Ecological Character Description
Vasse-Wonnerup Wetlands Ramsar Site
South-west Western Australia

prepared on behalf of

Department of
Environment and Conservation

GeoCatch

Australian Government

SOUTH WEST CATCHMENTS COUNCIL

Department of Water
Government of Western Australia

by

—— Wetland Research & Management ——

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Frontispiece: Aerial photograph of Vasse Estuary, looking north-west toward the Port Geographe development on the coast. In the foreground, the Abba River can be seen entering to the left of the broad Malbup Creek (photo: Martin Pritchard, GeoCatch).

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LIST OF ABBREVIATIONS

ANZECC/ARMCANZ	Australian and New Zealand Environment and Conservation Council, and the Agriculture and Resource Management Council of Australia and New Zealand http://eied.deh.gov.au/water/quality/nwqms/volume1.html
CALM	Department of Conservation and Land Management; 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 www.environment.gov.au/biodiversity/migratory/waterbirds/index.html
CCI	Coastal Catchments Initiative www.environment.gov.au/coasts/pollution/cci/index.html
CMS	Convention on the Conservation of Migratory Species of Wild Animals, ratified in Bonn in 1983 www.cms.int/
Coastal CRC	The Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (national co-operative) www.coastal.crc.org.au/
CSIRO	Commonwealth Scientific & Industrial Organisation www.csiro.au
DAF	Department of Agriculture and Food (WA) www.agric.wa.gov.au/
DIA	Department of Indigenous Affairs (WA) www.dia.wa.gov.au/
DIWA	Directory of Important Wetlands in Australia (Environment Australia 2001) www.environment.gov.au/water/publications/environmental/wetlands/database/
DEC	Department of Environment and Conservation (WA) www.dec.wa.gov.au/
DEW	Australian Government Department of the Environment and Water Resources www.environment.gov.au/
DoE	Department of Environment (now Department of Environment and Conservation, WA)
DoW	Department of Water (WA) http://portal.water.wa.gov.au/portal/page/portal/home
DPI	Department of Planning and Infrastructure (WA) www.dpi.wa.gov.au/
EPA	Environment Protection Authority (WA) www.epa.wa.gov.au/
GeoCatch	Geographe Catchment Council Inc., Busselton www.geocatch.asn.au/pages/framesetgeo.html?=geocatch2.html
IUCN	The International Union for the Conservation of Nature and Natural Resources www.iucn.org/
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 www.environment.gov.au/biodiversity/migratory/waterbirds/index.html
LCDC	Land Conservation District Committee
MAFRL	Marine and Freshwater Research Laboratory, Murdoch University (WA) wwwscience.murdoch.edu.au/centres/mafrl/
NHT	Australian Government National Heritage Trust www.nht.gov.au/
NLWRA	National Land and Water Resources Audit, National Heritage Trust (Australian Government) www.nlwra.gov.au/
NRM	Natural Resource Management www.nrm.gov.au/
Ramsar	Ramsar Convention on Wetlands, ratified in Ramsar, Iran in 1975. Officially known as *The Convention on Wetlands of International Importance, especially as Waterfowl Habitat* www.ramsar.org/
SWCC	Southwest Catchments Council www.swcatchmentscouncil.com/
WAPC	Western Australian Planning Commission www.wapc.wa.gov.au/

EXECUTIVE SUMMARY

Background

The Vasse-Wonnerup Wetlands were originally nominated for listing under the Ramsar Convention in 1990. The Ramsar Convention (*The Convention on Wetlands of International Importance, especially as Waterfowl Habitat*) is an intergovernmental multilateral treaty on the conservation of designated Wetlands of International Importance and the wise use of wetlands generally. In 2000, the listed area was extended and the Ramsar Site now covers over 1,115 ha including Wonnerup Inlet, the Vasse and Wonnerup estuaries (lagoons) and lower reaches along the Sabina and Abba rivers (see maps Appendix A). A natural sand bar across the mouth of Wonnerup Inlet closes the system to the sea for much of the year and there are floodgates on the exit channels that connect the Vasse and Wonnerup estuaries to the narrow Wonnerup Inlet. The floodgates were installed in the early 1900s to mitigate flooding of adjoining agricultural land (Lane *et al.* 1997) during high river flows in winter and to prevent seawater inundation caused by storm surges. The gates effectively transformed the estuaries into shallow, winter-fresh/summer-saline lagoons, unique in Western Australia. The wetlands regularly support peak numbers of 25,000 - 35,000 waterbirds in most years, and provide the most significant regular breeding habitat for Black Swan *Cygnus atratus* in the State.

The Site meets two of Ramsar's nominating criteria - it regularly supports more than 20,000 waterbirds and it regularly supports at least 1% of the relevant Ramsar populations of Black-winged Stilt, Red-necked Avocet, Australian Shelduck and Australasian Shoveler (see Section 2.4). Contracting Parties to the Ramsar Convention have a number of responsibilities. Prominent among these are commitments to develop and implement management plans for the conservation of the Ramsar listed values and for wise use. These plans must include effective monitoring for any change in the ecological character of the wetland as a result of human activity. There must also be measures in place that enable managers to respond to any perceived or actual threats in an appropriate and timely manner. Change may be adverse or beneficial. Describing the ecological character of a Ramsar site is therefore a fundamental step so that a baseline condition is documented and can then be used to guide management actions and monitoring. 'Ecological character' has been defined by IX.1 Annex A Resolution under the Ramsar Convention (2005a) as "the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time". Although Ramsar provides guidelines for management planning, establishing monitoring programs and undertaking risk assessments, there is at present no method recommended under the Convention for describing ecological character. The approach taken for the Vasse-Wonnerup Wetlands was therefore consistent with that outlined in the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007).

The Vasse-Wonnerup Wetlands and their floodgates play an important role in provision of waterbird habitat and in flood and storm-surge protection for low-lying coastal properties, including the township of Busselton (Lane *et al.* 1997). The floodgates however, also act as a partial barrier to upstream/downstream movement of fish and reduce flushing flows that may otherwise help ameliorate high nutrient concentrations from catchment runoff. Excessive algal blooms, blooms of potentially toxic cyanobacteria, anoxia and fish deaths are not uncommon. On several documented occasions, sudden, mass fish deaths have occurred in the lower reaches of Vasse-Wonnerup, principally in the channel immediately upstream of the Vasse estuary floodgates (Lane *et al.* 1997). Though installation of the gates was not the cause of fish deaths, it has exacerbated the situation. In summer 1988, in an attempt to improve water quality, the (then) Water Authority of Western Australia manually opened the floodgates, allowing seawater to enter and fish to escape the adverse conditions that prevail throughout summer and autumn. However, the continued manual opening of the gates over summer-autumn in subsequent years (to 1997), is believed to have lead to other problems such as increased salinisation of adjoining pastoral lands and death of colonising native vegetation that has encroached upon lower elevations since the floodgates were installed.

There are already a number of collaborative monitoring, rehabilitation and restoration programs for the Vasse-Wonnerup catchment undertaken by the State Department of Environment and Conservation (DEC), the Geographe Catchment Council (GeoCatch), Land Conservation District Committees (LCDCs), the Department of Agriculture and Food (DAF) and the Department of Water (DoW). The majority of these are related, either directly or indirectly, to problems of water quality. In order to implement a unified and holistic approach to catchment management, all key ecological attributes (features) must first be identified, together with "limits of acceptable change" upon which management actions and future monitoring can be based. To that end, this report provides a summary of all available information on the key ecological components (biota, hydrology, geomorphology, physico-chemistry), the interactions between them (processes) and the social and cultural importance (benefits/services) of the Site. The Vasse-Wonnerup ECD is an integral part of the Water Quality Improvement Plan (WQIP) component of the Vasse-Geographe Coastal Catchments Initiative. The Department of Water in partnership with GeoCatch is responsible for preparing the WQIP, aimed at providing a management approach to reducing nutrient levels in Geographe Bay and the Vasse Wonnerup wetlands using scientific models and decision support tools prepared under this new initiative. The agencies involved also wish to ensure that any measures adopted to improve water quality, do not themselves pose further risk to the ecological integrity of the wetlands.

The starting point for documenting the ecological character was an investigation of the wetland's Ramsar values as nominated in 1990. In turn, other fundamental components and processes are described, and finally, the services/benefits offered by the wetland system. Table 26 (page 89) provides a synopsis of key Site components and processes and the ecosystem services they directly support.

Change in ecological character is defined as the change in Site condition relative to that at the time of Ramsar listing in 1990. However, as the Site was already highly modified at that time and there are on-going problems associated with water quality and algal blooms, consideration has been given to the historic condition in order to aid restoration and rehabilitation activities.

Available Data

Little baseline research has been undertaken at the Site. Data that are available pertain mostly to waterbirds, water levels and water quality. However, the quality and quantity of most of these data are inadequate to detect other than gross change, with inconsistencies in both collection method and sampling periods. There is much that is still unknown about the functioning of the Vasse-Wonnerup Wetlands ecosystem. There are few quantitative data on the relationships between the biota, physico-chemistry, geomorphology and hydrology. Because of this, the role of key ecosystem components and processes that support wetland services/benefits could not be quantified. Knowledge gaps identified are summarised in Table 29 (page 122) and include:

- Relationships between waterbirds, water depth, salinity and nutrients;
- Chronic direct effects of med-high nutrient loads on birds and on fish and aquatic invertebrates which provide a food source for many waterbird species (and there is little published in the world-wide literature to assist with benchmarking for systems, such as the Vasse-Wonnerup, that are already eutrophic);
- Variation in presence and abundance of non-vagrant and non-irruptive bird species;
- Effect of off-Site variables (*e.g.* rainfall) on regional abundances and distributions of waterbird populations;
- Specific diet of adult waterbirds, breeding adults and juveniles in relation to food items present and accessible in the Site;
- Current use of the Site for waterbird breeding is inadequately understood (Lane *et al.* 2007);
- The year-by-year occurrence of waterbird species on Vasse-Wonnerup is not fully known (Lane *et al.* 2007);
- Relationships between benthic and planktonic invertebrates and nutrients;
- The importance of benthic invertebrates to nutrient fluxes within the estuaries;
- Factors affecting algal bloom development, *e.g.* growth rate, nutrient fluxes, salinity concentration and flow interactions;
- Successional dynamics in macrophyte-phytoplankton dominance are only now (2006) being investigated (Wilson *et al.* 2006);
- Relative contributions of groundwater, river inflow and overland runoff - baseline data collection for hydraulic modelling of the entire Vasse-Geographe catchment, including the Site, commenced in 2006 (DoW 2006) under the Vasse-Geographe Coastal Catchments Initiative Water Quality Improvement Plan;
- Mass-balance equations for carbon, nitrogen and phosphorus and the chemical and biological carrying capacity (*i.e.* the ability of the system to cope with high loads);
- Effect of altered salinity regimes and summer-autumn openings of floodgates on riparian vegetation and soil salinities has not been quantified;
- Effect of climate change on groundwater recharge and plant growth /evapotranspiration is unknown.

For future management to be successful, a more systematic approach to monitoring is required. A review of the current understanding of general wetland processes has been included in the report to demonstrate the complexity and the challenges for managers (see Section 5). Theoretical conceptual models of surface flows, nutrients and algal (*Lyngbya*) bloom formation are provided for the same reason and to aid visualisation of the type of information required to generate specific models for the Vasse-Wonnerup Site (see Section 7.2).

Available raw data has not been included within this report as much of it was considered to be of limited value for trend analysis or determining causal relationships. While there are some relevant databases that are actively maintained and updated, the historic data is of variable quality. For the most up to date data, we refer the reader to the database holding authorities and have provided contact information within Sub-sections 4.1 - 4.14.

Changes to Ecological Character since Ramsar Nomination

Other than for waterbirds, there is insufficient baseline and monitoring data to identify changes since Ramsar nomination in 1990. The most recent waterbird monitoring results (1998 - 2000) showed that despite on-going water quality problems, the Site continued to support waterbird abundance and species populations for which it was Ramsar listed in 1990. Abundances of a number of waterbird species recorded in the 1998 - 2000 surveys were less than previous estimates. For a few of these species, this was attributed to the fact that most, but not all habitats were included in post-1998 (and pre-1998) surveys (Lane *et al.* 2007). For others, closer investigation of historic data is needed to determine if apparent declines are indeed actual and not just artefacts of differences in areas surveyed or sampling technique (Lane *et al.* 2007). Species of local and/or regional concern include Blue-billed Duck, Great Cormorant, Great Egret, Curlew Sandpiper, Long-toed Stint and Wood Sandpiper.

Largely anecdotal evidence does suggest some detrimental changes have occurred since extensions to the Ramsar Site in 2000. Frequency of severe phytoplankton blooms during spring, summer and autumn are believed to be on the rise (Jim Lane, DEC, pers. obs.). An increase in toxic algal blooms is suggested by a recent, new report of two commercial fishermen suffering skin lesions following contact with estuary waters (Jim Lane, pers. comm.). Macroalgal blooms appear to be increasing in some parts of the Vasse and Wonnerup estuaries. There have been recent reports that problem cyanobacterial blooms now too occur in the Wonnerup Estuary (Paice 2001). These increases in algal blooms are of particular concern as they may signal a shift in stable state from a seagrass-macrophyte dominated ecosystem to a phytoplankton-macroalgal dominated one (Wilson *et al.* 2006). There is the very real risk of ecosystem collapse if nutrient export to the estuary continues to rise. Available nutrient and flow data suggest total nutrient loads to the system have not decreased and that eutrophication of the Ramsar Site is likely to continue to worsen (Hall *et al.* 2006). During 2005/06 and 2006/07, local residents also experienced an increase in the severity of noxious odours emitted from drying sediments of the lower Vasse Estuary as water levels declined over summer (Ron Assan, Wonnerup, pers. comm.).

On a more positive note, monitoring refinements to operation of the estuary floodgates and summer openings of the sandbar at the mouth of Wonnerup Inlet appear to have reduced the incidence of sudden mass fish deaths. Continuous water level monitoring equipment was installed at the floodgates in 1998 and the gates were upgraded in 2004 and small fish gates installed that can be left open for longer periods without the risk of sea-water flooding the estuary. Operation of the floodgates and fish gates is now remotely controlled by telemetry.

Setting Indicators and Targets

The original intent of this report was that limits of acceptable change (LOAC) would be determined and that these would inform *inter alia* the development of a water quality improvement plan for the Vasse-Wonnerup catchment. The current lack of robust empirical data however, has made it difficult to set definitive LOAC for many key ecological features. Where sufficient knowledge exists to provide a benchmark, interim LOAC have been proposed until adequate quantifiable baseline data can be gathered for the Site (see Table 27, page 102). For some features, such as waterbird diversity, the LOAC will be no change from the 1990 condition, taking into account natural seasonal and year-to-year variation. For others, such as water quality, an improvement over conditions at time of Ramsar listing in 1990 is desirable in order to ameliorate problem algal blooms. The ability of wetlands to absorb excess nutrients depends on their individual biological and chemical carrying capacity. It is considered highly unlikely that achievable reductions in nutrient loadings would reduce productivity to the extent that waterbird diversity or abundance would be adversely affected. Only once adequate baseline data are available will it be possible to select a definitive suite of indicators and targets for monitoring future change in ecological character of the Site (see Section 8, page 101). Targets for any particular indicator in one wetland type within the Site may need to be quite different to those in another wetland type.

Setting suitable indicators and targets can be difficult due to the complex nature of biological and chemical interactions within ecosystems. In theory, the final suite of indicators should cover a variety of aspects of ecosystem health, including both components (species abundance and diversity, water quality, metal levels *etc*) and processes (primary production, nutrient cycling). In reality, it is often more efficient and effective to select indicators which address specific management objectives, can be readily measured and are not unduly expensive to monitor. In all cases, indicators must be well defined and have sound scientific meaning, *i.e.* knowledge of cause-effect pathways.

Trends in nutrient loadings and concentrations have not been quantified for the Site, nor is there available data on concomitant changes in wetland values. There is however anecdotal evidence that the ecosystem is changing - increased phytoplankton and macroalgal blooms, increased incidence of toxic algal blooms, an increase in noxious odours emitted from estuary sediments and emerging trends of increasing nitrogen concentrations in some tributary rivers. The most recent (DoW 2004) estimates of nitrogen loadings to the Vasse-Wonnerup Site are very high in comparison with values documented as causing detrimental change in other estuaries and lagoons both in Australia (Harris 2001) and overseas (Verhoeven *et al.* 2006). Spot measurements of water column nutrient concentrations (Hall *et al.* 2006) have revealed phosphorus levels in the estuaries and tributary rivers in excess of levels known to cause shifts in ecosystem stable state (Sheffer 1990, Novak & Chambers 2005). Ecosystems are subject to threshold effects; change is often abrupt and dramatic and they are highly resistant to switching back even if nutrients are reduced below the critical load.

Research, Monitoring and Management Needs

To some degree, the Vasse-Wonnerup Estuary would have undergone natural nutrient enrichment due to geomorphologic processes, low hydrodynamic energy and accumulation of suspended and deposited organic materials. Nutrient enrichment can be beneficial, leading to increased primary productivity (algae & seagrasses) and associated increases in abundance of invertebrates, fish and waterbirds (McComb & Davis 1993). However, excessive nutrient loadings (either external or internal) can have detrimental effects on ecosystem functioning resulting in persistent, severe toxic phytoplankton blooms, proliferation of opportunistic macroalgae such as *Ulva*, loss of vascular plants, turbid, foul smelling (mephitic) water, oxygen depletion and associated mass mortality of animals (de Jong *et al.* 2002). Large persistent blooms may cause hindrance to intertidal feeding by wading birds and ducks. Ultimately, ecosystem collapse can ensue due to over-enrichment beyond the “maximum critical self-regulatory level” to an extent that detrimental processes cause irreversible changes in aquatic ecosystems (Elliot & de Jong 2002). The chronic direct effects of medium to high nutrient loads on waterbirds, fish and invertebrates in the Vasse-Wonnerup Site are unknown. Ammonia and nitrite are both known to be acutely toxic to fish. Even nitrate is toxic at very high concentration.

The relative contribution of the various point and diffuse sources to nutrient loads to the Vasse-Wonnerup Estuary is unknown, but accumulation of leached nitrogen and phosphorus in the estuary sediments is believed a major contributor to the eutrophication (McAlpine *et al.* 1989). While it is far more difficult to manage internal loads, some attempt must be made to reduce catchment inputs to prevent, or at the very least delay, a switch in stable state and possible ecosystem collapse. In particular, priority should be given to:

1) Development of predictive water balance and nutrient balance models to help focus management activities and help set specific water quality targets for the Site. This could be readily incorporated as part of existing broad-scale collaborative research being conducted by the Aquatic Sciences Branch, DoW, under the Vasse-Geographe CCI Water Quality Improvement Plan.

2) Investigation of phytoplankton-macroalgal-seagrass dynamics. This would involve expansion of the snap-shot survey undertaken in 2006 by DEC and GeoCatch in association with the Marine and Freshwater Research Laboratory, Murdoch University.

3) Regular mapping of aerial extent of wetland types/habitats and aerial extent of inundation. This could include the distribution of macrophytes and seagrasses and could be undertaken using either aerial

surveys or satellite imagery (*e.g.* CSIRO imagery). Ground-truthing should be done and could be incorporated into the existing DEC vegetation mapping program.

4) Thorough, regular and systematic waterbird counts of the Site with targeted surveys for individual species (refer Section 12.8, page 142).

Further management action in regard to actual or likely threats to the Site are summarised Table 28 (page 121). Research and monitoring needs are presented in Table 32 (page 144).

Collection of a minimum two to three years baseline data can go a long way to helping identify which parts of a wetland catchment are in most need of management intervention and where management intervention is likely to be of most benefit.

There is the need for collection of systematic records on water depth, water flow (magnitude, frequency, depth, duration, velocity), water quality, aerial extents of vegetation communities/habitat types, presence of invertebrates and fish, presence of waterbirds, breeding of waterbirds, waterbird counts and presence, or otherwise, of threatened painted snipe and Australasian bittern. Currently available information is not sufficient to adequately describe the ecological character of the Site nor statistically robust enough to evaluate future change or even change since time of listing. That this be rectified is of vital importance in lieu of continuing urban expansion (Port Geographe & other developments), changes in agricultural land-use and nearby mineral sands mining. There is also the need to monitor the lethal and sub-lethal effect of pollutants such as hydrocarbons, oils, heavy metals, pesticides, herbicides *etc* and the risk of acid sulphate soils resultant of ground disturbance and or water-table drawdown.

