		X
	Melaleuca incana	X	X
	Melaleuca lanceolata	X	
	Melaleuca lateriflora subsp. *acutifolia*		X
	Melaleuca lateritia		X
	Melaleuca nesophila	X	
	Melaleuca pauciflora (*Melaleuca leptoclada*)		X
	Melaleuca preissiana	X	X
	Melaleuca rhaphiophylla	X	X
	Melaleuca systena	X	
	Melaleuca teretifolia	X	X
	Melaleuca thymoides	X	
	Melaleuca viminea		X
	Pericalymma ellipticum		X
	Pericalymma spongiocaule	X	
	Regelia ciliata	X	X
	Scholtzia involucrata	X	X
	Verticordia densiflora	X	X
	Verticordia drummondii	X	
	Verticordia lindleyi subsp. *lindleyi*		X

Onagaraceae			
	Epilobium billardiereanum	X	X
	Epilobium hirtigerum	X	X
Orchidaceae			
	Caladenia discoidea	X	X
	Caladenia flava	X	X
	Caladenia georgei	X	
	Caladenia huegelii	X	
	Caladenia latifolia	X	X
	Caladenia longicauda	X	X
	Caladenia marginata		X
	Cyanicula gemmata	X	
	Cyrtostylis huegelii	X	X
*	*Disa bracteata* (*Monadenia bracteata*)	X	X
	Diuris amplissima	X	
	Diuris emarginata	X	
	Diuris laxiflora	X	X
	Diuris longifolia		X
	Diuris purdiei		X
	Drakaea elastica		X
	Elythranthera brunonis	X	X
	Eriochilus dilatatus	X	
	Eriochilus helonomos	X	
	Leporella fimbriata	X	X
	Leptoceras menziesii	X	X
	Microtis media subsp. *media*	X	X
	Microtis orbicularis		X
	Pheladenia deformis (*Cyanicula deformis*)	X	X
	Prasophyllum ovale	X	
	Prasophyllum parvifolium	X	X
	Pterostylis brevisepala	X	
	Pterostylis pyramidalis (*Pterostylis nana*)	X	X
	Pterostylis rogersii	X	
	Pterostylis sanguinea		X
	Pterostylis sp. Slender Snail Orchid (G.J. Keighery 14516)	X	
	Pterostylis vittata	X	
	Pyrorchis nigricans (*Lyperanthus nigricans*)	X	X
	Thelymitra antennifera		X
	Thelymitra campanulata	X	
	Thelymitra crinita	X	X
	Thelymitra flexuosa	X	X
	Thelymitra macrophylla (*Thelymitra nuda*)		X
Orobanchaceae			
	Orobanche minor (*Orobanche australiana*)	X	X
Oxalidaceae			
	Oxalis perennans	X	
*	*Oxalis pes-caprae*	X	X
*	*Oxalis purpurea*	X	
Papilionaceae			
	Aotus intermedia	X	
	Bossiaea eriocarpa	X	X
*	*Chamaecytisus palmensis*		X
	Daviesia decurrens/incrassata	X	
	Daviesia nudiflora	X	
	Daviesia physodes	X	
	Daviesia preissii	X	
	Daviesia triflora	X	

	Euchilopsis linearis	X	X
	Eutaxia virgata	X	X
	Gastrolobium capitatum (*Nemcia capitata*)	X	
	Gastrolobium nervosum (*Nemcia reticulata*)	X	
	Gompholobium tomentosum	X	X
	Hardenbergia comptoniana	X	X
	Hovea stricta (*pungens*)	X	
	Hovea trisperma	X	X
	Isotropis cuneifolia	X	
	Jacksonia furcellata	X	X
	Jacksonia sericea (*Jacksonia gracilis*)		X
	Jacksonia sternbergiana	X	X
	Kennedia prostrata	X	X
*	*Lotus angustissimus*	X	X
*	*Lotus subbiflorus* (*Lotus suaveolens*)		X
*	*Lotus uliginosus*	X	
*	*Lupinus angustifolius*	X	
*	*Lupinus cosentinii*	X	
*	*Medicago polymorpha*	X	X
*	*Melilotus indicus*	X	X
*	*Ornithopus compressus*	X	
	Pultenaea ochreata	X	
	Pultenaea reticulata	X	
	Sphaerolobium vimineum	X	
*	*Trifolium angustifolium*		X
*	*Trifolium campestre*	X	
*	*Trifolium dubium*	X	
*	*Trifolium repens*	X	
*	*Trifolium resupinatum*		X
*	*Vicia hirsuta*	X	
*	*Vicia sativa* subsp. *nigra*	X	X
	Viminaria juncea	X	
Phormiaceae			
	Dianella revoluta	X	X
	Stypandra glauca		X
Pinaceae			
*	*Pinus pinaster*		X
Phytolaccaceae			
*	*Phytolacca octandra*	X	
Plantaginaceae			
*	*Plantago lanceolata*	X	
Poaceae			
*	*Aira cupaniana*	X	X
	Amphipogon laguroides	X	
	Amphipogon turbinatus	X	X
*	*Anthoxanthum odoratum*	X	X
	Austrodanthonia occidentalis (*Danthonia occidentalis*)	X	
	Austrodanthonia setacea (*Danthonia setacea*)	X	
	Austrostipa compressa (*Stipa compressa*)	X	X
	Austrostipa elegantissima		X
	Austrostipa flavescens (*Stipa flavescens*)	X	
	Austrostipa pycnostachya (*Stipa pycnostachya*)	X	
	Austrostipa semibarbata		X
	Austrostipa tenuifolia (*Stipa tenuifolia*)	X	
*	*Avena barbata*	X	X
*	*Avena fatua*	X	
*	*Brachypodium distachyon*	X	
*	*Briza maxima*	X	X