To be effective, sufficient funding, resources and personnel must be made available to ensure not only that adequate baseline data is collected, but that long-term monitoring can be undertaken and all data records are appropriately analysed in a timely manner.

Other recommendations of particular importance include:

- <u>Ongoing funding and support</u> for existing/recent catchment management initiatives:
    - DairyCatch (collaboration with DAF);
    - Nutrient Smart (GeoCatch);
    - Greener Pastures (collaboration with DAF);
    - River Action Plans (GeoCatch);
    - Clean Drains Program.
- Support the on-going process of State Government acquiring and conserving estuary foreshore lands. Investigate pros and cons of selective livestock grazing as a means to maintaining waterbird habitat along estuary foreshore.
- Investigate the potential of dredging to help ameliorate noxious gases released from drying sediments of the lower Vasse Estuary over summer. This may only require dredging of a ca. 100 m reach along Estuary View Drive down to the Vasse floodgates (Jim Lane, DEC, pers. comm.).
- <u>Standardised</u> monitoring techniques must be used for all data collection:
    - all reporting should detail methodologies;
    - <u>statistically rigorous</u> sampling design;
    - regular calibration/maintenance of automated monitoring equipment (*e.g.* Water Corporation needs to ensure that automatic loggers on the estuary floodgates are properly maintained).
- Analysis of baseline/monitoring data and reporting of results must be done in a timely manner (in the order of <u>months not years</u>).
- Assurance of <u>funding to maintain long-term monitoring</u> is vital if management plans are to succeed:
    - better State funding rather than reliance on NHT and/or NRM funds;
    - funding cycles of 5-10 years, not 2-3 years to maintain continuity of monitoring programs and provide job security to attract and keep experienced personnel.
- Enforce existing statutory & subsidiary legislation. Ensure commitments made by urban, agricultural and industrial developers are sufficient to protect the Site and that they are actually met.

Wonnerup Estuary, January 2007 (Andrew Storey)

PART I. BACKGROUND

1. INTRODUCTION

1.1 Ramsar and Ecological Character Descriptions

Australia is one of 155 countries (at July 2007) that are party to the Ramsar Convention on Wetlands, which was ratified in Ramsar, Iran in 1975. This treaty, officially known as *The Convention on Wetlands of International Importance, especially as Waterfowl Habitat*, currently lists more than 1,600 wetlands worldwide (Ramsar Convention 2006). Australia has 64 Ramsar listed wetlands that in total cover some 7.3 million hectares. Twelve of these occur in Western Australia and include the Vasse-Wonnerup Wetland system, near Busselton on the south-west coast. Contracting Parties to the Ramsar Convention have a number of responsibilities. Prominent among these are commitments to formulate and implement planning so as to promote wetland conservation and wise use, and to arrange to be informed at the earliest possible time if the ecological character of any listed wetland has changed, is changing, or is likely to change as a result of human activity (Convention Articles 3.1 and 3.2). Contracting Parties are expected to have mechanisms in place to help detect threats that are likely to, or may, change the 'ecological character' of the wetland. Describing the 'ecological character' of a Ramsar site is therefore a fundamental step so that a baseline condition is documented and can then be used to guide management actions and monitoring. Threats posed to Australian Ramsar sites in general include hyper-eutrophication (excessive nutrients), weed and feral pest invasion, plant diseases, catchment overgrazing, encroaching development, inadequately managed visitor access, salinisation, chemical/pesticide pollution and altered water supply. In order to conserve Australian Ramsar sites in the face of such threats, informative and affordable monitoring programs, interactive with management, are needed. Wetlands need to have a management mechanism that ensures participation of the local people in planning and enforcing balanced policies of sustainable use of resources.

1.2 Objectives of Ecological Character Descriptions

1.2.1 General Aims

'Ecological character' is defined under the Ramsar Convention (2005a) 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". Obviously there must be a description of ecological character before change in ecological character can be ascribed. Although Ramsar provides guidelines for management planning, establishing monitoring programs and undertaking risk assessments, there is at present no method recommended under the Convention for describing ecological character.

In a recent State audit of Ramsar wetlands in Western Australia, it was recognised that management of these wetlands was not always adequate, particularly the ability to assess change in ecological character (Auditor General for Western Australia, Report No. 9, September 2006). Although the ecological assets for the sites were usually well described on the Ramsar Information Sheet (RIS; see Section 1.3 and Appendix B) at the time of nomination (*i.e.* number of birds, fish species *etc*), the ecological character of the sites was usually not well documented or understood. Ecological character descriptions are intended to address this shortfall.

The overall goal of an ECD is to detail current understanding of the wetland ecosystem - its physical, chemical and biological components, the complex interactions between each and their influence on direct and indirect wetland services to the community. The general aims of ECDs 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 Australian Government *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) Regulations:
    a) to describe and maintain the ecological character of declared Ramsar wetlands in Australia and
    b) to formulate and implement planning that promotes:
        i) conservation of the wetland and
        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, 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.

1.2.2 Objectives of the Current Study

There are already a number of collaborative monitoring, rehabilitation and restoration programs for the Vasse-Wonnerup catchment undertaken by the Department of Environment and Conservation (DEC), GeoCatch, Land Conservation District Committees (LCDCs), the Department of Agriculture and Food (DAF) and the Department of Water (DoW). The majority of these are related, either directly or indirectly, to problems of water quality. In order to implement a unified and holistic approach to catchment management, all key ecological features must first be identified, together with "limits of acceptable change" upon which management actions and future monitoring can be based. To that end, an Ecological Character Description (ECD) for the Vasse-Wonnerup Ramsar Site has been prepared in accordance with the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007). ECDs typically consider all aspects of a wetland; its biota, hydrology, geomorphology, physico-chemistry and social, cultural and economic significance. The Vasse-Wonnerup ECD is an integral part of the Water Quality Improvement Plan (WQIP) component of the Vasse-Geographe Coastal Catchments Initiative. The Department of Water in partnership with GeoCatch is responsible for preparing the WQIP, aimed at providing a management approach to reducing nutrient levels in Geographe Bay and the Vasse Wonnerup wetlands using scientific models and decision support tools prepared under this new initiative. The agencies involved also wish to ensure that any measures adopted to improve water quality, do not themselves pose further risk to the ecological integrity of the wetlands.

The specific objectives for the current Vasse-Wonnerup Wetlands ECD may be summarised as follows:

- Identify the ecosystem components and processes of the Wetlands, and the ecosystem services they deliver;
- Develop a conceptual model(s) that describes the 'ecological character' in terms of ecosystem components, processes and services;
- Identify key ecological features that are impacted by threatening processes and "limits of acceptable change" for these features upon which management actions and monitoring can be based;
- Clearly identify and summarise knowledge gaps in the data available for the Wetlands.

1.3 The Vasse-Wonnerup Wetlands Ramsar Site

Nomination of a site for Ramsar listing entails provision of a formal description of the site to the Ramsar Secretariat in Gland, Switzerland. This description must be submitted in the form of a standardised 'Ramsar Information Sheet' (RIS) as specified under the Convention. Summary details of the Vasse-Wonnerup Wetlands as required by the Ramsar Secretariat (Gland, Switzerland) and the Australian Ramsar Administrative Authority (the Federal Department of the Environment) to describe the site are given in Table 1. Maps and RIS for the Site are given in Appendices A and B, respectively. To be accepted for inclusion as a Wetland of International Importance, the Site must meet one or more Ramsar criteria. There are currently nine qualifying criteria based on representative, rare or unique wetland types and on conserving biological diversity (see Table 2). The Vasse-Wonnerup site meets two of these criteria - criteria 5 and 6 - both of which relate to waterbirds (see Table 1). Owing to the lack of data on other biota, criteria 7 and 8 (which pertain to fish) could not be applied at the time of listing, while criterion 9 was only incorporated into the Convention in 2005.

Table 1. Site details for the Vasse-Wonnerup Wetlands Ramsar site.

Site Name	Vasse-Wonnerup Wetland System, Western Australia
Location in coordinates	Latitude: 33° 35' S to 33° 39' S Longitude: 115° 22' E to 115° 28' E
General location of the site	Temperate, coastal south-west of Western Australia. Shire: Busselton (local authority). Biogeographic region: Swan Coastal Plain. The site is an extensive, shallow, nutrient-enriched wetland system located immediately east north-east of the township of Busselton, 225 km by road south of Perth. The site comprises the Vasse and Wonnerup estuaries, their seasonally inundated floodplains, their connecting channels and shared sea inlet, and the marshes on the deltas of their inflow rivers (Vasse, Sabina, Abba and Ludlow rivers).
Area	1,115 ha
Date of Ramsar site designation	Originally nominated in 1990. Site was extended in 2000.
Ramsar/DIWA[1] Criteria met by wetland	Criterion 5 - regularly supports ≥ 20,000 waterfowl. Criterion 6 - regularly supports at least 1% of the SE Asia-Australasia population of Black-winged Stilt *Himantopus himantopus*, at least 1% of the Australian populations of Red-necked Avocet *Recurvirostra novaehollandiae*, and at least 1% of the south-west Australian populations of Australian Shelduck *Tadorna tadornoides* and Australasian Shoveler *Anas rhynchotis*..
Management authority	Territorial: The State Government of Western Australia. Functional: The Conservation Commission of Western Australia (vesting of reserves) and the Western Australian Department of Environment and Conservation (DEC) (management of reserves and Unallocated Crown Land). Management authority: The Blackwood District (based in Busselton) of the Central Forest Region, Western Australian Department of Environment and Conservation.
Date the ecological character description applies	1990
Status of Description	This is the first ecological character description for the site.
Date of Compilation	August 2007
Name(s) of compiler(s)	Susan Creagh and Andrew Storey, Wetland Research & Management, 28 William Street, Glen Forrest WA 6071 (Tel: +61-8-6488-2275; email: screagh@cyllene.uwa.edu.au), on behalf of Western Australian Department of Environment and Conservation..
References to the Ramsar Information Sheet	The Blackwood District (based in Busselton) of the Central Forest Region, Western Australian Department of Environment and Conservation (DEC; formerly Western Australian Department of Conservation and Land Management). All enquiries should be directed to Jim Lane, DEC, 14 Queen Street, Busselton WA 6280, Australia, (Tel: +61-8-9752-5555; Fax: +61-8-9752-1432; email: Jim.Lane@dec.wa.gov.au). RIS was originally compiled by DEC in 1990 and updated by Roger Jaensch (Wetlands International - Oceania) on behalf of DEC, in 1998, and by DEC staff in 2000 and 2003.
References to the Management Plan(s)	No management plan or interim management guidelines currently exist. Management is guided by the Busselton Wetlands Conservation Strategy 2005 (produced by the WA Planning Commission). The purpose of the strategy is to provide a framework to guide sustainable land use and wise management of the biodiversity and environmental values of the Busselton wetlands area.

Table 2. Ramsar criteria for inclusion as Wetlands of International Importance.

Group A Criteria: 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 of the Criteria: Sites of international importance for conserving biological diversity	
Criteria based on species and ecological communities	
Criterion 2:	A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities.
Criterion 3:	A wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.
Criterion 4:	A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions.
Specific criteria based on waterbirds	
Criterion 5:	A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds.
Criterion 6:	A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.
Specific criteria based on fish	
Criterion 7:	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:	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.
Specific criteria based on other taxa	
Criterion 9:	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.

The Vasse-Wonnerup Site as originally nominated for inclusion in 1990, largely consisted of non-freehold wetlands within the boundaries of the Vasse and Wonnerup estuaries (lagoons) and Wonnerup Inlet (Government of Western Australia 1990) (refer Appendix A Figure A1). This area included the estuaries' seasonally inundated floodplains and the marshes in the lower reaches of tributary rivers (*i.e.* Sabina and Abba rivers). In 2000, the site was extended to encompass much of the northern shore of the Vasse Estuary, the lower reaches of the Sabina River (Reserve 31188) and part of the Tuart Forest National Park (Reserve 40250) including the lower reaches of the Abba River (Government of Western Australia 2000) (refer Appendix A Figure A1). The site now covers over 1,115 ha of seasonal brackish lakes and marshes and a saline lagoon. A natural sand bar across the mouth of Wonnerup Inlet closes the system to the sea for much of the year and there are floodgates on the exit channels that connect the Vasse and Wonnerup estuaries to Wonnerup Inlet. These were installed in 1908 to mitigate flooding of adjoining agricultural land (Lane *et al.* 1997) during high river flows in winter and to prevent seawater inundation caused by storm surges. The gates effectively transformed the estuaries into shallow, winter-fresh/summer-saline lagoons, unique in Western Australia. The wetlands regularly support peak numbers of 25,000 - 35,000 waterbirds in most years, and provide the most significant regular breeding habitat for Black Swan *Cygnus atratus* in the State. The floodgates however, act as a partial barrier to upstream/downstream movement of fish and reduce flushing flows that may otherwise help ameliorate high nutrient concentrations from catchment runoff. Excessive algal blooms, anoxia and fish deaths are not uncommon. On several documented occasions, sudden and mass fish deaths have occurred in the lower reaches of Vasse-Wonnerup, principally in the channel immediately upstream of the Vasse estuary floodgates (Lane *et al.* 1997).

Though installation of the gates was not the cause of fish deaths, it has exacerbated the situation. In summer 1988, in an attempt to improve water quality, the (then) Water Authority of Western Australia manually opened the floodgates, allowing seawater to enter and fish to escape the adverse conditions that prevail throughout summer and autumn. However, the continued manual opening of the gates over summer-autumn in subsequent years (to 1997), is believed to have lead to other problems such as increased salinisation of adjoining pastoral lands and death of colonising native vegetation that has encroached upon lower elevations since the floodgates were installed. This loss of native vegetation has also been implicated in a possible decline in bird numbers (Lane *et al.* 1997).

The Vasse-Wonnerup wetlands and their floodgates play an important role in provision of waterbird habitat and in flood and storm-surge protection for low-lying coastal properties, including the township of Busselton (Lane *et al.* 1997). The fringing native vegetation has significant nature conservation, landscape and aesthetic values (Lane *et al.* 1997).

1.4 Legislative Framework

There are numerous international, national and state legislation and policies that apply either directly or indirectly to the Vasse-Wonnerup Ramsar Site. The most relevant of these are summarised in Table 3 and discussed further in the following sub-sections. The success of the various Acts and policy in protecting environmental and cultural heritage lies in the will and ability of the relevant authorities to enforce regulations.

1.4.1 International Treaties/Agreements

Ramsar Convention

The Ramsar Convention (*The Convention on Wetlands of International Importance, especially as Waterfowl Habitat*) is an intergovernmental multilateral treaty on the conservation of designated wetlands of international importance and the wise use of wetlands generally. The convention was signed by representatives of eighteen nations in Ramsar, Iran in 1971 and brought into force in 1975. Australia is credited with being its first Contracting Party (Environment Australia 2001). The Convention is overseen by the Ramsar Convention Secretariat which is based in Gland, Switzerland. Sites may be nominated for listing based on "… their international significance in terms of ecology, botany, zoology, limnology or hydrology" and contracting parties are to "formulate and implement their planning so as to promote the conservation of the wetlands included in the List" (Ramsar Convention 1987). Further information on the Convention is available online at www.ramsar.org.

The Australian Government is working with the state and territory governments to establish a systematic and strategic approach to the management of Australia's Ramsar wetlands. This will ensure that Australia's responsibilities under the Ramsar Convention are effectively and efficiently discharged, with particular emphasis on the maintenance and improvement of the ecological character of Ramsar sites in Australia.

The *National Framework and Guidance for Describing the Ecological Character Descriptions of Australia's Ramsar Wetlands* (DEW 2007) was developed to establish a standard method for describing ecological character for wetlands in Australia. The framework was developed using the outcomes from a national workshop held in Canberra in May 2006, the *Framework for Describing Ecological Character of Ramsar Wetlands* developed by the Victorian Department of Sustainability and Environment (DSE 2005) and using substantial input from the Natural Resource Management Ministerial Council's Wetlands and Waterbirds Taskforce, which includes representatives from Australian, state and territory government agencies.

Convention on the Conservation of Migratory Species of Wild Animals

The Australian Government is also party to the multilateral *Convention on the Conservation of Migratory Species of Wild Animals* (CMS or Bonn Convention), which seeks to protect all migratory species, including waterbirds. The CMS came into force in 1983 and membership currently (2006) includes 97 parties from Africa, Central and South America, Asia, Europe and Oceania. Like Ramsar, contracting parties meet every three years with the next CMS meeting scheduled for 2008. The CMS is coordinated by a Secretariat under the auspices of the United Nations Environment Program (UNEP). The Secretariat is based in Bonn, Germany. At least 37 bird species listed under CMS have been recorded from the Vasse-Wonnerup Site.

Table 3. Summary of international treaties and national and state Acts directly relevant to the Vasse-Wonnerup Ramsar Site.

Legislation / Policy	Provision for Wetlands	Applies to Vasse-Wonnerup Site
International Treaties/Agreements		
Ramsar Convention 1971	Protection of migratory waterbirds and their habitat.	Regularly supports > 20,000 waterbirds and at least 1% of the relevant Ramsar populations of black-winged stilt, red-necked avocet, Australian shelduck and Australasian shoveler.
CMS (Bonn Convention) 1984	Protection of migratory species and their habitat.	37 species currently listed under CMS.
JAMBA, CAMBA, ROKAMBA	Protection of migratory birds within the East Asian-Australasian flyway.	25 species currently listed under JAMBA and/or CAMBA (23 of these also listed under CMS).
National Policy		
Environment Protection and Biodiversity Conservation Act 1999	Protection of the environment, particularly matters of national environmental significance.	Matters of national environmental significance include: Ramsar wetlands of international importance, migratory species protected under international agreements (see above), threatened species (e.g. Australasian Bittern, Painted Snipe) and National Heritage Places.
Australian Heritage Council Act 2003	Protection of places of national heritage.	Vasse-Wonnerup Estuary and the Tuart Forest National Park are listed on the Register of the National Estate.
Native Title Act 1993	Develop an understanding of native title and reach enduring native title and related outcomes that recognise everyone's rights and interests in land and waters.	All crown lands within the Site are included within two registered native title claims.
State Policy		
The Environmental Protection Act 1986	Principles for identification and protection of wetlands in Western Australia. Policy: Wetlands Conservation Policy WA 1997; Swan Coastal Plain Lakes Policy 1992 (EPP); SWQMS 2001.	Listed as an EPP wetland by the EPA and as a Conservation Category Wetland by the Dept. of Environment and Conservation.
Rights in Water and Irrigation Act 1914	Protection of State wetlands from physical disturbance, pollution and detrimental effect of surface and ground water abstraction.	Abstraction of surface and ground waters for stock and crops on adjoining lands.
Soil and Land Conservation Act 1945	Controls clearing and drainage statewide in particular private lands and pastoral leases.	Applies to clearing of any native vegetation for areas > 1 ha, including wetland vegetation.
Conservation and Land Management Act 1984	Protection and management of certain public lands and waters and flora and fauna thereof national parks	Site contains areas of National Park, Nature Reserve and Conservation Parks.
Wildlife Conservation Act 1950	Protection of wildlife including all "Declared Rare or Threatened" flora and fauna.	Specially protected fauna: Water Rat. Other specially protected fauna that periodically occur within the Site: Carnaby's Cockatoo, Southern Brush-tail Phascogale, Western Ringtail Possum, Quenda, Western False Pipistrelle.
Water and Rivers Commission Act 1995	The Act gives the Department of Environment and Conservation (formerly Water & Rivers Commission) functions that relate to the conservation, management and assessment of water resources and planning for their use.	All wetlands are covered by the Act, but no specific provisions exist for protection of the Site.
Aboriginal Heritage Act 1972	Protection of places and objects which may be of importance and significance to people of Aboriginal descent in Western Australia.	The Sabina and Abba Rivers are listed as important mythological Aboriginal heritage sites protected under the Act.

CAMBA, JAMBA and ROKAMBA

As well as multilateral treaties, Australia currently has three bilateral agreements relating to conservation of migratory birds:

- *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* (JAMBA), signed in Tokyo in February 1974;
- *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* (CAMBA), signed in Canberra in October 1986;
- *The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds and their Environment* (ROKAMBA), initialled in 2006.

While these agreements cover all migratory bird species, the majority of listed species are shorebirds. Subsequent to the JAMBA and CAMBA treaties, and other bilateral agreements between regional Parties, the *Asia Pacific Migratory Waterbird Conservation Strategy* and its component *Action Plan for the Conservation of Migratory Shorebirds in the East Asian-Australasian Flyway: 2001-2005* were developed. The East Asian-Australasian Flyway extends from the Arctic through Asia to Australia and New Zealand. Birds fly through this route twice a year from north to south and back, travelling up to 25,000 kilometres per year. In 2002, Australia and the Republic of Korea agreed to develop a similar bilateral agreement for protection of migratory shorebirds. Australia seeks to foster multilateral cooperation between Parties in order to better formulate and manage migratory bird conservation strategies across the flyway. Government and non-government representatives of Parties meet every two years to discuss amendments and management issues. At least 25 bird species listed under JAMBA and/or CAMBA have been recorded from the Vasse-Wonnerup Site (refer Table 20, Section 4.14). Of these, 23 are also listed under CMS (see above).

1.4.2 National Policy

The Australian Government has direct management responsibility for significant areas of Australian wetlands and administers environmental programs that impact on wetland conservation around the country. The *Wetlands Policy of the Commonwealth Government of Australia* developed in 1997 aims to ensure that the Australian Government's actions would be consistent with those expected under the Ramsar Convention and, in particular to promote the adoption of the Ramsar Convention's 'wise use' principles for managing wetlands (Environment Australia 1997). The goal of the policy is to conserve, repair and manage wetlands wisely. Australia addresses its Ramsar site obligations through the:

- Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act); *Environment Protection and Biodiversity Conservation Regulations 2000*;
- Australian, state and territory government wetland policies;
- State and local government legislation that contributes to wetland conservation (*e.g.* planning legislation and protected area legislation);
- Australian, state and territory government Natural Resource Management (NRM) programs.

At the regional level, Regional NRM bodies across Australia prepare and coordinate the implementation of catchment-based strategies that are expected to recognise, amongst other things, the importance of Ramsar sites and identify strategies that contribute to the maintenance of their ecological character.

EPBC Act

The EPBC Act regulates actions that will have or are likely to have a significant impact on any matter of national environmental significance, which includes the ecological character of a Ramsar wetland (EPBC Act 1999 s16(1)). An action that will have or is likely to have a significant impact on a Ramsar wetland is subject to environmental assessment and approval under the EPBC Act. An 'action' includes a project, a development, an undertaking or an activity or series of activities (http://www.environment.gov.au/epbc/index.html).

The EPBC Act establishes a framework for managing Ramsar wetlands, through the Australian Ramsar Management Principles (EPBC Act 1999 s335) which are set out in Schedule 6 of the Environment Protection and Biodiversity Conservation Regulations 2000. These principles are intended to promote national standards of management, planning, environmental impact assessment, community involvement, and monitoring, for all of Australia's Ramsar wetlands in a way that is consistent with Australia's obligations under the Ramsar Convention. Some matters protected under the EPBC Act are not protected under local or state/territory legislation, and as such, many migratory birds are not specifically protected under State legislation (though they are in Western Australia). All species listed under international treaties JAMBA, CAMBA and CMS are covered by the Act. This includes 39 bird species recorded from the Vasse-Wonnerup Site (refer Table 20, Section 4.14). Other EPBC fauna recorded within the Site include the Australasian Bittern, Carnaby's Cockatoo and Western Ringtail Possum. The Regulations also cover matters relevant to the preparation of management plans, environmental assessment of actions that may affect the site, and the community consultation process (http://www.environment.gov.au/epbc/matters/ramsar.html).

Australian Heritage Council Act

The Australian Heritage Commission appointed in 2004 under the *Australian Heritage Council Act 2003* accepted nomination and listing of the Vasse-Wonnerup Estuary (and the Tuart Forest National Park) on the Register of the National Estate, on the basis of its significant conservation and heritage value. This listing covers the Wonnerup and the north-eastern half of the Vasse, including farmland between the wetlands and the Tuart Forest National Park. As such, all development proposals must be referred to the Heritage Commission.

Native Title Act

The *Native Title Act 1993* set up the National Native Title Tribunal as an independent body to process native title applications. All Crown land encompassed by the Ramsar Site is currently included within two registered native title claims: the Harris family and the South-West Boojarah family, for whom the Noongar[1] Land Council is the representative Aboriginal Body.

1.4.3 Western Australia State Policy

Environmental Protection Act

The *Environmental Protection Act 1986* (EP Act) and the *Environmental Protection Regulations 1987* of Western Australia was "to create an Environmental Protection Authority (EPA), for the prevention, control and abatement of environmental pollution, for the conservation, preservation, protection, enhancement and management of the environment". Statutory environmental protection policies and environmental impact assessments are governed by the EPA. Under the EP Act there are two current policies designed to protect and conserve Western Australian wetlands, including the Vasse-Wonnerup Site. These policies stipulate that authorisation from the EPA is required to fill-in, excavate, mine, discharge effluent, remove water or damage vegetation around a wetland:

- *Wetlands Conservation Policy for Western Australia 1997* is a statement of the State government's commitment to "identifying, maintaining and managing the State's wetland resources, including the full range of wetland values, for the long-term benefit of the people of Western Australia". The policy is administered by the Department of Environment and Conservation, the Department of Water and the Department of Planning and Infrastructure. The Policy is currently under review with planned completion in late 2007.
- *Environmental Protection (Swan Coastal Lakes) Policy 1992* (Lakes EPP) applies to all wetlands on the Swan Coastal Plain bioregion that had an area of more than 1,000 m^2 of standing water at 1 December 1991. This includes the Vasse-Wonnerup Ramsar Site. The policy aims to protect the environmental values of lakes on the Swan Coastal Plain and was subject to a statutory review in 1999. On 23rd August 2006, the State Minister for the Environment announced he would not approve the revised draft *Environmental Protection (Swan Coastal Plain Wetlands) Policy 2004*. The 1992 Lakes EPP remains in force.

[1] There are many different spellings of the name 'Noongar'. Spelling in this report follows that of Whitehurst (1997) as cited by Brearley (2005).

- *Environmental Protection (South West Agricultural Zone Wetlands) Policy 1998* designed to protect social and environmental values of significant wetlands located on both Crown and private property within the south-west agricultural areas. Nomination and listing of a wetland on the policy register requires landowner consent and consequently only two wetlands are protected under this Policy. Though no part of the Ramsar Site has been listed on this register, its catchment lies within the zone covered by the Policy. A review of this policy has been deferred till after 31st June 2008 and subsequent to a finalised review of the *Swan Coastal Lakes Policy*.

There are also numerous strategies and frameworks produced as part of environmental protection policy regulation. Of particular relevance to the Vasse-Wonnerup Site is the *State Water Quality Management Strategy 2001*, developed to implement the NWQMS in Western Australia. Several State government agencies have responsibility for implementing the SWQMS. The Department of Water (formerly Water and Rivers Commission) is the primary authority where SWQMS relates to the *National Competition Policy* and *Water Reform Framework*. Responsibilities for implementing environmental protection components of the SWQMS fall with the EPA and the Department of Environmental and Conservation.

Water Act (in preparation)

The State government is in the process of formulating a new *Water Act*, which will consolidate 14 water resources Acts. The new Act is part of water law reform subsequent to the establishment of the Department of Water (DoW) in January 2006 and the signing of the National Water Initiative in April 2006. DoW effectively replaces the Water and Rivers Commission that was set up under the *Water and Rivers Commission Act 1995* (WRC Act) as a government agency with functions relating to water resources conservation, protection and management functions vested in it by various written laws. The WRC Act was repealed in May 2006 in order to formally transfer the functions of WRC to DoW. DoW will administer the *Water Act* on behalf of the Minister for Water Resources. Like WRC before it, DoW's goal is to "manage the water resources of Western Australia for the benefit of present and future generations in partnership with the community". Till formally replaced or amended, many policies developed under the WRC Act 1995 remain current. There are two policies of most relevance to the Ramsar site, both of which are currently under review:

- *Environmental Water Provisions Policy for Western Australia 2000*. This statewide policy describes principles and processes to be applied by the Department in determining how much water should be retained for the environment when allocating and reviewing water use rights. It also identifies important linkages to the State's statutory framework.
- *Giving and Undertaking to Grant a License or a Permit under the Rights in Water and Irrigation Act 1914, September 2006*. The intent of this policy is to define the circumstances under which the Department will give undertakings for the granting of licences to take water, the approval of agreements with respect to water entitlements, permits to interfere with a water course or licences to construct a well.

Other organisations involved in water resource management in Western Australia, include the Office of Water Regulation which regulates policy, pricing and services quality and the Water Corporation, which is responsible for public water supplies, wastewater, main drainage and irrigation schemes.

Rights in Water and Irrigation Act

Under the *Rights in Water and Irrigation Act 1914* (RIWI Act), a permit issued by the State Department of Water (or authority under another Act) is required before disturbing a wetland (*e.g.* physical disturbance of soil, chemical pollutants, dumping of rubbish):

- on any land within a proclaimed area or irrigation district and
- on Crown land outside a proclaimed area or irrigation district.

Failure to obtain a licence is an offence, and subject to a maximum penalty of $10,000. A licence is also required to take water from wetlands, watercourses and groundwater in "proclaimed areas" and "irrigation districts" unless allowed under a statutory right (*i.e.* "riparian" or "public" rights). A licence is generally not required to take water from a wetland outside a proclaimed area or irrigation district, unless the area is prescribed under Regulations. The RIWI Act is subject to the *Environmental Protection Act 1986*.

In 2006, the State Government signed the National Water Initiative which requires that water resources be subject to statutory management plans and that these plans are binding. While the current RIWI Act provides for statutory management plans, these plans are not binding. The EPA has strongly recommended that "new water resource management legislation being prepared to replace the RIWI Act should establish a framework which meets the requirements of the National Water Initiative".

Soil and Land Conservation Act and Conservation and Land Management Act

The *Soil and Land Conservation Act 1945* (SLC Act) and the *Conservation and Land Management Act 1984* (CALM Act) relate to the conservation of soil and land resources, including erosion, salinity, flood and native vegetation management. Under these Acts, proposals to build drains for agricultural or urban development, clear remnant vegetation or discharge saline water directly or indirectly into a wetland are subject to a notification process. For private property, relevant notification must be given to the Commissioner for Soil and Land Conservation who administers the SLC Act on behalf of the Minister for Agriculture. Public conservation lands such as Nature Reserves, National Parks and State Forests, are covered under the CALM Act and administered by the State Department of Environment and Conservation (DEC) on behalf of a number of statutory bodies including the Conservation Commission of Western Australia. In addition, provisions exist within the RIWI Act and the EP Act and Amendments.

Wildlife Conservation Act

Wildlife Conservation Act 1950 (WC Act) provides for the conservation and protection of wildlife. This includes protection of flora and fauna, including provisions for special protection of declared threatened (declared rare) flora and its habitat on all land classifications and for threatened fauna wherever that fauna occurs. DEC also administers the approvals required to take declared rare flora, threatened fauna and to carry out activities that impact on threatened ecological communities, under the Act. The Wildlife Conservation (Rare Flora) Notice 2006(2) (Rare Flora Notice) and the Wildlife Conservation (Specially Protected Fauna) Notice 2006(2) (Specially Protected Fauna Notice) have been made under the Wildlife Conservation Act 1950 and list the current rare flora and specially protected fauna. The Rare Flora Notice and the Specially Protected Fauna Notice revoke the Wildlife Conservation (Rare Flora) Notice 2006 and the Wildlife Conservation (Specially Protected Fauna) Notice 2006, respectively. There are 7 specially protected fauna species known to periodically occur within the Tuart Forest National Park section encompassed by the Vasse-Wonnerup Site. These include: Water Rat, Carnaby's Cockatoo, Southern Brush-tail Phascogale, Western Ring-tail Possum, Quenda and Western False Pipistrelle.

Other Acts

There are a number of other State Acts that are indirectly related to the Site. These mostly concern urban and agricultural development and mining activities on surrounding lands, which have the potential to alter the ecological character of the Site. These include:

- *Land Administration Act 1997* which relates to the conservation of soil and land resources, and to the mitigation of the effects of erosion, salinity and flooding. In addition, provisions also exist within the SLC Act and the CALM Act and Amendments.
- *Western Australian Planning Commission Act 1985* which was established in order to create a body with responsibility for urban, rural and regional land use planning and land development and related matters in the State, and for connected purposes.
- *Town Planning and Development Act 1928* which relates to the planning and development of land for urban, suburban, and rural purposes.
- *Statements of Planning Policy* (SPP) - SPPs are legally enforceable and must be incorporated into local government town planning schemes. For example, the Port Geographe marina and residential canal development on the western boundary of the Vasse Estuary is subject to SPPs. SPPs formulated for

protection of conservation and landscape values rely, in part, on statutes contained in other legislation such as the EP Act, CALM Act, SLC Act and Mining and Heritage Acts. One such SPP is the Leeuwin-Naturaliste Region Plan Stage One 1988 which applies to all of the Shire of Busselton and was adopted as policy by the (then) State Planning Commission. Under this plan, the Vasse-Wonnerup Estuary and adjoining rural land are "recognised as areas of landscape value and significant environmental value" (WAPC 2005).

- *Mining Act 1978* was created to consolidate and amend the law relating to mining and for incidental and other purposes. Policy relating to water use and discharge on mining leases also exists under the *Water and Rivers Commission Act 1995*. Mining for minerals sands has been conducted on the south bank of the Vasse Estuary exit channel and within a range of 2 - 6 km east of the Ramsar Site. Mining exploration and production within conservation reserves are subject to environmental impact assessment by the EPA, under the EP Act and mining is not permitted where it is incompatible with the primary purpose of the reserve. However, mining has proceeded in a number of other State conservation reserves following Government excision of lands from the reserve in order to allow mining while still complying with the EP Act.
- *Heritage of Western Australia Act 1990* Several historic places situated within or beside the Site are listed on the Municipal Inventory of Heritage Places. Much of the Ramsar site is also listed on the register of the National Estate (see Section 1.4.2, above).
- *Aboriginal Heritage Act 1972* applies in relation to the protection of places and objects which may be of importance and significance to people of Aboriginal descent in Western Australia. In particular it applies to places and objects (and storage areas for objects) that may have sacred, ceremonial and ritual significance. The Western Australian Aboriginal Sites Register contains at least 16 recorded sites within or in close proximity to the Ramsar Site. Under the Act, it is an offence to damage these sites, whether they are registered or not. The entirety of the Sabina and Abba Rivers are listed as important mythological Aboriginal heritage sites associated with the Waugal and specially protected by the Act.
- *Agriculture and Related Resources Protection Act 1976*. The object of this Act is to protect primary industries and the resources related to primary industries. Infestations of the weeds Arum Lily and Bridal Creeper occur over large areas of riparian zone of the Vasse-Wonnerup Site. Both these species are currently listed by the Agricultural Protection Board as 'declared plants' under this Act.
- *Fish Resources Management Act 1994* (FRMA) was created to conserve fish and to protect their environment as well as achieving optimal economic, social and other benefits from the use of fish resources.

1.4.4 Site Management

The Australian Government is the Contracting Party to the Ramsar Convention, however, under the Australian Constitution, responsibility for land and water management is vested in the States and Territories within their respective areas of jurisdiction. The States and Territories also retain responsibility for the management of sites within their jurisdiction following listing and therefore have a major responsibility for meeting Ramsar obligations and expectations with respect to the conservation of those sites and the detection and reporting of adverse changes, and threats of adverse change, in their ecological character.

At State level, the Wetlands Coordinating Committee, established in 1997, implements Western Australia's Wetlands Conservation Policy. Committee members include representatives from DEC, DAF, DPI, EPA, and the World Wide Fund for Nature (WWF), as well as local government members and independent scientists.

Of the Vasse-Wonnerup Ramsar Site itself, most (Vasse estuary, Wonnerup Inlet and a large part of Wonnerup estuary) is Unallocated Crown Land. Two Nature Reserves and part of the (Tuart Forest) National Park that adjoin the Vasse estuary are managed by Western Australia's Department of Environment and Conservation. There is a pastoral lease over the northern end of the Site and there is strong community support for preservation of both the wetlands as waterfowl habitat and continued use for agriculture within the area (Jim Lane, DEC, pers. comm.). DEC has delegated responsibility for operation of the floodgates during summer-autumn in relation to maintenance of minimum water levels and fish and water quality issues, while Water Corporation (which owns the structures) is responsible for their maintenance and for management of potentially flooding flows (typically occurring in winter). The State Department of Water (DoW) has a direct role in the monitoring of water quality particularly in relation to potentially toxic algal and diatom blooms and an indirect role in management through the allocation of water resources. DoW is also the designated "fish kill response agency" in relation to rivers and estuaries. The WA Department of Fisheries is responsible for sustainable management of commercial and recreational fisheries, while the WA Department of Agriculture and Food has responsibilities in sustainable management of farmlands, which in turn affects agricultural runoff and nutrient loads to the Site. The Shire of Busselton, the neighbouring Shire of Capel and the State Department for Planning and Infrastructure have indirect roles through land-use planning decisions such as the Port Geographe residential and canal development which directly adjoins the wetland boundary. The Vasse Estuary Technical Working Group (VETWG), convened by DEC, coordinates government agency (DEC, DoW, Shire, DFA), Water Corporation and GeoCatch on-Site management and monitoring activities. Geographe Catchment Council Inc. (GeoCatch) facilitates collaboration between government and non-government organisations and the broader community, principally on issues related to the Site's catchment.

There are a number of national, state and catchment-specific guidelines/initiatives in place to help with the management of the Site and with integrated catchment management in general. These are listed in Appendix C. However there is currently no comprehensive management plan for the Site itself. Preparation of a formal (statutory) management plan is currently dependent upon satisfactory resolution of Native Title issues and vesting of the Unallocated Crown Land portions of the Site (*i.e.* most of the Site) in the Conservation Commission of Western Australia (Jim Lane, pers. comm.).

In the last decade or so substantial productive efforts have been made towards better coordination of policy, planning, management and monitoring in relation to the Site, for example through the preparation of the Busselton Wetlands Conservation Strategy and the establishment of the Vasse Estuary Technical Working Group and Geographe Catchment Council.

1.5 Approach taken for the Current Study

1.5.1 Framework

The approach taken for the Vasse-Wonnerup Wetlands ECD was consistent with that outlined in the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007). This draft provides an updated protocol to that described in DSE (2005) for establishing site-specific monitoring for Australian Ramsar sites. In accord with the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007.), the starting point for documenting the ecological character of the Vasse-Wonnerup Site was an investigation of the wetland assets (components) as nominated under the February 1990 Ramsar listing (Government of Western Australia 1990). In turn, other fundamental components and processes are described, and finally, the services/benefits offered by the wetland system.

1.5.2 Terminology

Terminology used in the current report follows that of the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007), which in turn is in accord with definitions of Millennium Ecosystem Assessment (2005) and the Ramsar Convention. The terminology of the 2006 framework and guidance is similar to that used by Phillips and Muller (2006) for the recent Coorong and Lakes Ramsar Site ECD, but differs in that geomorphology and hydrology are here defined as wetland 'components' rather than 'drivers'.

RAMASAR DEFINITIONS

Wetland
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).

Ecosystem Components
The physical, chemical and biological parts of a wetland (from large scale to very small scale, *e.g.* habitat, species and genes (Ramsar Convention 2005, Resolution IX.1 Annex A).

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 (Benefits)
The benefits that people receive or obtain from ecosystems and include provisioning (*e.g.* food & water), regulating (*e.g.* flood control), cultural (*e.g.* spiritual, recreational, educational) and supporting (*e.g.* nutrient cycling, ecological values, Ramsar values) (Ramsar Convention 2005, Resolution IX.1 Annex A).

Ecological Character
The combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time (Ramsar Convention 2005, Resolution IX.1 Annex A)

Change in Ecological Character
The human-induced adverse and/or positive alteration of any ecosystem component, process, and/or ecosystem benefit/service (Ramsar Convention 2005, Resolution VIII.8 Annex A).

1.5.3 Change in Ecological Character

Change in ecological character is here defined as the change in wetland condition relative to that at the time of the 1990 listing. At that time, the Vasse-Wonnerup Site was already highly modified and regulated compared to the natural condition. As discussed by Phillips and Muller (2006), the ecological character of an already degraded Ramsar wetland may improve from the time of listing consequent of restoration and rehabilitation activities. In these cases the definition of "change" as defined under the Convention includes desirable as well as adverse change.