*	*Briza minor*	X	X
*	*Bromus catharticus*	X	
*	*Bromus diandrus*	X	X
*	*Bromus hordeaceus*	X	
*	*Bromus madritensis*	X	
*	*Cortaderia selloana*	X	X
*	*Cynodon dactylon*	X	X
	Deyeuxia quadriseta	X	X
	Dichelachne crinita		X
*	*Digitaria sanguinalis*	X	
*	*Ehrharta calycina*	X	X
*	*Ehrharta longiflora*	X	X
*	*Eragrostis curvula*	X	X
	Hemarthria uncinata	X	
*	*Holcus lanatus*	X	X
*	*Hordeum leporinum*	X	
*	*Hyparrhenia hirta*		X
	Lachnagrostis filiformis (*Agrostis avenacea*)	X	X
	Lachnagrostis plebeia (*Agrostis plebeia*)	X	
*	*Lagurus ovatus*	X	X
*	*Lolium rigidum*	X	X
	Microlaena stipoides	X	
	Neurachne alopecuroidea	X	
*	*Paspalum dilatatum*	X	X
*	*Paspalum distichum*	X	
*	*Paspalum urvillei*		X
*	*Paspalum vaginatum*	X	
*	*Pennisetum clandestinum*	X	X
*	*Phalaris angusta*		X
*	*Phalaris paradoxa*	X	
*	*Poa annua*		X
	Poa drummondiana	X	
	Poa poiformis		X
	Poa porphyroclados	X	
*	*Polypogon monspeliensis*	X	X
*	*Stenotaphrum secundatum*	X	X
*	*Vulpia bromoides*	X	
*	*Vulpia myuros*	X	X
Phytolaccaceae			
*	*Phytolacca octandra*		X
Polygalaceae			
	Comesperma calymega	X	X
	Comesperma virgatum	X	X
Polygonaceae			
*	*Acetosella vulgaris*	X	
	Muehlenbeckia polybotrya	X	
	Persicaria decipiens (*Persicaria salicifolium*)	X	
	Persicaria prostrata	X	
*	*Rumex crispus*	X	X
*	*Rumex pulcher*	X	
Portulacaceae			
	Calandrinia calyptrata	X	X
	Calandrinia corrigioloides	X	X
Primulaceae			
*	*Anagallis arvensis*	X	X
	Samolus junceus	X	