1.5.4 Limits of Acceptable Change

The *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007) uses Phillips (2006) definition of limits of acceptable change; *i.e.* "…the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland" (see also Phillips and Muller 2006). In order to quantify limits of acceptable change in a given component, process or service, the typical or, for many features, <u>the natural variability must first be assessed</u>. The limit is then the point outside the typical/natural variability at which there is unacceptable reduction or loss of values for which the site was Ramsar listed. The *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007) states that wherever possible, limits of acceptable change should be based on "quantitative information from relevant monitoring programs, scientific papers, technical reports and other publications or documented information on the wetland (including oral histories)". Climate change presents obvious difficulties in defining limits of acceptable change for components and processes. Discussion of limits of acceptable change for the Vasse-Wonnerup Ramsar Site is given in Section 8.

1.5.5 Specific Tasks

To successfully address the objectives of the study (refer Section 1.2.2), a series of specific tasks were undertaken:

1) Comprehensive literature search and review of existing knowledge of hydrology, geomorphology, water physico-chemistry, aquatic biota (flora & fauna), dependent terrestrial biota, ecological water requirements of dependent biota, socio-economic values, cultural and heritage values. Information sought included local and catchment-scale quantitative and qualitative data, including (where appropriate) anecdotal evidence. Published and documented information was sought as well as consultation with knowledgeable stakeholders, local and indigenous community members, and experts familiar with the site. Organisations contacted included the Department of Environment and Conservation (DEC, Perth and Busselton offices), GeoCatch, South West Catchments Council (Bunbury), Shire of Busselton, Department of Water (DoW, Perth), Department of Fisheries (Busselton), Murdoch University (Marine & Freshwater Research Laboratory) and the Department of Indigenous Affairs (DIA, Perth). Information was sought on temporal and spatial variability (seasonal, yearly, drought, flooding) in components and processes. Given that water quality problems are the result of catchment wide degradation, attempts were made to source to both local and catchment-scale data.
2) Analysis and comparison of the past and present state of the wetland based on available data (Sections 4, 5 & 6), including any changes to the ecological character description from that provided when initially listed under Ramsar (Section 9).
3) Conceptual models (diagrams) were prepared based on available data (Section 7.2). Given that available baseline data for the Site was limited, conceptual models presented are largely theoretical. Diagrams illustrate ecosystem components and processes, their interconnectivity (in particular pertaining to water quality) and benefits/services.
4) Actual and potential risks/threats to ecosystem components, processes and benefits/services were identified and detailed (Section 10).
5) Knowledge gaps pertaining to information on ecosystem components, functions, processes, and services/products were identified and detailed (Section 11).
6) Completion of a proposed Ramsar Information Sheet update for the site, including updated maps and aerial image (Appendices A & B).
7) Discussion of monitoring and management (Sections 12 & 13) includes fundamental considerations about the design of rigorous monitoring programs, *e.g.* how and what parameters to measure, setting acceptance criteria against which the threats and remediation work can be assessed, correct statistical design and appropriate methods for data analysis.
8) The ECD for the Vasse-Wonnerup wetland system was finalised such that it provides a basis for environmental research and sampling programs to gather more adequate baseline data that can be used to help develop and integrated management plan.

To date, there has been no systematic survey of ecosystem function of the Vasse-Wonnerup Wetlands as a whole, nor comprehensive literature review. However, much of the background information pertaining to the Vasse and Wonnerup estuaries has already been collated by McAlpine *et al.* (1989) and by Lane *et al.* (1997) for the Vasse Estuary Technical Working Group. These reports have been extensively referenced in the current study. Lane *et al.* (1997) provided a detailed and comprehensive review of the historical management of the wetlands, the changes in water levels and water quality. They recommended a number of appropriate/sound management and monitoring options for fish, waterbirds, fringing vegetation and adjoining pastoral land, most of which have been acted upon. The recommendations of the current ECD incorporate and expand upon these earlier recommendations.

2. SITE DESCRIPTION

2.1 Site Location

2.1.1 Regional Setting

The Busselton Wetlands

The Vasse-Wonnerup Ramsar Site is located in the temperate, coastal south-west of Western Australia, within the Swan Coastal Plain biogeographic region and within the Shire of Busselton (local authority), 225 km by road south of Perth. The Swan Coastal biogeographic region contains 3 other Ramsar sites (Peel-Yalgorup, Forrestdale-Thomsons Lakes, Becher Point) that together with the Vasse-Wonnerup, cover 21,188 ha. The region also contains an additional 23 wetlands of national significance, covering ca. 9,282 ha (Environment Australia 2001).

Maps and an ortho-rectified aerial image of the Site are presented in Appendix A Figures A1-A8. The Vasse-Wonnerup Site is part of an extensive, shallow, nutrient-enriched system known as the Busselton Wetlands (Appendix A Figures A1-3). These wetlands comprise estuarine marshland, tidal floodplain and river 'deltas' that have formed behind narrow coastal dunes lining Geographe Bay. The wetlands lie parallel to the coast extending either side of the township of Busselton (population ca. 19,000[2]) - one of Australia's fastest growing centres for residential and tourism development (WAPC 2005). The wetlands cover some 2,500 ha and extend a total distance of 50 km with the northernmost portion lying within the Shire of Capel (Lane *et al.* 1997). The main wetland area is located within the 1:100 year floodline (WAPC 2005); the approximate area of annually inundated open water area is shown in Appendix A Figure A4. The major components of the Busselton Wetlands system are the Vasse-Wonnerup Ramsar Site, New River and The Broadwater. The major waterbodies within the Ramsar Site are the Vasse and Wonnerup estuaries ('lagoons'), which are located immediately east and north-east of Busselton, extending some 14 km (Lane *et al.* 1997). The *Busselton Wetlands Conservation Strategy* released by WAPC in 2005 provides a guide aimed at sustainable land use and wise management of the wetlands, including the Ramsar Site. However it does not (and was not intended to) contain a formal management plan specific to the Ramsar Site.

Geographe Bay and the 'Capes' Marine Park

The Vasse-Wonnerup estuaries form part of the larger Geographe Bay catchment within the Busselton Drainage Basin. The basin covers an area of approximately 2,560 km^2 and contains some 26 creek and river systems (Pen 1997). Geographe Bay catchment comprises 78% of the basin area and extends from the township of Bunbury to Cape Naturaliste (Weaving 1998). The major rivers are the Capel, Ludlow, Abba, Sabina, Vasse, Carbunup and Buayanyup, which arise in forested regions of the Blackwood Plateau and flow westward out across the flat, low-lying Swan Coastal Plain. All these rivers historically flowed into the Vasse-Wonnerup estuaries and thence to the sea via the narrow Wonnerup Inlet. Historically, tidal exchange in the estuaries would have been restricted by periodic closing of the sand bar at the mouth of Wonnerup Inlet, mostly in summer. Tidal exchange is now very much reduced and artificially controlled by the floodgates. Much of the coastal plain vegetation has been cleared from the Geographe Bay catchment and extensive drainage networks constructed for agriculture (beef, dairying, plantations) and to reduce flooding of the estuaries in winter. As a result, approximately 96% of the original wetlands of the Geographe Bay catchment have been lost or greatly modified (Dept. Fisheries & Wildlife 1978, Halse 1989). Therefore any wetlands that have survived, in particular those with remnant bush, are of conservation significance irrespective of their Ramsar values (Pen 1997).

Geographe Bay itself is of high conservation value and high social value (cultural, tourism, recreation, commercial fishing). The Bay supports the most extensive temperate seagrass communities on the west coast (MPRSWG 1984). The seagrass beds provide important habitat for marine invertebrates and for a variety of fishes. Humpback whales (*Megaptera novaeangliae*) are often seen with small young in the Bay, suggesting it may be used as a nursery area (DEC 2006b). Resident groups of bottle-nosed dolphins (*Tursiops truncatus*) also

[2] Taken from estimates given in Shire of Busselton (2002) as 66% of projected Shire population of 29,000 by 2006.

inhabit the Bay. All whales and dolphins in Australian waters (*i.e.* beyond three nautical miles from the coast) are protected under the EPBC Act. Seagrasses are protected under the State WC Act and under policy based on the EP Act. Geographe Bay is included in DEC's recently proposed Geographe Bay/Leeuwin-Naturalist/Hardy Inlet Marine Park ('Capes' Marine Park). Under this proposal, a 2,084 ha conservation zone is to be established immediately north of Wonnerup Inlet to protect seagrass communities and their associated species assemblages (DEC 2006b). This is the Eastern Geographe Bay Sanctuary Zone and it will be influenced by outflow from the Vasse and Wonnerup estuaries and thus potentially affected by management practices within the Ramsar Site (DEC 2006b).

Tuart Forest National Park

The eastern boundary of the Ramsar Site encompasses part of the Tuart Forest National Park. An issue paper (DEC 2006a) on the proposed management plan for the Park was released for public comment in 2006 and DEC hope to finalise the management plan during 2007. The park contains the largest and most southern contiguous, remnant, tall tuart (*Eucalyptus gomphocephala*) woodland. Mature tuarts within this area provide important habitat for various waterbirds, including hollows for both roosting and nesting (DEC 2006a). The Park is also important for the conservation of some threatened fauna, including the western ringtail possum (*Pseudocheirus occidentalis*) and Carnaby's cockatoo (*Calyptorhynchus latirostris*). The area is valued for its 'sense of place' by the community and has significant cultural heritage and tourism value (DEC 2006a).

2.1.2 Climate

The climate of the area is Mediterranean, typified by cool, wet winters (June - August) and hot, dry summers (December - February). The weather is determined by eastward moving high and low pressure systems. During winter, rain-bearing, cold fronts and strong westerly winds frequently cross the coast, though storms typically last one day or less (Hill & Ryan 2002). In summer, high pressure systems block the passage of low pressure systems and deflect rain-bearing fronts south of the continent (Pen 1997). Changing weather patterns associated with 'greenhouse effects' have led to a persistence of high pressure systems into winter, with a resultant increase in storm activity and intensity in the south-west, but reduced annual rainfall (Kay *et al.* 1992, Jones *et al.* 2005). The most recent CSIRO (2002) models for global warming predict a general increase in temperature for the south-west of between 0.4 - 2.0°C by the year 2030. A decreasing trend (-20% to +5%) in winter and spring rainfall is also predicted and a ±10% change in summer/autumn rainfall. While the intensity of specific winter rainfall events may increase, their duration is expected to decrease. Correspondingly, the duration of drought events and rates of evaporation are also expected to increase. The ~20% decrease in south-west regional rainfall experienced over the last 30 - 40 years has resulted in a 30 - 40% decrease in average annual streamflow (WRC 2001). For the Busselton Shire, Bureau of Meteorology (BOM) records show a decline in average annual rainfall of 17% (Busselton rainfall station 9515) over the last 11 years and of 11% over the last 30 - 40 years. Average annual rainfall was 860.2 mm (median 856.2 mm) for the period 1917 - 1969, declining to 717.3 mm (median 699.0 mm) for the period 1996 - 2006 (Figure 1). Maximum monthly falls continue to be recorded during June - July, but winter rainfall has decreased (Figure 2). Light local rainfall can occur during summer and autumn with occasional widespread heavy rain and storm surges associated with decaying tropical cyclones. The storm associated with Cyclone Alby in 1978 produced a storm surge of 1.94 m AHD (WAPC 2005).

Winter temperatures currently range from a mean daily maximum of 18.2°C to a minimum of ca. 8.0°C (Figure 3). In summer, the prevailing pattern is hot easterly winds that are usually moderated by strong afternoon south-westerly sea breezes, with a localised, weaker north-westerly sea breeze for several hours between the two (Jim Lane, pers. comm.). Summer temperatures range from a mean daily maximum of 28.8°C to a minimum of 13.3°C. Evaporation rates are in the order of 1 - 1.4 metres per year.

The effect of decreased rainfall on groundwater recharge and discharge is currently unknown. While reduced freshwater inflows to the Vasse-Wonnerup Estuary may reduce catchment nutrient input, lower water levels in spring and early summer are likely to exacerbate poor water quality. Increased salinity levels will ultimately alter the estuarine ecosystem with more salt tolerant species and fewer salt-sensitive species. Increased soil salinity levels may also limit agriculture around the estuary.

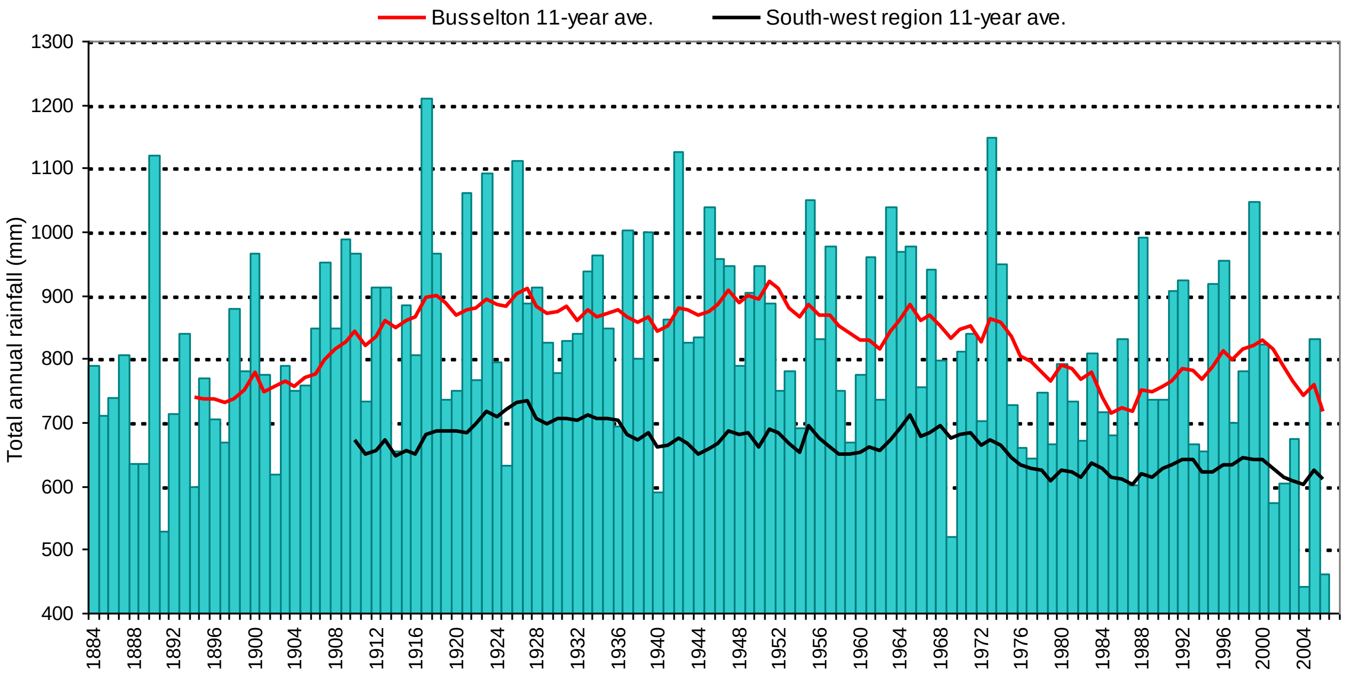

Figure 1. Total annual rainfall for Busselton (station 9515) together with the 11-year running average for Busselton and for the south-west region as a whole (data supplied by Climate Services, BOM, Perth).

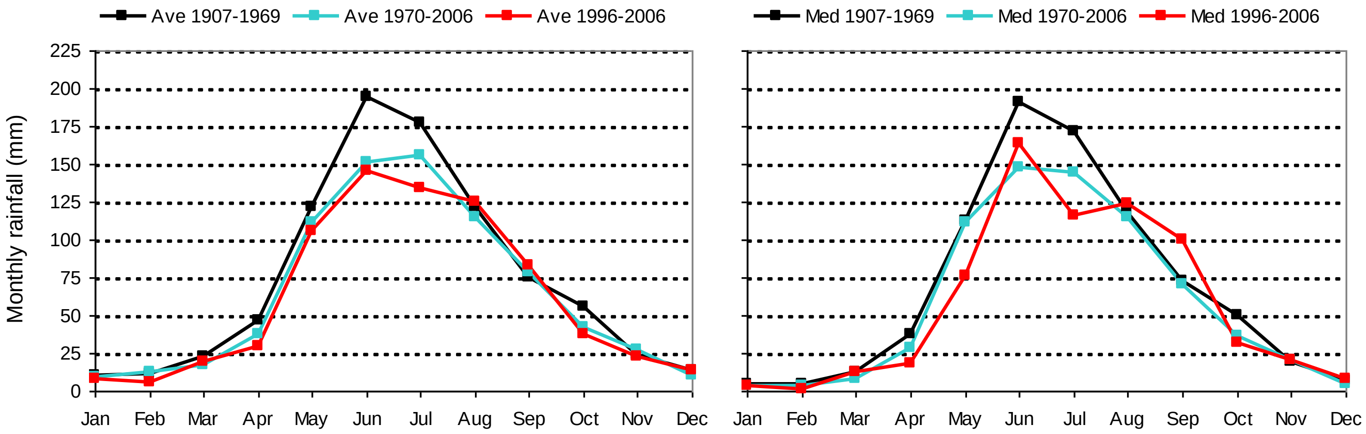

Figure 2. Average and median monthly rainfall for Busselton (station 9515) (data supplied by Climate Services, BOM, Perth).

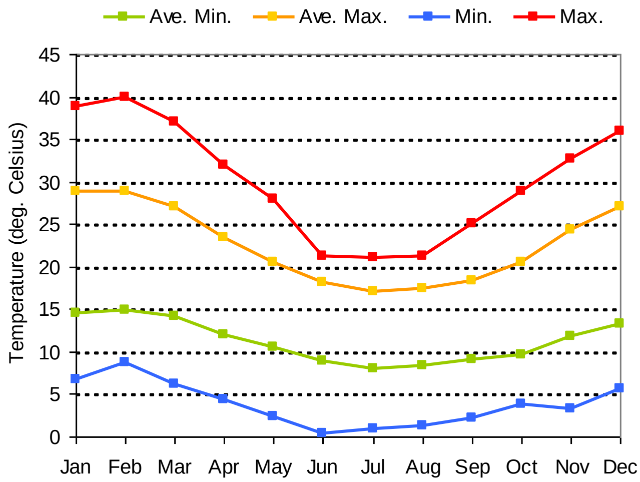

Figure 3. Maximum and minimum monthly temperature for Busselton together with average maxima and minima for the period 1998 - 2006 (data supplied by Climate Services, BOM, Perth). Note: temperature data for BOM station 9515 were incomplete, so data were sourced from nearby station 9569.

Current predictions for global sea level rise due to climate change are between 9 cm and 88 cm by 2100 (IPCC 2001). However, more recent analysis of sea level data indicates this range may be an underestimate (IPCC 2007). The coastline of Geographe Bay is regarded as one of Australia's most vulnerable to the future potential impacts of sea-level rise (Kay *et al.* 1992, Jones *et al.* 2005). The entire coastline of the Bay is susceptible to erosion (Searle & Semeniuk 1985). A vertical rise in sea level can translate to a 100-fold increase in vertical erosion of sandy shores if preventative measures are not taken (Kay *et al.* 1992). The effect on the Vasse-Wonnerup wetlands of sea-level rise and of increased erosion and loss of shoreline is uncertain, particularly given the presence of the floodgates, which act so as to prevent seawater incursion. The South West Catchments Council (SWCC) has already recommended that mapping and monitoring of coastal erosion be made a priority area for research in Geographe Bay and neighbouring coastal zones.

2.1.3 Site Boundaries

The Ramsar Site currently comprises 1,115 hectares; less than half of the overall Busselton Wetlands system which covers some 2,500 ha (Appendix A Figure A1). The Ramsar Site as originally nominated in 1990 consisted of non-freehold wetland (including the Vasse Estuary portion of Reserve 31188) within the boundaries of the Vasse and Wonnerup estuaries and Wonnerup Inlet, and an adjoining area of non-freehold wetland (formerly part of Wonnerup Estuary) between Wonnerup Estuary and Forrest Beach Road. The Vasse, Sabina, Abba and Ludlow Rivers and The Deadwater were not included in the Site, though they remain ecologically and hydrologically connected (Lane *et al.* 2007). The New River and Broadwater wetlands that lie south-east were also not included. These latter wetlands were once connected to the Vasse Estuary *via* the Vasse River, but are now cut-off by the Vasse River diversion drain. Dryland parts of the Sabina Nature Reserve (Reserve 31188) and dryland parts of unallocated Crown Lands that extended into the estuaries were also not included.

In November 2000, the Site was extended to include:

- the remainder of Reserve 31188, which includes a part of the Sabina River;
- those parts of Tuart Forest National Park (*i.e.* Reserve 40250) that are between the Vasse-Wonnerup Ramsar Site as originally nominated and Tuart Drive. This extension includes a length of the Abba River, however road reserves are not included;
- Nature Reserve 41568, which includes a substantial part of the northern shore of Vasse Estuary.

2.2 Wetland Types

The Site as originally nominated in 1990 includes 750 ha of coastal brackish lagoons and seasonal brackish marshes. The 2000 extensions added 365 ha, including lower reaches of seasonal tributary streams (*i.e.* Sabina & Abba rivers). There are at least four different Ramsar wetland types contained within the total area of the site:

i). Seasonal brackish/saline lagoons;
ii). Estuarine mud flats and marshes;
iii). Freshwater/brackish deltas (mouth of the Ludlow, Abba & Sabina rivers);
iv). Freshwater swamps and channels of tributary streams (lower reaches of the Abba & Sabina rivers).

The aerial extent of each of these wetland types is yet to be mapped.

2.3 Land Tenure

Within the Site, open waters of the Vasse-Wonnerup estuaries are mostly Unallocated Crown Land (UCL), though the northern end of the Site, including a significant part of Wonnerup estuary, is leased for grazing (Appendix A Figures A5-A7). Portions of the Site are also contained within smaller conservation reserves. These are vested in the Conservation Commission and managed by DEC and include:

- a small part of the Vasse estuary and floodplain near Sabina River that lies within Nature Reserve 31188,
- a small section of floodplain on the north side of Vasse estuary Nature Reserve 41568,
- those parts (*i.e.* Nature Reserve 40250) of Tuart Forest National Park that are between the Vasse-Wonnerup Ramsar Site as originally nominated and Tuart Drive. This extension includes a length of the Abba River, however road reserves are not included.

Most lands adjoining the Site are privately owned, though there are also several small recreation reserves managed by the Busselton Shire. Some of the low terraces and flats surrounding the Wonnerup Estuary and a small portion of flats around the Vasse Estuary are used for hay production and pasture for stock. Crops and pasture are grown on low lying lands that prior to the installation of the floodgates would have been too waterlogged and/or too saline for agriculture. Floodgates enable crops and pasture to be grown on low-lying lands that would otherwise be too wet in winter and spring due to flooding from the estuary or too saline in summer and autumn due to seawater inundation.

Dairying comprised the bulk of agricultural production up until deregulation of the industry in 2000. Since then there has been increasingly more beef production. Lands surrounding the Wonnerup Estuary are also used for horticulture, vegetables and other ground crops (Appendix A Figure A6). The remainder of the privately owned lands adjoining the Ramsar Site, are either special rural, residential (*e.g.* Busselton township, Port Geographe canal development) or under proposal for urban development (*e.g.* rural land sub-divisions for residential housing) (Appendix A Figures A7-A8). Within the greater catchment of the Vasse-Wonnerup Estuary, landuse is predominantly beef and dairy, with small percentage of sheep farms and irrigated crops (McAlpine *et al.* 1989). Irrigated agriculture and livestock are not dependent on water sourced directly from the Site.

Current floodgate operation coupled with hydrogeological regimes that maintain soil salinity and moisture are vital to sustain agricultural productivity. However there has been no systematic survey of changes in soil and groundwater salinities or changes in watertable over time. There are no estimates of the contribution agricultural lands bordering the Site make to the local or regional economy.

The Shire of Busselton's *Biodiversity Incentive Strategy* (see White 2002) and the *Busselton Wetlands Conservation Strategy* (WAPC 2005) provide incentives to private landowners and developers to protect and rehabilitate remnant vegetation and wetlands on their property. Incentives take the form of rebates, financial assistance and subdivision/development rights in exchange for protection of biodiversity values (including ceding of land adjacent to wetlands, as reserves for conservation, landscape and foreshore protection purposes (WAPC 2005)). Given current rates of residential and urban growth within the Shire, it is hoped this will lead to a significant area of privately owned lands and estuary foreshore being added to conservation reserve or placed under a conservation covenant. There are also specific provisions under the Shire of Busselton's District Town Planning Scheme No. 20 (DTPS No 20, September 1999) designed to restrict clearing of remnant vegetation and to minimise disturbance to watercourses, wetlands, estuary and groundwater. No development, clearing, filling or draining may be carried out within the floodway[3] or flood-fringe of the Vasse-Wonnerup estuaries without Shire approval and subject to the advice of DEC, DoW and the Water Corporation. DTPS No. 20 stipulates that developments be assessed in relation to the "maintenance and enhancement of existing landscape character and impacts on wetlands, wildlife and habitats".

[3] WAPC (2005) have defined floodway as "including the river channel (or estuary) and portion of the floodplain which forms the main flow of floodwaters once the main channel has overflowed. Flood-fringe is the area of the floodplain, outside the floodway, which is affected by flooding, generally covered by still or very slow moving waters during the 1:100 year flood. A 1:100 year flood is a severe flood event that has a 1% chance of occurring in any given year *i.e.* on average, a probability of occurring once in 100 years". The most recent estimate (Bretnall 1987) of the 1:100 year flood level for the Vasse-Wonnerup estuary is 1.35 AHD; 1.45 m AHD including the flood-fringe.

2.4 Ramsar Criteria Met

2.4.1 Specific Criteria Based on Waterbirds

The Site is recognised as one of the more important breeding habitats for waterbirds in the State and the second most important in the south-west in terms of bird numbers (Jim Lane, DEC Busselton, pers. comm.). The criteria used under Ramsar to qualify sites as Wetlands of International Importance are discussed in Section 1.3, above. The Vasse-Wonnerup site meets two of these criteria:

Criterion 5: More than 34,000 waterbirds have been counted (December 1998) at the Vasse-Wonnerup Site (Lane *et al.* 2007). Waterbird data recorded to March 2000 indicates the Site regularly supports peak numbers of 25,000 - 35,000 waterbirds (Lane *et al.* 2007). Thus the site "regularly supports 20,000 waterfowl".

Criterion 6: At least 1% of the South East Asia-Australasia population of Black-winged Stilt *Himantopus himantopus*, at least 1% of the Australian populations of Red-necked Avocet *Recurvirostra novaehollandiae* and at least 1% of the south-west Australian regional populations of Australian Shelduck *Tadorna tadornoides* and Australasian Shoveler *Anas rhynchotis* "regularly" use the Site (Lane *et al.* 2007). Note: Australian Shelduck and Australasian Shoveler are an update to the 2000 RIS following the Lane *et al.* (2007) review of waterbird data (refer Section 9.2).

Ramsar guidelines (see Ramsar Convention 2006) for applying Criteria 5 and 6, define "regularly" as:

i). occurring "in two-thirds of the seasons for which adequate data are available, the total number of seasons being not less than three, or

ii). 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 (means based on three or four years may be quoted in provisional assessments only)".

Another five shorebirds have been recorded in numbers greater than 1% of the Flyway population in some years:

- Curlew Sandpiper *Calidris ferruginea*,
- Common Greenshank *Tringa nebularia*,
- Long-toed Stint *Calidris subminuta*,
- Sharp-tailed Sandpiper *Calidris acuminata*, and
- Wood Sandpiper *Tringa glareola*.
- Red-capped Plover *Charadrius ruficapillus*

Other species occurring in significant numbers include:

- Australiasian Grebe *Tachybaptus novaehollandiae*,
- Australian Pelican *Pelecanus conspicillatus*,
- Australian Shelduck *Tadorna tadornoides*,
- Australasian Shoveler *Anas rhynchotis*,
- Eurasian Coot *Fulica atra*,
- Great Egret *Casmerodius alba*,
- Whiskered Tern *Chlidonias hybrida*,
- White-faced Heron *Egretta novaehollandiae*,
- White-winged Tern *Chlidonia leucoptera*, and
- Yellow-billed Spoonbill *Platalea flavipes*.

While it is possible the Site may qualify against Ramsar Criterion 3 as applied to waterbirds, this could not be confirmed with currently available data. The possible application of this criterion should be reviewed when contemporary data for the Site and the bioregion are available and following further, more-general consideration of the application of Ramsar Guideline 70 (v)[4], in particular definition of the terms "supports" and "particularly characteristic" (Jim Lane, DEC, pers. comm.). Waterbird diversity and abundances at the Vasse-Wonnerup Site are discussed in detail in Section 4.14, below.

The Site was not considered to qualify against Ramsar Criterion 4 as applied to waterbirds (Jim Lane, DEC, pers. comm.). None of the waterbird species recorded are considered to rely on the wetland at critical life stages, *i.e.* migration stop-over, moulting phase, breeding or drought refuge. The Site is not considered to "contain particularly high proportions of (waterbird) populations gathered in relatively small areas at particular (*i.e.* critical) stages of life cycles" as would be required to meet Guideline 74 of Criterion 4. In order to meet this criterion, it was considered that a species would first need to meet Criterion 6. While five waterbird species do meet Criterion 6, none are known to gather at ≥ 1% of population levels for the purpose of migration stop-over, moulting, breeding or drought refuge, *i.e.* for critical stages of their life cycle (Jim Lane, DEC, pers. comm.).

2.4.2 Specific Criteria Based on Fish

There is a current paucity of data on fish communities within the Site. At least 29 species are known to occur, including freshwater, estuarine and marine fishes. However abundances, distributions and timing of spawning migrations are unknown. While it is possible the Site may qualify against Ramsar Criteria 7 and 8 for fish and against Criterion 9 as applied to fish populations, this could not be confirmed with currently available data.

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[4] Guidelines for the application of Criteria 3 and 4 (Ramsar Convention 1999a):

Criterion 3 Guideline 70. When Contracting Parties are reviewing candidate sites for listing under this Criterion, greatest conservation value will be achieved through the selection of a suite of sites that have the following characteristics. They:

i) are "hotspots" of biological diversity and are evidently species-rich even though the number of species present may not be accurately known; and/or
ii) are centres of endemism or otherwise contain significant numbers of endemic species; and/or
iii) contain the range of biological diversity (including habitat types) occurring in a region; and/or
iv) contain a significant proportion of species adapted to special environmental conditions (such as temporary wetlands in semi-arid or arid areas); and/or
v) support particular elements of biological diversity that are rare or particularly characteristic of the biogeographic region.

Criterion 4 Guideline 74. Critical sites for mobile or migratory species are those which contain particularly high proportions of populations gathered in relatively small areas at particular stages of life cycles….For example, many waterbirds use relatively small areas as key staging points (to eat and rest) on their long-distance migrations between breeding and non-breeding areas. For Anatidae species, moulting sites are also critical…..

PART II. ECOLOGICAL CHARACTER DESCRIPTION

3. SELECTING KEY COMPONENTS, PROCESSES AND SERVICES

Sections 4, 5 and 6 describe the key components, processes and benefits/services that most strongly determine the ecological character of the site and the relationships between them. Phillips and Muller (2006) describe "keystone species" as those endemic species whose loss or change has the potential to cause a fundamental shift in ecological character of the whole site. This definition was considered appropriate when selecting which components, processes and benefits/services be considered as 'key' for the Vasse-Wonnerup Site. They include but are not restricted to the values for which the Site was Ramsar listed.

Fauna such as water rats (*Hydromys chrysogaster*), frogs, long-necked turtles (*Chelodina oblonga*) and other wetland-dependent reptiles (*e.g.* tiger snakes *Notechis scutatus* and some skinks) have not been included as key ecosystem components. Although they play important roles in wetland food-webs, they were not considered as components most strongly influencing or determining the ecological character of the Ramsar Site. Nor are any of these species likely to be restricted to the Site. The *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007) states the aim of an ECD "is not to list all the components and processes that support a service", rather "preference should be given to those which have a known, direct relationship" to the values for which the Site is Ramsar-listed". For example, the key components and processes required to support 20,000 waterbirds will likely be: water regime, food resources (invertebrates, fish & aquatic plants), nesting resources (aquatic plants, riparian vegetation) and breeding habitat. As per the *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007), consideration has also been given to "components or processes outside the wetland that may also be critical in maintaining the values".

Regulation of greenhouse gases has not been included as a key ecosystem service as there were no available quantitative or qualitative data on the global warming potential (GWP) of the Site. GWP is measured as a function of net greenhouse gas production/consumption. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In low oxygen environments such as the bottom of wetlands, lakes, estuaries and the ocean, CH_4 is naturally produced by anaerobic bacteria during decomposition of organic matter (IPCC 2001, Ruddiman 2003, EPICA 2004). Under oxygenated conditions, organic decomposition is done by aerobic bacteria that produce CO_2 as they respire. Wetlands can also be a natural source of N_2O as part of the conversion of nitrate nutrients (NO_3) by microbes present in muds and in biofilms on stems and roots of aquatic plants. Significant increases in N_2O emissions have been recorded from highly nitrate-enriched wetlands overseas (Verhoeven *et al.* 2006).

Yellow-billed Spoonbill *Platalea flavipes* (Sue Creagh)

4. WETLAND COMPONENTS

A summary list of key components of the Vasse-Wonnerup Wetlands is given in Table 4 and a discussion of each presented in the following sub-sections.

Table 4. Key ecosystem components of the Vasse-Wonnerup Wetlands.

Component Type	Component
Physical Form	Geomorphology / Estuary morphology - broad, shallow basin, large seasonal variation in area of inundation - seasonally closed estuary Soil type - sandy; poor nutrient retention; acid sulphate soils - sedimentation and erosion Hydrology / Hydrogeology - seasonal freshwater inflows
Water Quality	Nutrients - eutrophication Salinity - seasonal salinity regime Dissolved oxygen - summer anoxia / hypoxia Turbidity / Water Clarity
Biological	Phytoplankton and aquatic macrophytes - microalgae, macro-algae, seagrasses Fringing vegetation - samphire; sedges/reeds; remnant eucalypts, paperbarks Habitat connectivity - Tuart National Park & Geographe Bay Aquatic invertebrates - zooplankton, benthic macroinvertebrates Fish community -freshwater, estuarine and marine fishes Waterbirds - international migratory species - Australian resident species

4.1 Geomorphology / Morphology of the Estuaries

The Vasse-Wonnerup Ramsar Site is located in an extensive, low lying, coastal depression formed between a series of small parabolic fore dunes that line Geographe Bay and higher lands of the Ludlow Plain to the south and east. The fore dunes are part of the Holocene Quindalup formation on the Swan Coastal Plain (Hill & Ryan 2002). Geographe Bay, is a long, broad (100 km wide), shallow, north-facing embayment at the southern end of the Rottnest Shelf. The bay is characterised by low profile, low energy, sandy shores vegetated by dense seagrass meadows (Searle & Semeniuk 1985). The shoreline consists of gently sloping shallows and beaches. The prevailing south-westerly swells are refracted around into the bay (Walker *et al.* 1987). The main current in the nearshore zone of the bay is easterly, resulting in net longshore sediment transport from west to east. Circulation and mixing within the bay and the estuaries is driven primarily by wind action. Tides are diurnal with a low tidal range usually < 1 m (*i.e.* microtidal). Though the bay is relatively protected from prevailing south-westerly swells, there is a natural regression of the shoreline that is due largely to diminishment of the sand supply caused by wind and wave erosion and chemical weathering (Hill & Ryan 2002). Localised erosion south of the estuary inlet has been exacerbated by the construction of groynes intended to slow beach erosion in the vicinity of Busselton township (WAPC 2005). The groynes can be seen in the aerial image provided in Appendix A Figure A3.

The Site is part of the Vasse-Wonnerup consanguineous wetland suite as described by V & C Semeniuk Research Group (1998). It comprises the Vasse and Wonnerup estuaries and their floodplains (notably the Vasse River delta marshes and areas adjacent to the central Vasse Estuary), 'Swan Lake', Wonnerup Inlet, and the lowest reaches of the Sabina, Abba and Ludlow rivers. The largest components are the Vasse and Wonnerup estuaries, which are 9 and 5 km long and up to 0.6 km wide and typically < 1 m deep even during winter (Lane *et al.* 1997). Exit channels are around 2 m deep. During winter flood flows, the estuaries are connected by the narrow Malbup Creek once water levels exceed 0.8 m AHD (McAlpine *et al.* 1989). Malbup Creek is partly included in the Site however, The Deadwater which comprises a shallow linear embayment between Wonnerup Estuary and the coast, connected to Wonnerup Inlet, is not.

Wonnerup Inlet and The Deadwater, together with a number of small wetlands west of Busselton township, are actually penetrations through the coastal dunes. The geomorphology of The Deadwater however, has been significantly altered from its natural state due to mineral sands mining operations conducted by Ilmenite Minerals Pty Ltd during the 1960s (Bernie Masters, Busselton, pers. comm.).

The Vasse and Wonnerup estuaries have constricted openings, each with a sinuous channel connecting to the ocean at (the shared) Wonnerup Inlet. The inlet itself is frequently closed to Geographe Bay due to sandbar formation at the mouth (Lane *et al.* 1997). Much of the land which surrounds the wetlands comprises a series of low relief terraces which are only slightly elevated above sea level (see Figure 4).

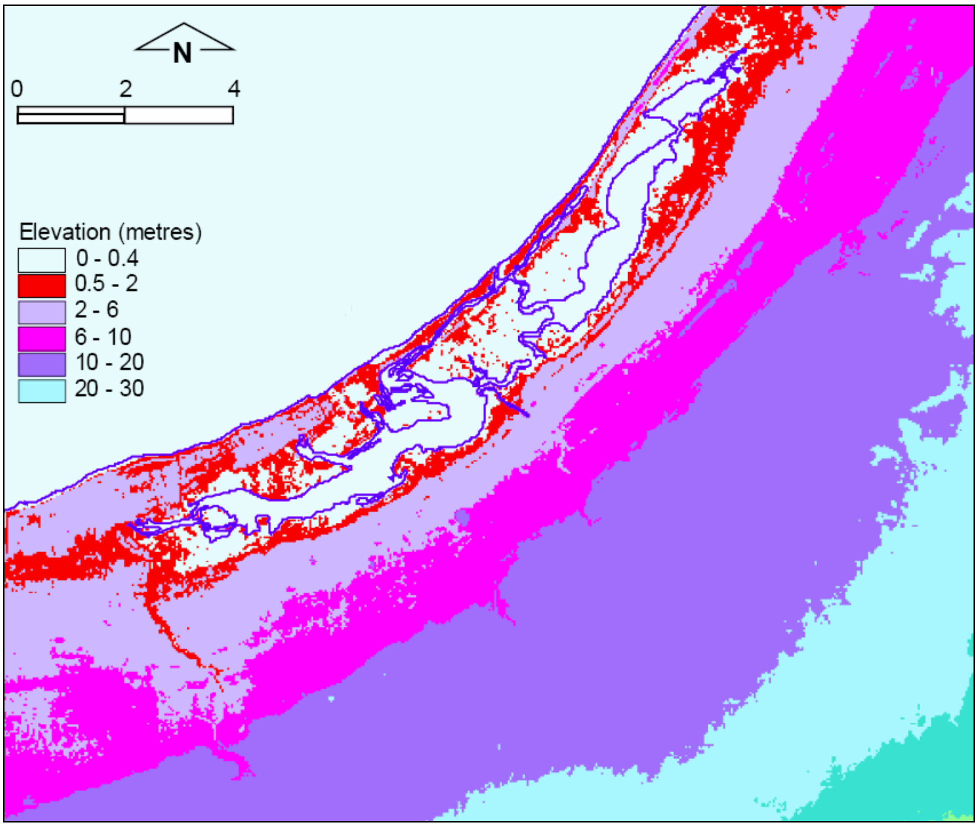

Figure 4. Broad-scale topography (m AHD) of the Vasse-Wonnerup Site and surrounding lands (map reproduced from DoE 2004a).