Proteaceae			
	Adenanthos cygnorum	X	X
	Adenanthos obovatus		X
	Banksia attenuata	X	X
	Banksia dallanneyi var. *dallanneyi* (*Dryandra lindleyana var. lindleyana*)	X	X
	Banksia grandis	X	
	Banksia ilicifolia	X	X
	Banksia littoralis	X	X
	Banksia menziesii	X	X
	Banksia sessilis (*Dryandra sessilis*)	X	
	Banksia telmatiaea		X
	Hakea prostrata	X	
	Hakea varia	X	X
	Persoonia saccata	X	
	Petrophile linearis	X	X
	Stirlingia latifolia	X	X
	Synaphea spinulosa	X	X
Ranunculaceae			
	Clematis aristata	X	
*	*Ranunculus muricatus*	X	
Restionaceae			
	Chaetanthus aristatus		X
	Desmocladus asper	X	X
	Desmocladus fasciculatus	X	X
	Desmocladus flexuosus		X
	Dielsia stenostachya	X	X
	Hypolaena exsulca	X	X
	Hypolaena pubescens	X	X
	Lepyrodia muirii	X	X
	Lyginia barbata		X
	Lyginia imberbis	X	
	Meeboldina cana		X
	Meeboldina coangustata	X	
	Meeboldina roycei		X
	Meeboldina scariosa	X	
Rhamnaceae			
	Cryptandra arbutiflora	X	
	Spyridium globulosum	X	
Rubiaceae			
*	*Galium aparine*	X	
*	*Galium murale*		X
	Opercularia hispidula	X	
	Opercularia vaginata	X	X
*	*Sherardia arvensis*	X	
Ruppiaceae			
	Ruppia polycarpa		X
Rutaceae			
	Boronia crenulata var. *crenulata*	X	
	Boronia crenulata subsp. *viminea*	X	
	Boronia dichotoma	X	
	Philotheca spicata	X	X
Santalaceae			
	Exocarpos sparteus	X	X
	Leptomeria empetriformis	X	
	Leptomeria pauciflora	X	
	Santalum acuminatum		X

Sapindaceae			
	Dodonaea hackettiana	X	
Scrophulariaceae			
*	*Bartsia trixago* (*Bellardia trixago*)	X	
*	*Cymbalaria muralis* subsp. *muralis*	X	
*	*Dischisma arenarium*	X	X
*	*Dischisma capitatum*	X	
	Gratiola pubescens	X	X
*	*Parentucellia latifolia*	X	X
*	*Parentucellia viscosa*	X	X
*	*Verbascum virgatum*	X	
Solanaceae			
*	*Nicotiana glauca*		X
*	*Physalis peruviana*	X	
*	*Solanum americanum*	X	X
*	*Solanum linnaeanum*		X
*	*Solanum nigrum*	X	X
	Solanum symonii	X	
Stackhousiaceae			
	Stackhousia monogyna (*Stackhousia huegelii*)	X	
	Stackhousia monogyna (*Stackhousia pubescens*)	X	
	Tripterococcus brunonis	X	
Stylidiaceae			
	Levenhookia pusilla	X	
	Levenhookia stipitata	X	
	Stylidium brunonianum	X	
	Stylidium calcaratum	X	
	Stylidium divaricatum		X
	Stylidium junceum	X	X
	Stylidium mimeticum		X
	Stylidium piliferum	X	X
	Stylidium repens	X	X
	Stylidium schoenoides	X	
Tamariaceae			
*	*Tamarix aphylla*		X
Thymeleaceae			
	Pimelea angustifolia	X	
	Pimelea rosea subsp. *rosea*	X	
Tremandraceae			
	Platytheca galioides	X	
Tropaeolaceae			
*	*Tropaeolum majus*		X
Typhaceae			
	Typha domingensis	X	X
*	*Typha orientalis*	X	X
Urticaceae			
	Parietaria debilis		X
Violaceae			
	Hybanthus calycinus	X	
Xanthorrhoeaceae			
	Xanthorrhoea preissii	X	X
Zamiaceae			
	Macrozamia fraseri		X
	Macrozamia riedlei	X	

Appendix E: Curriculum Vitae of the Authors

Professor Jennifer Ann Davis

Current Position:	Professor of Freshwater Ecology
Work Address:	School of Biological Sciences, Monash University, Clayton, Victoria 3800 Email: Jennifer.Davis@sci.monash.edu.au

Qualifications:

1982	Doctor of Philosophy (PhD), University of Tasmania.
1975	Bachelor of Science (Hons First Class), University of Tasmania.

Career Outline

2009	Professor of Freshwater Ecology, School of Biological Sciences, Monash University.
2001	Promoted to Associate Professor, Murdoch University
2000–2001 & 1996–1997	Head of School, Environmental Science, Murdoch University.
1997	Promoted to Senior Lecturer, Murdoch University.
1991–1995	Lecturer in Aquatic Ecology, School of Biological and Environmental Sciences, Murdoch University.
1990–1991 (June)	Temporary Lecturer, Centre for Water Research, University of Western Australia.
1985–1989	Tutor & Senior Tutor, School of Environmental and Life Sciences, Murdoch University.
1982–1984	Queen's Fellow in Marine Science, Civil Engineering & Zoology, University of Western Australia.
1978–1981	Demonstrator, Zoology Department, University of Tasmania.
1976–1977	Science Teacher, Education Department (Tasmania).