In their natural state, the estuaries would have been typical of wave-dominated estuaries common around the south-west coast. Wave-dominated estuaries are those whose overall geomorphology has been largely determined by wave action (OzEstuaries 2007). They are characterised by a sandy barrier or sand bar (partially constricting the entrance) behind which lies a broad central basin with tidal sand banks and fluvial deltas where rivers enter the basin. This geomorphology means that the estuaries have naturally high sediment trapping efficiency, naturally low turbidity, a salt wedge/partially mixed circulation and are at increased risk of sedimentation (OzEstuaries 2007). In their natural state, the central basins are low energy areas characterised by organically rich (and often nutrient-rich) muds. Deposition of muds, organics and their nutrients, occurs naturally as the energy of tributary waters dissipates on entering the broader expanse of the estuaries. Deposition of river bedload material results in shallowing of the central basins and growth of deltas at the river mouths. As layers of organically rich muds accumulate, sub-surface sediments may become anoxic due to high rates of bacterial decomposition. This anoxia may be offset, at least partially, by bioturbation of sediments by invertebrate fauna living in (infauna) or on them (epifauna) and by some species of fish and birds. If deposition at the deltas continues over hundreds or thousands of years, wave-dominated estuaries may evolve naturally into "wave-dominated deltas as the central basin is completely infilled (or is bypassed by the river channel), and fluvial sediment is exported directly to the ocean rather than being trapped" (OzEstuaries 2007).

The Vasse and Wonnerup estuaries however, are no longer true estuaries because inflow of seawater is largely prevented by floodgates installed on their exit channels in 1908 (refer Section 4.4.1). The estuaries now act as compensating basins for water discharging from the Ludlow, Sabina, Abba and Vasse Rivers. The narrow entrance and sand bar formation naturally restricts tidal flushing of the estuary, but this has been exacerbated by construction of the floodgates and is believed to have lead to more frequent closing of the bar (McAlpine 1989). At present, the bar naturally opens most winters, except if large storms result in greater accumulation of sand and seaweed. Discharge from the estuaries and tidal exchange keep the sand bar at the mouth of Wonnerup Inlet open for limited and varying periods (days, weeks, months) each year and the bar may close at any time of the year depending on sea conditions, tide heights and rate of discharge from the estuaries. In summer, however, the bar is artificially opened by means of a hydraulic excavator to a width of 13 m and depth of around 2 m. Typically, the bar is opened in December to flush poor quality water from the Inlet and/or Vasse Estuary exit channel. When the bar is closed, water quality in the Inlet can rapidly deteriorate due to decomposition of resident macrophyte beds and large quantities of decaying seaweed washed in during winter storms. The result can be black, lifeless waters that produce a noxious hydrogen sulphide odour (Jim Lane pers. comm.). Hydrogen sulfide has high acute (short-term) toxicity to aquatic life. Chronic exposure at low concentrations (irritations of airways, *etc*) can cause illness in people and can be lethal at higher concentrations (Hicks & Lamontagne 2006).

The bar has been present since at least 1829 (Cross 1833, cited in Lane *et al.* 1997). At one time there were two entrances a few hundred meters apart, but the westernmost closed over late in the 19th century, while the other has migrated a little further east (Bunbury & Morrell 1930, cited in Lane *et al.* 1997). Artificial opening of the bar was standard practice most years in the early 1900s to allow sea water entry at high tide to flush the estuary of stagnant water and prevent the death of thousands of fish (*The South-Western News*, February 3, 1905, cited in Lane *et al.* 1997). Comment at the time was that siltage at the mouth of the Inlet was the cause of the problem. Though not specified, it is likely the increased siltation was (and is) the result of catchment land clearing and diversion of the Capel River, as the floodgates were not installed till 1908. Early records suggest that the mouth of Wonnerup Inlet was often open to the sea during summer in the 1800s. Lane *et al.* (1997) cite Public Works records from 1919 and 1928 that indicate installation of the gates may have made artificial opening of the sand bar more difficult. Due to constantly shifting sands, there is a preference for not opening of the bar in winter unless there is sufficient head in the estuaries to keep the bar open. When the bar does close over summer, water quality in Wonnerup Inlet can deteriorate below that in the Vasse Estuary. Lane *et al.* (1997) made the point that opening the floodgates under these conditions would not prevent fish deaths unless the bar was open as well. Artificial opening of the Vasse floodgates and of the sandbar means the main channel and lower third of Vasse Estuary basin typically contains permanent water over summer to a depth of ca. -0.1 m AHD. The deeper mid channel of the lower Wonnerup Estuary also holds some water into autumn, typically only -0.4 m AHD. The surrounding terraces are only inundated during winter (McAlpine *et al.* 1989).

Limited flushing means waters typically have long residence times within the estuaries. This increases the rate of sediment, carbon and nutrient deposition, and increases capacity for carbon and nutrient recycling. Under natural conditions, turbidity would also be expected to be low, as low wave energy would limit re-suspension of deposited sediments and organics except during winter storms and/or periods of high river discharge. However there is no available data on residence times, sediment nutrient stores, carbon-nutrient processing or seasonal variability in turbidity within the Vasse-Wonnerup Estuary.

OzEstuaries (2007) cites a limited amount of data on the geomorphology of the Vasse-Wonnerup Estuary. These data were compiled from the Australian Estuarine Database (Digby) Survey 1998 and Geoscience Australia mapping of the Vasse-Wonnerup Estuary in 2000 as part of the National Land and Water Resources Audit (2001). Data provided on the OzEstuaries website are reproduced in Table 5, together with area estimates of the Vasse and Wonnerup lagoons and The Deadwater provided by McAlpine *et al.* 1989. There are no current depth contour maps of the estuary or river deltas. The most recent bathymetry maps are from 1968 and copies are held by DEC, Busselton.

Table 5. Vasse-Wonnerup estuary features. Sources: McAlpine *et al.* 1989 and OzEstuaries. (OzEstuaries - http://www.ozcoasts.org.au/ downloaded March 2007).

Facies	Area	Tidal Period	Average
Barrier	8.05 km²	Perimeter	37.49 km
Central Basin	7.50 km²	Water Area	8.29 km²
Fluvial Bayhead Delta	1.11 km²	Estuary Catchment Area	725 km²
Flood/ebb Delta	0.01 km²	Area of Open Water	7.16 km²
Saltmarsh Saltflat	1.12 km²	Estuary Length	5.76 km
Tidal Sand Banks	0.02 km²	Estuary Width	1.28 km
Channel	1.32 km²	Entrance Length	2.60 km
Bedrock Perimeter	4.91 km	Total Entrance Width (1 entrance)	0.21 km
Vasse Lagoon	5.9 km²		
Wonnerup Lagoon	3.1 km²	Mean Depth	0.5 m
The Deadwater	0.3 km²		

Note: Estuary Length = length of the estuary from mouth to end of tidal range.
Estuary Width = width of the estuary at the point of constriction, or otherwise identified entrance. If more than one entrance is identified, the sum of the entrances is supplied.
Perimeter = derived from the polygon obtained in measuring the estuarine water area. This reflects the amount of shoreline environment, so 'island' polygons are added to the total perimeter.
Total Entrance Width = total entrance width that takes into account multiple entrances.
Water Area = area of water comprising the estuary between the upstream and downstream estuarine limits.

Bathymetry Data

Original (1965) bathymetry data for the Vasse-Wonnerup Site is held by DEC. Enquiries should be directed to Department of Environment and Conservation, 14 Queen Street, Busselton WA 6280, Australia, (Tel: +61-8-9752-5555; Fax: +61-8-9752-1432).

Copies of the data are also held by DoW. Enquiries should be directed to Decision Support Team, Aquatic Sciences Branch, Department of Water, The Atrium, 168 St Georges Tce, Perth, WA 6000, Australia, (Tel: +61-8-6364-7600; Fax: +61-8-6364-7601).

4.2 Soil Types and Acid Sulphate Soils

There are two major physiographic units of the Vasse-Wonnerup catchment; the Blackwood Plateau to the south, where tributary rivers arise, and the Swan Coastal Plain which contains the Ramsar Site. On the Swan Coastal Plain, the rivers cross the Abba and Ludlow plains before entering the Vasse-Wonnerup wetlands (DoE 2004a). The coastal plain soil types are largely the product of sea-level changes over the past 4,000 to 20,000 years. Current sea-levels were reached some 6,000 years ago though there were minor fluctuations as recently as 4,000 years ago (Balla 1994). The soils are thus largely comprised of aeolian and marine deposits of unconsolidated quartz grain sand and calcareous material. These sandy soils are alkaline, have poor nutrient-binding and water-holding capacity but in many areas are prone to water-logging (V & C Semeniuk Group 1998). They require drainage and the application of fertilisers to establish and maintain agricultural productivity. There are three basic soil-landscape units as described by McArthur and Bettanay (1974) and Tille and Lantzke (1990) and given in Table 6 and in Figure 5. All are Pleistocene in age. Much of the Ramsar site is contained within the Vasse unit. Beneath these sediments are the underlying older mid Jurassic - early Cretaceous (170 - 100 mya) sedimentary sandstone units of the Vlaming Sub-basin within the larger Perth Basin.

Table 6. Major soil-landscape units of the Vasse-Wonnerup Ramsar Site (source: McArthur & Bettanay 1974, Tille & Lantzke 1990, GeoCatch 2002, DoE 2004a).

<table>
<tr><th>Soil-landscape Unit</th><th colspan="2">Description</th></tr>
<tr><td>Quindalup Dunes</td><td colspan="2">Coastal dunes with calcareous deep sands and yellow sands; vegetation that occurs on these soils is characterised by coastal scrub.</td></tr>
<tr><td rowspan="4">Vasse Deposits or Quindalup Flats</td><td colspan="2">Poorly drained estuarine flats including tidal-flat soils, saline wet soils and pale deep sands. The major vegetation associations on these soils are samphire heathlands, sedges and paperbark woodland.</td></tr>
<tr><td>Flats</td><td>Flats and low rises with deep pale calcareous sands.</td></tr>
<tr><td>Wet Flats</td><td>Poorly drained wet flats on raised terraces around the edge of the estuaries and consist of a variety of soils with dark calcareous sands mixed with estuarine and lacustrine sediments. Generally these soils have high organic matter and calcium carbonate content, have low phosphorus retention capability and are often saline.</td></tr>
<tr><td>Very Wet Saline Flats</td><td>Vasse-Wonnerup estuaries, The Deadwater, the Broadwater and in low-lying depressions which are often underwater in winter and saline in summer.</td></tr>
<tr><td rowspan="3">Spearwood Dunes and Flats</td><td colspan="2">Immediately east of the Vasse soils and overlie Tamala limestone with deep yellow, sand, pale deep sand and yellow/brown shallow siliceous sand; they have better nutrient retention (i.e. phosphorus).</td></tr>
<tr><td>Dunes</td><td>East of the Sabina River are mainly well drained throughout the year and support tuart forest and woodlands.</td></tr>
<tr><td>Ludlow Flats</td><td>West of the Sabina River are areas where some subsoil waterlogging occurs in winter and remnant vegetation is dominated by flooded gum and peppermint woodland.
Adjoining the Vasse-Wonnerup wetlands, is a narrow strip of poorly drained land, with shallow brownish yellow sands overlying clay.</td></tr>
</table>

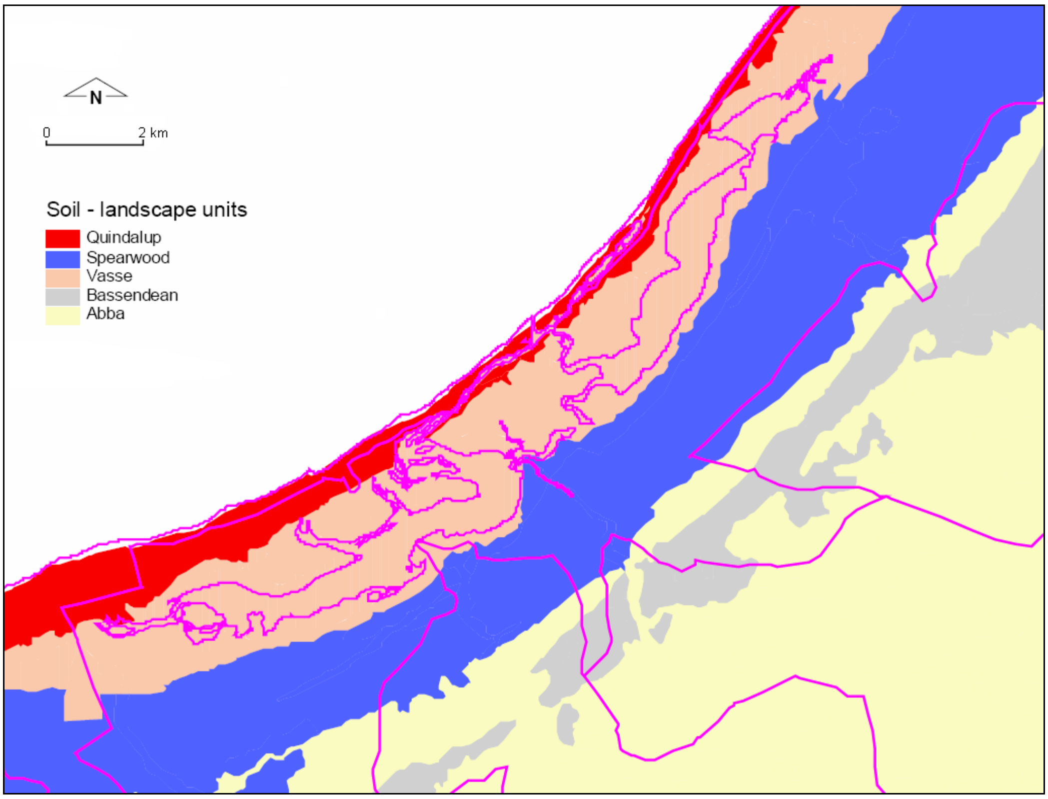

Figure 5. Soil-landscape units of the Vasse-Wonnerup Ramsar Site; — estuary boundary and river sub-catchment boundaries (map reproduced from DoE 2004a).

The sea level changes during the Holocene resulted in the inundation of Australia's coastal swamps, marshes and wetlands. The peat sub-soil horizons in these waterbodies are naturally rich in organic material and iron oxides. They are also frequently low in oxygen due to bacterial decomposition of the abundant organic material. When inundated, sulfate in the sea water mixed with wetland sediments producing large quantities of iron sulfides (*e.g.* pyrite) under anoxic conditions. Sulfate-reducing bacteria transform the sulfate from seawater into hydrogen sulfide gas (rotten egg gas). The sulphide in the gas then reacts with available iron to form pyrite. If subsequently exposed to air, by either natural or anthropogenic disturbance, these sulfides oxidise to form sulfuric acid, resulting in acid sulfate soils (ASS) with pH < 4 (Johnston *et al.* 2003, Appleyard *et al.* 2004). Potential acid sulphate soils (PASS) are those which contain unoxidised sulphidic materials and generally have a pH > 6. Much of the low-lying coastal plains of the south-west have large areas of ASS or potential acid soils (Appleyard *et al.* 2004). Most of the Vass-Wonnerup Site is at high risk from ASS (Figure 6).

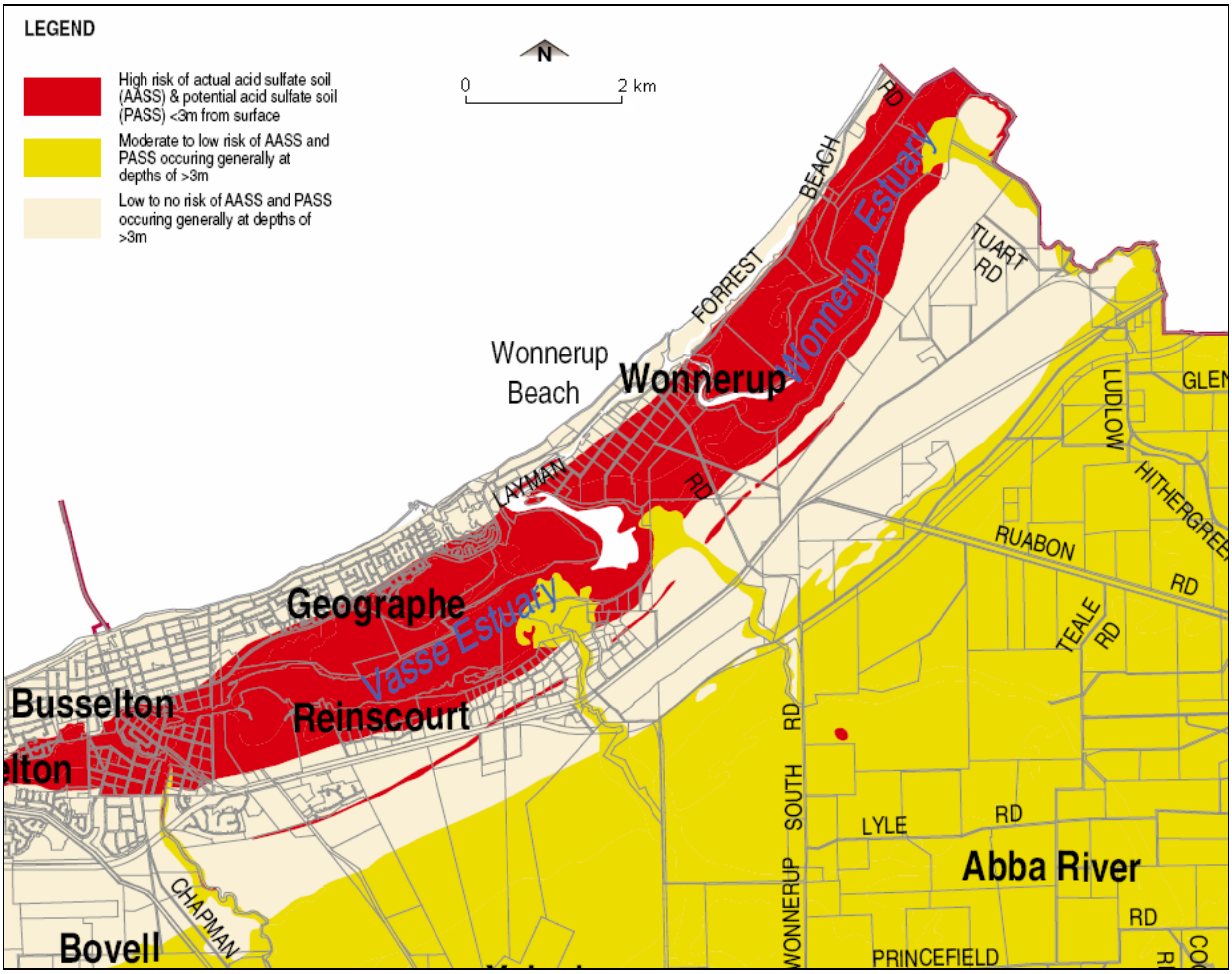

Figure 6. Actual and potential acid sulphate soils of the Vasse-Wonnerup Ramsar Site and surrounding lands (map from: http://portal.environment.wa.gov.au/portal/page?_pageid=53,34347&_dad=portal&_schema=PORTAL downloaded March 2007).

4.3 Hydrogeology

The Vasse-Wonnerup Site is considered one of a number of significant groundwater-dependent ecosystems on the Swan Coastal Plain (EPA 2006). The wetlands and river reaches on the plain lie within the Quaternary superficial groundwater formation (aquifer) which forms the surface of the plain. The superficial aquifer is unconfined[5] and relatively thin in this area, with a saturated thickness typically less than 10 metres (DoE 2004a). The depth of the watertable varies seasonally between about 0.5 and 3 m. Water levels in the wetlands are generally related to the water level within the superficial aquifer, though there is a varying degree of interconnectedness between the superficial aquifer and underlying Leederville and Yarragadee aquifers. While the superficial aquifer is recharged predominantly by rainfall, there is also some upward leakage from and downward leakage to the Leederville aquifer (DoE 2004a). The extent of connectivity between the superficial and Leederville aquifers is not known (Hall *et al.* 2006). All three aquifers contain low salinity waters. The Busselton Water Board abstracts water from the Leederville and Yarragadee aquifers for potable supply to Busselton township. Water Corporation abstracts water from the Leederville aquifer for potable supplies to the Dunsborough township (WAPC 2005). Most abstraction by domestic bores is from the Leederville aquifer.

The Leederville aquifer is confined, Cretaceous in age of variable thickness; from 50 m in the west to some 500 m east of Busselton Shire. The Yarragadee aquifer is a major aquifer of the southern Perth Basin and varies in thickness from around 600 to 1,600 m. The Yarragadee comprises a number of formations which range in age from Jurassic to Permian. Recharge of the Leederville and Yarragadee aquifers, is mainly *via* direct infiltration of rainfall on the Blackwood Plateau. Most discharge from the Leederville aquifer is into the underlying Yarragadee, but there is also some discharge into the Blackwood River and the coast (DoE 2004a). There is also upward leakage from the Yarragadee aquifers into Leederville Aquifer, but the amount is believed minor in comparison to the discharge which occurs in the Blackwood River (and probably the Donnelly and Warren rivers) to the south, and the main discharge which occurs along Geographe Bay and south coasts (DoE 2004a).

Widespread clearing on the coastal plain has increased the capacity for rainfall infiltration and recharge. However, extensive drainage networks on the coastal plain means much of the surface flow is channelled away before infiltration can occur. Losses through drainage compound naturally high evapotranspiration losses (EPA 2006).

Groundwater flow in all three aquifers is generally towards the coast (WAWA 1995). Natural groundwater flow can be altered by heavy groundwater abstraction. This is a potential issue for any future proposals to abstract water from the Yarragadee and would need to be closely monitored (DoE 2004a). There is already substantial abstraction from each of the Superficial, Leederville and Yarragadee aquifers, but no currently available hydrogeological model to predict specific changes in the water table (DoE 2004a). While levels in superficial aquifers do not appear to have significantly altered over the past 20 years, data records are poor and there is a need for further investigation of monthly trends (Hall *et al.* 2006). The Aquatic Sciences Branch of DoW is in the process of developing a detailed hydraulic model for the Vasse-Geographe catchment and has recommended high frequency monitoring of flow and water quality in the superficial aquifer (DoW 2006). This hydraulic model is the first phase in developing a predictive model for water quality for the Vasse-Geographe catchment under the Vasse-Geographe CCI Water Quality Improvement Plan. DoW has termed the model SQUARE (Streamflow Quality Affecting Rivers and Estuaries). SQUARE is the result of the modification of LASCAM (Large Scale Catchment Model) originally developed by Sivapalan *et al.* (1996a,b,c).

[5] Confined = held within rock or clay layers. The unconfined superficial aquifers are predominantly sand and limestone.

4.4 Surface Hydrology

4.4.1 Surface Flow, River Diversion and the Floodgates

Over the past 130 years, the catchment has been extensively cleared and drainage networks constructed for agriculture (dairy & beef). The catchment of Vasse-Wonnerup estuary would originally have covered ca. 1,500 km^2. However, several rivers that formerly discharged to the Vasse-Wonnerup Estuary have been diverted to the sea and floodgates were installed in 1908 to limit seawater inflow and provide storage capacity for floodwaters. Total annual discharge from the catchment has been estimated at 210 GL, but much of this no longer discharges to the Wonnerup Inlet (Pen 1997).

The floodgates operate 'automatically' through hydrostatic pressure; opening when water levels are higher on the upstream side and closing when levels are higher downstream. Installation of the floodgates enabled cropping and stock grazing on lands that would otherwise have been flooded by estuary waters in winter and spring or inundated by saltwater during summer and autumn. It has also enabled colonisation by dry-land native plants. Water levels and quality have thus been greatly altered. Dramatic fluctuations in water level now occur in winter, stabilise in spring and then decline in summer (Lane *et al.* 1997).

Pre-European settlement, the system received direct inflow from the Capel, Ludlow, Abba, Sabina and Vasse rivers and indirect flow from Iron Stone Gully, Buayanyup and Carbunup rivers which discharged to The Broadwater-New River and then into the Vasse River (Lane *et al.* 1997). All were seasonal in flow. In the Ludlow and Abba, salty waters extended about 0.8 km and 1.2 km respectively, upstream from the river mouths and somewhat less in the Sabina River (Bunbury & Morrell 1930, cited in Lane *et al.* 1997). In 1880, the Capel River was diverted to the ocean *via* Higgins Cut, 5 km NE of Wonnerup Estuary. In 1908, timber floodgates were installed on the exit channels of the estuaries effectively restricting the entry of seawater and transforming the ecosystem from that of an estuarine basin to one of seasonal, fresh-brackish lagoons, unique in Western Australia. The gates resulted in the annual drying of most of both estuaries, which prior to installation would likely have been a relatively rare event. Only a small amount of permanent water remained in the deeper mid channel areas of the lower Vasse and Wonnerup estuaries.

In 1915, a cut was made to drain water from New River to the ocean. During the 1920s extensive drainage networks were put in place throughout the catchment, increasing the volume of river inflow to the system and resulting in more frequent flooding of low-lying coastal properties (including Busselton township). In 1927, a major drain, the Vasse River Diversion Drain, was constructed to divert the upper Sabina and virtually all of the Vasse River flow to the ocean. Approximately 60% of the total inflow from the Sabina River and 90% inflow from the Vasse River has been diverted away from the estuaries. The Diversion Drain has also effectively cut-off the Broadwater from the Vasse-Wonnerup system. Flow from Iron Stone Gully, Buayanyup and Carbunup rivers was also diverted to the ocean. McAlpine *et al.* (1989) estimated the present combined catchment of the Vasse, Sabina, Abba and Ludlow rivers to be 686 km^2, but that drainage diversions had effectively reduced this to 403 km^2 (refer Table 13, Section 4.10.1, below).

In 1928, the timber floodgates were upgraded and, at the request of landowners, the floodgate sill heights lowered by 0.46 m (to $^-$0.45m AHD) to further reduce winter flooding. This however, proved too effective at reducing water levels and measures were then taken to raise the water level in the estuaries in spring to prevent pastoral lands from drying too early in the season (Lane *et al.* 1997). Initially, artificial closing of the sand bar was trialled but proved unsatisfactory, and in 1948, four removable stop-boards were fitted to the floodgates to raise estuary water levels in winter-spring by as much as 0.76 m above sill levels (*i.e.* $^+$0.31m AHD). The stop-boards were installed seasonally in early spring (usually Sept. - early Oct.) and removed after the first rains. In spring, before freshwater inflow had finished for the season, the stop-boards were fixed at a height of 0.4 m in order to retain freshwater for as long as possible to facilitate breeding of black swan. Water levels in 'Swan Lake' at the northern end of the Wonnerup estuary were (and still are) similarly manipulated. In 1964, a levee bank was constructed across the northern end of the Wonnerup Estuary to prevent back-flooding by the Ludlow River which had been diverted south of the levee (McAlpine et al. 1989). Since that time, adjacent landholder Keith Forrest has operated the flap-valved culvert in the levee to maintain a suitable level of seasonal freshwater for the 50 - 150 breeding pairs of swans which nest annually on 'Swan Lake' (Jim Lane, DEC, pers. comm.).

Stop-boards are also installed on the lower Vasse River at the Old Butter Factory. Flow in the lower reach of the Vasse River is thus highly regulated by both the stop-boards and the Diversion Drain further upstream. Morgan and Beatty (2004) described this lower reach as a stagnant, elongate reservoir, subject to severe macroalgal and cyanobacteria blooms over summer. At present, at the beginning and end of each winter, some water from the Diversion Drain is re-diverted into the lower Vasse River to a maximum height of $^{+}$0.45 m AHD. This is primarily for aesthetic purposes and to provide some flushing with better quality water. Subsequent to the flooding of Busselton township during winter 1997, further flood control measures have been put in place by the Water Corporation between 2000 and 2007. These included detention basins in the upper catchment of the Vasse River, together with a minor upgrade of the Diversion Drain to provide 1:100 year flood protection to Busselton township (WAPC 2005). Previous estimates of the 1:100 year estuary flood level were $^{+}$1.35 m AHD, not including the flood-fringe (*i.e.* "that area of the floodplain in which landfill was considered acceptable from a flood management perspective" (Bretnall 1987). Including the flood fringe the 1:100 Year level was $^{+}$1.45 m AHD.

During the 1980s, the Busselton Naturalist Club lead a campaign for manual openings of the floodgates over summer-autumn to help ameliorate poor water quality and sudden, mass fish deaths in the estuary (Bernie Masters, Busselton, pers. comm.). This was finally implemented in 1988 at the Vasse floodgates. Extended summer-autumn openings however, resulted in saline to hypersaline waters persisting over large areas for up to five months each year; there is now permanent water over the lower third of the Vasse Estuary (Lane *et al.* 1997). Thus from winter to early summer the estuaries were brackish, while in summer-autumn they were saline-hypersaline due to evapo-concentration and leakage of seawater past the gates. This change in salinity and flow regime post-1988 was implicated in the salinisation of pastoral lands adjoining the Vasse Estuary and death of fringing native vegetation which had colonised the estuary terraces since floodgates were installed in 1908 (Lane *et al.* 1997) and deaths of trees lining the Abba River (Jim Lane, pers. comm.). It was also suggested as a possible contributing factor to the decline in waterbird numbers recorded in 1989 (Ninox 1989) (see Section 5.2, below). Between 1988 and 1990, saline waters were allowed to reach elevations up to $^{+}$0.1 m AHD, resulting in complaints from landholders and concern being expressed about death of riparian vegetation (Lane *et al.* 1997). As a consequence, in August 1990, the (then) Water Authority revised its operational guidelines for the floodgates to limit salt water entry raising upstream estuary levels above $^{-}$0.10 m AHD. However higher levels of up to (and possibly beyond) $^{+}$0.3 m continued to occur until February 1997. Since that time, closer attention to water levels and gate openings has resulted in stricter adherence to the 1990 guidelines (Jim Lane, pers. comm.). The Wonnerup floodgates have been manually opened only occasionally on an as need basis, and for short periods of time (hours to 1-2 days).

In 2004, Water Corporation again upgraded the floodgates by replacing the entire structures with concrete. The position of the new floodgates is within 20 m of the original wooden structures. The new concrete floodgates have reduced the leakage of salt water which had increased following the last upgrade (replacement of wooden with stainless steel gates) in 1998. They also have small fish gates that can be left open for longer periods without the risk of sea-water flooding the estuary. Operation of the fish gates is now remotely controlled by telemetry.

Water Corporation has automatic data loggers at the gates to relay water level, temperature and salinity data to DEC in Busselton, who monitor fish activity and open and close the fish gates. DoW manually checks dissolved oxygen at the gates and co-ordinates with DEC to open the fish gates once dissolved oxygen concentrations at the floodgates decline to very low levels (*i.e.* around 2 mg/L). Water Corporation is also responsible for opening the sandbar on Wonnerup Inlet to allow flushing by sea water and enable fish to escape (refer Section 4.1). Coordination of the various agency activities with respect to the gates and sandbar is achieved through the Vasse Estuary Technical Working Group, formed in 1997 and convened by DEC.

GeoCatch (2000) reported the observation by a number of long-term residents that despite lower rainfall, surface water flows in the Vasse River catchment in particular, are increasing in volume. There is anecdotal evidence that since the 1950s flooding is more frequent and longer in duration, floods move more rapidly down the catchment, soil compaction has reduced infiltration and increased run-off, there are greater volumes of surface water in the lower catchment and estuary, and dry-land salinity is beginning to appear in the mid to lower Vasse River sub-catchment (GeoCatch 2000). Residents believe remnant vegetation has declined in some areas as a result of increasingly prolonged inundation by river floodwaters. All these factors are of potential issue for the hydrology of the Ramsar Site, nutrient loadings and for its native vegetation.

4.4.2 Flow and Water Level Records

Prior to 1992, there are only periodic records for water levels in the Vasse and Wonnerup estuaries. All Vasse Estuary water levels (sourced from Water Corporation) for the period 1927-1991 may be found in Lane *et al.* (1997).

In July 1992, the Water Authority commenced continuous water level recording of the Vasse estuary (near the south shore, midway between the mouths of the Abba and Sabina Rivers) and Wonnerup estuary (in the exit channel) at CALM's request. This monitoring was discontinued in December 1993 (Jim Lane, pers. comm.).

In August 1994, CALM installed two water level recorders on the Vasse estuary, two on the Wonnerup estuary and one on 'Swan Lake'. In March 2001, CALM installed water level recorders immediately upstream of both sets of floodgates. These last two recorders continue to be maintained, whereas the earlier recorders have been removed. CALM (now DEC) recorders have and continue to provide inexpensive (and utilised) 'backup' for the Water & Rivers Commission (2001-2004) and Water Corporation (since 2004) water level recording equipment at the floodgates (Jim Lane, pers. comm.).

The Water & Rivers Commission (now DoW) installed water level (and water temperature, salinity and dissolved oxygen) monitoring equipment at the Vasse Estuary floodgates in 1998 and maintained this equipment until February 2004, when it was removed shortly prior to replacement of the floodgate structure. Since mid 2004, continuous water level recordings have been made at the Vasse and Wonnerup floodgates (upstream and downstream) by the Water Corporation (Table 7).

Table 7. Summary of water level monitoring conducted in the Vasse-Wonnerup Estuary.

Summary of Estuary Water Level Monitoring (m AHD)			
Location	**Date**	**Type**	**Agency**
Vasse and Wonnerup floodgates gauge boards upstream side of the gates	1926 - 1944 1967 - 1982 1980 - 1991	Non-continuous and incomplete winter-spring records. Non-continuous weekly winter-spring records. Incomplete summer-autumn recordings. Many records only taken following unseasonal rains.	Water Corporation; see also Lane *et al*. 1997. Water Corporation; see also Lane *et al.* 1997. Water Corporation; see also Lane *et al.* 1997.
Vasse floodgates upstream station 610019 downstream station 610022	1998 - 2004 2004 - present	Continuous automatic recorder. Continuous automatic recorder.	DoW. Water Corporation and DEC Busselton.
upstream only	2001 - present	Continuous automatic recorder.	DEC Busselton.
Wonnerup floodgates upstream & downstream	2004 - present	Continuous automatic recorder (upstream data of variable quality).	Water Corporation and DEC Busselton.
upstream only	2001 - present	Continuous automatic recorder.	DEC Busselton.
Vasse Estuary south shore between mouth of Sabina and Abba Rivers	1992 - 1993 1994 - 2000	Continuous automatic recorder. Continuous automatic recorder.	DoW DEC Busselton
north shore	1994 – 2000	Continuous automatic recorder.	DEC Busselton
Wonnerup Estuary south end	1994 - 2002	Continuous automatic recorder.	DEC Busselton
north end	1994 - 2000	Continuous automatic recorder.	DEC Busselton

These automatic recorders are maintained by Water Corporation and the data is sent *via* telemetry to both the Water Corporation depot and DEC in Busselton. Currently, river flow in the estuary sub-catchment is only gauged at three sites (Table 8). The custodian for these continuous flow records is DoW. In order to develop their detailed hydraulic model (SQUARE) for the Vasse-Geographe catchment (refer Section 4.3 above), the Aquatic Sciences Branch of DoW have recommended continuous flow data be gauged at an additional three sites (DoW 2006). This hydraulic model is the first phase in developing a predictive model for water quality for the catchment.

Table 8. Summary of surface flow monitoring sites in the Vasse-Wonnerup Estuary catchment.

Summary of Surface Flow Monitoring Sites			
Location	**Date**	**Required for DoW predictive modelling**	**Agency**
Ludlow River – Happy Valley - 610005	1973 - 1999	Yes	DoW
Ludlow River – Claymore - 610007	1972 - 1999	No	DoW
Ludlow River – Ludlow - 610009	1991 - present	No	DoW
Abba River - Wonnerup Siding - 610016	1995 - 2001	Yes	DoW
Sabina Diversion - Wonnerup East Road - 610025	2000 - present	No	DoW
Vasse River - Chapman Hill - 610003	1972 - present	Yes	DoW
Lower Vasse River - immediately below confluence with Diversion Drain (G5)	Required	Yes	DoW

Flow Data

All historic flow data for the Vasse-Wonnerup Site have been collated by the Aquatic Sciences Branch, DoW, Perth. Enquiries should be directed to Decision Support Team, Aquatic Sciences Branch, Department of Water, The Atrium, 168 St Georges Tce, Perth, WA 6000, Australia, (Tel: +61-8-6364-7600; Fax: +61-8-6364-7601).

Current continuous flow records are also available from the DoW HYDSTRA database. Enquiries should be directed to Water Information Officer (Tel +61-8-6364 6505; Fax: +61-8-9426 4821; email waterinfo@water.wa.gov.au or refer to DoW website http://portal.water.wa.gov.au/portal/page/portal/home.

Water Level Data

Most historical and contemporary water level data for the Vasse-Wonnerup Site are maintained and updated by DEC, Busselton. Enquiries should be directed to Department of Environment and Conservation, 14 Queen Street, Busselton WA 6280, Australia, (Tel: +61-8-9752-5555; Fax: +61-8-9752-1432). The Department of Water, Bunbury, holds Vasse Estuary floodgates logger data collected from 1998 - 2004. Water Corporation, Bunbury, maintains and updates water level data from Vasse and Wonnerup estuary floodgates loggers from mid 2004 onwards.

Floodgates on the Vasse Estuary, Jan. 2007 (Andrew Storey)

Floodgates on the Wonnerup Estuary, Jan. 2007 (Andrew Storey)

4.5 Nutrients

The Vasse-Wonnerup Site is highly nutrient-enriched (eutrophic) due to run-off of agricultural fertilisers, stock wastes, drainage and unsewered areas of Busselton township (McAlpine *et al.* 1989, Paice 2001, DoE 2004a). The lower Vasse River and estuary reaches near the floodgates experience frequent phytoplankton, cyanobacterial and macroalgal blooms associated with the high nutrient loads (McAlpine *et al.* 1989, Lane *et al.* 1997, Paice 2001). The relative contributions of the various point (*e.g.* waste discharge from dairies; drains) and diffuse sources (*e.g.* groundwater, overland run-off) is unknown, but accumulation of leached nitrogen and phosphorus in the estuary sediments is believed a major contributor to the eutrophication (McAlpine *et al.* 1989, Innes Zagoui, DoW, pers. comm.).

During the 1980's, estimates of nutrient loads were in the order of 4 - 20 tonnes TP/annum, 29 - 150 tonnes TN/annum to the Vasse Estuary, and 1 - 38 tonnes TP/annum, 33 - 117 tonnes TN/annum to the Wonnerup Estuary (see McAlpine *et al.* 1989). Variation in total annual river discharge during wet and dry years accounted for the wide range in annual loadings. Spatial variation in nutrient concentrations within estuary sediments has not been researched. The bioavailability (whether they have the potential for biological use) of these stores depends on complex interrelationships with the overall water chemistry of the water body. It is likely that adsorption/desorption hotspots exist within the basins. More recent estimates are those modelled by DoE (2004a) for total catchment export to the estuaries of ca. 15 tonnes TP/annum and 209 tonnes TN/annum. To help reduce total nutrient inputs, all of the first winter flush in the Vasse River is currently diverted to the Diversion Drain thereby moderating loads to the lower Vasse River and hence the Vasse Estuary.

Nutrient levels and loads to the estuaries have been monitored only periodically prior to the 1980s, but more frequently since 1996. As discussed in Section 4.3 above, the Aquatic Sciences Branch of DoW is in the process of developing a predictive model (SQUARE) for the Vasse-Geographe catchment based on detailed hydrodynamics and water quality (see DoW 2006, Hall *et al.* 2006). Sites from which nutrient (and other water quality) data will be incorporated into this model are summarised in Table 9 and shown in Appendix A Figures A9-A10. Some of the historic data comes from collaborative nutrient management projects such as the on-going Greener Pastures project with DAF, the Busselton Environmental Improvement Initiative Hotspot Sampling (EII) with Water Corporation, and DoW monitoring of water quality and phytoplankton near the estuary floodgates and lower Vasse River.

Hall *et al.* (2006) extensively analysed the available total nitrogen and total phosphorus data for catchment rivers as part of the first phase of DoW's predictive modelling under the Vasse-Geographe CCI Water Quality Improvement Plan. They used non-parametric tests (Mann-Kendall & Seasonal-Kendall) to search for statistically significant trends in the historic data and to assign current nutrient status using median concentrations measured over a 3 year period (2003 - 2005/06). A minimum 3 year period was used in order to accommodate natural variation. Variations in rainfall and river flows were also taken into account. Only sites for which there were a minimum 20 measurements over at least 3 or more consecutive years were included in trend status analysis. Status analysis and median calculations included only those sites with at least 10 measurements recorded over at least 2 consecutive years. The study found the quality and quantity of much of the historic water quality data to be inadequate, with inconsistencies in both method of collection and sampling periods. For this reason, few statistically significant trends were detected. Results for sites with adequate nutrient data indicated moderate to very high total nitrogen and phosphorus concentrations in the water column in tributary rivers (Table 10).