Recent Awards

2006	Limnology Medal, Australian Society for Limnology
2005	British Ecological Society's - Photographic Competition
2004	Vice-Chancellor's Award for Excellence in Postgraduate Supervision, Murdoch University

Summary of Research and Professional Activities

Over the course of my research career I have published (individually or collaboratively) over 170 works, including a total of 4 books, 70 peer-reviewed papers and conference proceedings, 83 technical reports and other articles, and 3 CD ROM's. I have supervised 72 research students through to successful graduation (12 PhDs, 8 Masters, 43 Honours and 9 Environmental Science Projects).

My research activities include wetland, river and estuarine ecology, conceptual modelling, the development of decision support tools for wetland management, biomonitoring, bioassessment and aquatic biodiversity research. More details of these

projects can be found at my previous website: http://wwwscience.murdoch.edu.au/centres/aer/.

Over $4 million has been obtained for aquatic research projects from a diverse range of sources. These have included: the Government of Sarawak, the Australian Research Council, Land and Water Australia, Commonwealth Department of Environment and Water Resources, WA Estuarine Research Foundation, WA Department of Water (previously Water and Rivers Commission) Water Corporation of Western Australia, WA Department of Environment, WA Department of Conservation and Land Management (now DEC), Alcoa Australia, Worsley Alumina, City of Cockburn, Town of Cambridge and Martinick McNulty.

I am actively involved in the Australian Society for Limnology and have held the positions of President and Newsletter Editor. I am the Chair of the Research Sub-Committee of the Australian Biological Resources Study (ABRS) Research Advisory Committee and a member of the Editorial Board of Freshwater Biology. I was the non-government scientist on the WA Wetlands Coordinating Committee for over ten years and completed two terms (6 years) on the Conservation Commission (the advisory body to the Department of Conservation and Land Management in Western Australia).

Recent Publications

Davis, J.A. and Brock, M. (2008) Detecting unacceptable change in the ecological character of Ramsar wetlands. *Ecological Management and Restoration*. 9:26-32.

Bonada, N., Rievadevall, M., Dallas, H., Davis, J., Day, J., Figueroa, Resh, V. and Prat, N. (2008). Multiscale assessment of macroinvertebrate richness and composition in Mediterranean-climate rivers. *Freshwater Biology* 53:772-788

Brim Box, J., Duguid, A., Read, R.E., Kimber R.G., Knapton, A., Davis J.A., and Bowland, A.E. (2008) Central Australian waterbodies: the importance of permanence in a desert landscape. *Journal of Arid Environments* 72: 1395-1413.

Giles, J.C. Kuchling, G. and Davis, J.A. (2008) Populations of the Snake-necked Turtle *Chelodina oblonga* in three suburban lakes of Perth, Western Australia. *Herpetological Conservation* 3:275-284

Stewart, B., Strehlow, K. and Davis, J.A. (2008) Impacts of deep open drains on water quality and biodiversity of receiving waterways in the wheatbelt of Western Australia. *Hydrobiologia DOI 10.1007/s10750-008-9603-x*

Sim, L.L., Davis, J.A. and Chambers, J.M. (2009). Development of conceptual models for ecological regime change in temporary Australian wetlands in *New models for ecosystem dynamics and restoration*. Hobbs, R.J. & Suding, K. (eds). Island Press.

Dr Kellie Maher

Current Position:	Research Fellow
Work Address:	School of Plant Biology, University of Western Australia, Crawley, Western Australia 6009

Qualifications:

2008	Doctor of Philosophy (PhD) in Environmental Science, School of Environmental Science, Murdoch University, Perth, Western Australia.
2003	Honours in Environmental Science (First Class), School of Environmental Science, Murdoch University, Perth, Western Australia.
2001	Bachelor of Science (Environmental Science), Murdoch University, Perth, Western Australia.

Career Outline

2009	Research Fellow, School of Plant Biology, University of Western Australia Perth, Western Australia.
2008	Research Fellow, School of Environmental Science, Murdoch University, Perth, Western Australia.
2004–2006	Tutor/Demonstrator (Environmental Restoration) School of Environmental Science, Murdoch University, Perth, Western Australia.
2001–2003	Environmental Technician, BP Oil Refinery (Kwinana), Perth, Western Australia.

Summary of Research and Professional Activities

My research activities include landscape and restoration ecology, wetland ecology, vegetation dynamics and the role of disturbance in fragmented landscapes, and restoring native vegetation after the removal of pine plantations.