A trend toward increasing TN concentration was apparent for the Sabina River, while TP and TN appeared to be decreasing for at least some sites in the lower Vasse River. However, the majority of sites showed no decline in nutrient concentration. While reductions in flow associated with climate change would be expected to reduce nutrient loads, concentration effects due to lower water levels can result in increased nutrient concentrations in the water column. The available nutrient concentration and flow data appear to indicate nutrient loads have not declined, suggesting nutrient status will continue to worsen (Hall *et al.* 2006).

Table 9. Existing and proposed water quality sampling for the Vasse-Wonnerup Site tributary sub-catchments.

Project	Dates	Frequency	Location (& number of sites)	Parameters	Agency
DoW river monitoring	1980 - 2004	periodic	Ludlow River (2) Abba River (1) Upper Vasse River (1) Diversion drain (1)	TN, NO_x, NH_3, TP PO_4	DoW
Busselton EII	2000 - 2002	5 occasions per site	Ludlow River (5) Abba River (14) Lower Sabina (4) Upper Sabina River & Vasse River (23)	TN, TKN, NO_x, NH_3, TP, PO_4, TSS	Water Corporation
Vasse-Wonnerup Estuary monitoring	1996 - 2006	fortnightly Aug.-May	Vasse exit channel (3) Wonnerup exit channel (1) The Deadwater (1) Lower Vasse River (2)	TN, TP, DO, colour (Hazen), conductivity, chlorophyll-a,b,c, phaeophytin, phytoplankton	DoW
Vasse-Geographe CCI Water Quality Improvement Plan predictive modelling	Feb. 2006 – Dec. 2006	fortnightly	Ludlow River (2) Lower Abba River (1) Lower Sabina River (1) Lower Vasse River (2)	TN, NO_2, NO_3, NH_3, DON, TP, PO_4, TSS, pH, temp., DO, colour, conductivity	DoW
	proposed	monthly	Vasse estuary (8) Wonnerup estuary (3) The Deadwater (1)	TN, TP, pH, temp., DO, colour, conductivity chl-a,b,c, phaeophytin, phytoplankton	DoW
Greener Pastures	Aug. 2006 - present	fortnightly May-Nov.	Vasse River (20)	TN, NO_x, NH_3, DON, TP, PO_4, TSS	DAF
Macrophyte Survey	Nov. 2006	once	Vasse Estuary (6) Wonnerup estuary (4)	TN, NO_x, NH_3, TP, PO_4, chlorophyll-a, conductivity	Murdoch University

Table 10. Median nutrient concentrations, current nutrient status (2003 - 2006) and trends for tributary rivers of the Vasse-Wonnerup Ramsar Site (from Hall *et al.* 2006).

River (site reference)	TN (mg/L)	Status	Trend	TP (mg/L)	Status	Trend
Ludlow (610009)	1.5	High	Insufficient data	--	Insufficient data	Insufficient data
Abba (610016)	1.04	Moderate	Insufficient data	--	Insufficient data	Insufficient data
Sabina (6101007)	2.79	Very High	Increasing	--	Insufficient data	Insufficient data
Lower Vasse (6101063 & 6101064)	0.19 - 1.6	High	Decreasing at one site; no trend at others	0.15 - 0.35	High - Very High	Decreasing at some sites

DoW monitoring of late spring to autumn nutrient levels has shown high median nutrient concentrations in the lower Vasse River and lower Vasse and Wonnerup estuaries upstream of the floodgates (Table 11). Moderate levels occur in Wonnerup Inlet and The Deadwater (Table 11). In all areas, concentration of particulate phosphorus (bound in plants, animals and sediments) tends to be similar to dissolved inorganic phosphorus (DIP = bioavailable P) except during summer-autumn, when there is increased uptake of DIP by phytoplankton and macrophytes. Most of the total nitrogen tends to be present as dissolved organic nitrogen N likely to be bound in phytoplankton and macroalgae (Paice 2001). Spot measurements by Wilson *et al.* (2007) in November 2006, recorded some very high concentrations of TN and TP in the water column of the Vasse and Wonnerup estuaries. In the Vasse Estuary, levels ranged from 1.6 mg TN/L and 0.19 mg TP/L in the upper reaches of the estuary, to 4.1 mg TN/L and 0.88 mg TP/L near the floodgates. In the Wonnerup Estuary, TN levels ranged from 2.6 to 3.4 mg/L with maximum levels recorded in the upper reaches, while TP ranged from 0.58 to 2.0 mg/L with maximum levels near the floodgates (Wilson *et al.* 2007). It is hoped a better understanding of rainfall-flow-nutrient dynamics and trends in the estuary will be achieved through DoW's predictive modelling.

Table 11. Median late spring-autumn (August 1996 - May 2000) nutrient concentrations and status of the Lower Vasse River, Vasse-Wonnerup Estuary and The Deadwater (from Paice 2001).

	TN (mg/L)	Status	TP (mg/L)	Status
Lower Vasse	1.7	High	0.22	Very High
Vasse Estuary	2.4	High	0.28	Very High
Wonnerup Estuary	1.5	High	0.14	High
Wonnerup Inlet	0.49	Low	0.07	Moderate
The Deadwater	0.99	Moderate	0.06	Moderate

Water Quality Data

All available water quality data for the Vasse-Wonnerup Site (including nutrients, DO, turbidity, TSS, salinity, chlorophyll and phytoplankton cell counts) have been collated by the Aquatic Sciences Branch, DoW, Perth. Enquiries should be directed to Decision Support Team, Aquatic Sciences Branch, Department of Water, The Atrium, 168 St Georges Tce, Perth, WA 6000, Australia, (Tel: +61-8-6364-7600; Fax: +61-8-6364-7601).

Records are also available from the DoW WIN database. Enquiries should be directed to Water Information Officer (Tel +61-8-6364 6505; Fax: +61-8-9426 4821; email waterinfo@water.wa.gov.au) or refer to DoW website http://portal.water.wa.gov.au/portal/page/portal/home.

4.6 Dissolved Oxygen

Dissolved oxygen (DO) in the water will show day-night fluctuations in response to rates of aquatic community respiration and photosynthesis. Hypoxic (low oxygen) or anoxic (zero oxygen) conditions are typically associated with severe algal blooms and/or high rates of microbial activity. Depletion of oxygen occurs as the algae respire at night and is exacerbated by high rates of bacterial respiration during decomposition of the decaying blooms.

There is a paucity of data on spatial and temporal changes in DO within the Vasse-Wonnerup Site and little data on day-night variation. Frequent (monthly or more often), regular monitoring of DO is only undertaken in the Vasse and Wonnerup exit channels, Wonnerup Inlet, The Deadwater and the lower Vasse River (see Table 9). Levels are monitored by DoW as part of management procedures aimed at preventing fish deaths over summer (refer Lane *at al.* 1997, Paice 2001). Temperature, salinity, chlorophyll-a and phytoplankton cell counts are also monitored to enable conditions resulting in fish deaths to be more precisely defined (Jim Lane, DEC, pers. comm.). Automatic monitoring using data loggers with attached DO probes has been trialled but was unsuccessful due to rapid algal growth covering the probes. However, DoW has used automatic data loggers to periodically monitor day-night DO levels at the floodgates (Paice 2001). Monitoring during February-March 1999 indicated exceptionally high day-night ranges, from early morning lows (hypoxia) of less than 1 mg/L to afternoon highs of greater than 10 mg/L. Anoxic and hypoxic levels have been recorded in association with algal blooms. Monitoring indicates, the majority of fish kills that occurred between 1997 and 2000 were associated with algal bloom decay and low DO (Paice 2001) during January-February. Though conditions of anoxia and hypoxia are more likely to occur in summer-autumn, salinity stratification in winter occasionally results in low DO concentrations (< 5 mg/L) in bottom waters near the floodgates (Paice 2001). Predictive water quality models currently being developed by DoW will incorporate DO (see Table 9). Further discussion of the effects of DO on aquatic biota is given in Section 5.4.2.

4.7 Salinity

Frequent (monthly or more often), regular monitoring of salinity is only undertaken in the Vasse and Wonnerup exit channels, The Deadwater and the lower Vasse River. This monitoring is conducted fortnightly by DoW (see Table 9). Salinity regime in the estuaries is largely dependent on inflow from groundwater and tributary rivers in winter-spring and evapo-concentration across the shallow basins in summer-autumn. Seawater inflow is restricted to leakage past the floodgates and to summer/autumn openings of the floodgates (or fish gates) that maintain brackish-saline pools in the exit channels and lower basins. Paice (2001) noted that occasional stratification has occurred in winter immediately upstream of the floodgates, with freshwaters overlying saline tidal water. Water Corporation installed automatic salinity and temperature recorders on the upstream and downstream side of the Vasse Estuary floodgate when the gates were upgraded in 2004. Only spot measurements are recorded and not vertical profiles through the water column. There are no automatic salinity or temperature recorders on the Wonnerup floodgates.

In general, estuary waters are fresh to brackish from June to August (< 5 ppt = 5,000 mg/L TDS), becoming saline (~15 ppt = 15,000 mg/L TDS) in December-January and approaching seawater (35 ppt) by February. In March-April remaining waters in exit channels and lagoons can become hypersaline (> 40 ppt) as the estuaries continue to dry out (Sinclair Knight Merz 2003). Predictive water quality models currently being developed by DoW will incorporate salinity measured as electrical conductivity (refer Table 9). Salinity plays an important role in structuring plant and animal communities within estuaries (see also Section 5.4.3). The large seasonal fluctuations in salinity can create environment conditions particularly harsh to many biota. Yet they also provide a diversity of sub-habitats that allow a wide range of communities (freshwater, estuarine & marine) to co-exist.

4.8 Water Turbidity

There are few historical data on water clarity (or turbidity) and total suspended sediments (TSS) within the Site (see Table 9) and no information on seasonal variability. Turbidity is affected by the amount, size and shape of fine particles that are held in suspension (*e.g.* phytoplankton & total suspended solids, TSS) and by coloured dissolved organic matter (*e.g.* tannins). Measurement of TSS can be used to estimate sediment loads.

Turbidity is an important factor influencing phytoplankton and macrophyte growth as it interferes with light penetration and thus photosynthesis. It is also related to nutrient levels, as organic compounds bound to suspended sediments transport nutrients. Turbidity can determine not only the type of plant growth but also its abundance. Turbidity in turn is related to stream flow, wind and wave action that resuspends sediments in shallow estuaries, and fetch which influences the spatial variability in turbidity (May *et al.* 2003). Wilson *et al.* (2006) have postulated that the more turbid waters of the Wonnerup Estuary may support less biomass of seagrasses than the comparatively lower turbidity waters of the Vasse Estuary. Continuous, artificially high turbidity and TSS also interfere with the feeding efficiency of visual predators such as fish and waterbirds, clog gills of fish and aquatic insect larvae and physically smother plants and animals (Lovett & Price 1999).

TSS is one of the parameters that will be incorporated into DoW predictive models under the Vasse-Geographe CCI Water Quality Improvement Plan (see Table 9). Other TSS data to be incorporated is that collected under the Greener Pastures Project of the Department of Agriculture. Since August 2006, the Greener Pastures Project has conducted seasonal (May - November), fortnightly sampling at 20 sites throughout the Vasse River catchment. As part of the predictive modelling, this will be extended year round. The only pre-2006 TSS data is that collected by Water Corporation between 2000 and 2002 as part of the Busselton Environmental Improvement Initiative Hotspot Sampling (see Table 9). These data will be used to help calibrate the predictive model (DoW 2006). However, TSS sampling will not be conducted within the estuaries.

4.9 Phytoplankton and Aquatic Macrophytes

Despite a history of problem algal blooms and the known importance of aquatic macrophytes as food for many birds and fish, there have been few comprehensive surveys of phytoplankton[6] or macrophytes[7] within the Vasse-Wonnerup Site, and no studies of their seasonal dynamics. Data prior to the Sites's Ramsar listing appear restricted to chlorophyll concentrations from only a few sites and sampling occasions. Walker *et al.* (1987) collected chlorophyll data from two sites on each of the Vasse and Wonnerup estuaries and from one site at the mouth of Wonnerup Inlet in May 1987. They concluded that chlorophyll concentrations within the estuaries were much higher than the Inlet site because of the permanent presence of the floodgates preventing mixing with oceanic water. Davis (1989) also measured chlorophyll in association with midge surveys at four sites in the Vasse Estuary, between September and November 1988. These data were subsequently evaluated by Pearce *et al.* (2000) who found them "to be very high (average 33 μg/L), commensurate with high nutrient loadings indicating that the estuary is nutrient-enriched".

Between August 1996 and December 2006, the Aquatic Sciences Branch of DoW monitored seasonal phytoplankton concentrations at 7 sites in the lower Vasse and Wonnerup estuaries, The Deadwater and the lower Vasse River (Paice 2001, DoW 2006). DoW maintain records of the phytoplankton monitoring expressed as chlorophyll-a concentrations and cell counts (cells/ml) of individual species and/or type of phytoplankton (see Table 9). Monitoring was extended in 2006 with SWCC funding as part of the Vasse-Geographe CCI Water Quality Improvement Plan (refer DoW 2006). Current funding will see the program continue till at least 2008 with monthly monitoring of chlorophyll-a, b, c, phaeophytin and phytoplankton proposed for 11 sites throughout the Vasse-Wonnerup Estuary - 8 sites in the Vasse Estuary and 3 in the Wonnerup (Appendix A Figures A9-A10).

In November 2006, GeoCatch, in partnership with DEC, commissioned the Marine and Freshwater Research Laboratory (MAFRL) of Murdoch University to conduct a snap-shot survey of abundance (biomass g/m^2) and distribution of vascular macrophytes and macroalgae, including filamentous forms of cyanophytes (blue-greens), in the estuaries (refer Wilson *et al.* 2007). Funding for the study was provided through SWCC; with logistical and field technical support provided by DEC. This study, which arose from DEC concern about the possible implications of an apparent increase in macroalgal abundance in recent years, was also aimed at providing baseline data to the Vasse-Geographe CCI Water Quality Improvement Plan (Jim Lane, DEC, pers. comm.). Fifteen sites in the Vasse Estuary and 13 in the Wonnerup were sampled (see Appendix A Figure A11 for their locations). The work was subsequent to anecdotal reports of increasing macroalgal blooms in both estuaries, and of blue-green blooms in the Wonnerup Estuary. Blooms of blue-green *Nodularia* were first reported in the mid and upper reaches of Wonnerup Estuary in January 2000 (Paice 2001). Large amounts of filamentous green algae (possibly *Ulva*, *Cladophora* & *Rhizoclonium*) are also often observed in upper reaches of the Wonnerup Estuary (Paice 2001). Local residents reported increased blooms of sea lettuce (*Ulva lactuca*) and filamentous *Ulva clathrata* and *Cladophora* in the lower Vasse Estuary over summer 2003/04 (Geographe Network News Issue 9 November 2004). If blooms are indeed increasing in frequency and occurrence it may indicate a shift in ecosystem stable state is underway (refer Section 5.4.1).

Geocatch, DoE and MAFRL have also been trialling three species of macrophyte for re-establishment in the lower Vasse River as part of the Vasse River Cleanup Program. Ribbonweed (*Vallisineria americana*), pondweed (*Potamogeton crispus*) and water milfoil (*Myriophyllum papillosum*) were trialled in spring 2003 and summer 2004, but only ribbonweed successfully re-established (Novak 2004). Failure of water milfoil was primarily due to an excessive epiphyte load, and death of the pondweed was due to phytoplankton blooms (Novak 2004).

A summary of the types and general distribution of phytoplankton and macrophyte collected from the above studies is listed in Table 12. At least ten of the taxa listed are known to form problematic blooms in the Vasse-Wonnerup estuary and/or the lower Vasse River - cyanobacteria (*Nodularia*, *Anabaena*, *Lyngbya*, *Microcystis, Oscillatoria*), green micro-algae (chlorophyte species), diatoms and macroalgae (*Ulva*, *Cladophora*, *Rhizoclonium*).

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[6] Phytoplankton = all microscopic plants, usually dominated by microalgae and including chlorophytes (green alage), diatoms (*e.g.* bacillariophytes), dinoflagellates (*e.g.* dinophytes) and cyanophytes (*i.e.* blue-greens = cyanobacteria).
[7] Macrophytes = 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).

The cyanobacteria (or blue-greens) are of particular cause for concern as many species of many genera are potentially toxic, *e.g. Anabaena, Lyngbya* and *Microcystis* (Lane *et al.* 1997, Wilson *et al.* 2007). A bloom (120,000 cells/ml) of the toxic haptophyte phytoplankton, *Prymnesiun* cf. *parvum*, was linked to the death of 232 fish in the Vasse Estuary exit channel in January 1998 (Paice 2001).

Algal blooms at the Vasse Estuary floodgates, Jan. 2007 (Andrew Storey)

4.9.1 Variation in Phytoplankton and Aquatic Macrophytes

The distribution, abundance and composition of phytoplankton and macrophyte communities changes annually, seasonally and with location within the Vasse-Wonnerup Site. Baseline data gathered by DoW and Murdoch University (outlined above) provide valuable insight, but as noted by Wilson *et al.* (2006), further detailed seasonal surveys and time series analyses are needed to determine the complex factors that influence succession and biomass of aquatic plant communities.

Algal blooms typically occur when densities of medium to large-celled microalgae (*i.e.* >15 micron) reach 20,000 cells/ml. For small-celled micro-algae, densities usually need to reach 100,000 cell/ml before discolouration of the water body is apparent (Paice 2001). The lower Vasse Estuary and lower Vasse River are particularly prone to severe algal blooms (>100,000 cells/ml) from late spring to autumn (Paice 2001). Since the 1970s, there have been persistent blooms of both green algae (chlorophytes) and blue-greens (cyanobacterial) in the Vasse River. In contrast, blooms in the lower Vasse Estuary tend to be dominated by blue-greens, even though diversity of microalgal species is higher in the estuary than in the lower Vasse River (Paice 2001). Blooms in the estuary typically occur in the exit channel immediately upstream of the floodgates and in the mid reaches where water persists over summer

Wilson *et al.* (2007) noted in November 2006, that abundance of the potentially toxic blue-green *Lyngbya* was highest in the vicinity of the Port Geographe canal development (see also Section 10.2.1). Microalgal abundance tends to be lower in Wonnerup Estuary and Inlet, though some diatom blooms do occur in the Wonnerup Estuary (Paice 2001). These have typically been considered to be within the natural variation of the system and not viewed as problematic (Paice 2001).

The snap-shot survey conducted by Wilson *et al.* (2007) in November 2006 found both estuaries to be dominated by macroalgae in terms of biomass; in particular *Ulva clathrata* (Figure 7). Distribution of seagrass communities (mainly *Ruppia megacarpa* & *Lepilaena cylindrcarpa*) was fairly uniform across the Vasse Estuary, but diminished in the lower reaches. Densities tended to be greatest in the mid to upper reaches. In the Wonnerup Estuary, the distribution of seagrasses was restricted to the lower and upper reaches with density greatest in the upper reaches. Of interest was the relatively greater abundance of stonewort (*Chara* sp.) in the Wonnerup Estuary. Wilson *et al.* (2007) reported total macrophyte biomass in the Vasse Estuary (96 tonnes/km^2) to be similar to that recorded for Peel Inlet (116.5 tonnes/km^2), while biomass in the Wonnerup Estuary was much lower (54 tonnes/km^2).

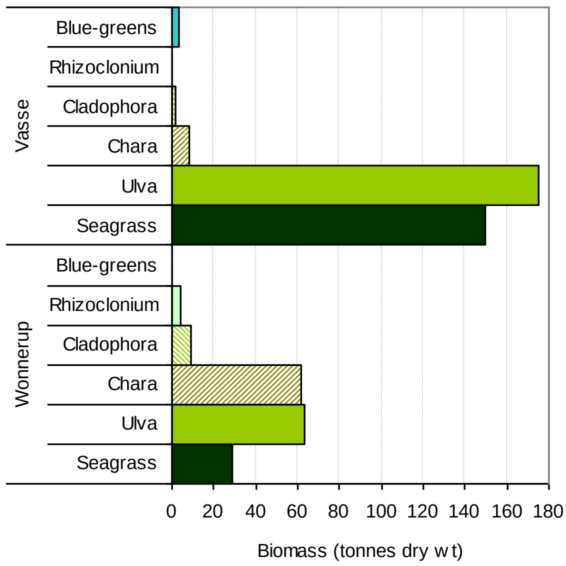


Figure 7. Total macrophyte biomass in the Vasse and Wonnerup estuaries in November 2006 (source Wilson *et al.* 2007).

<u>Macrophyte Data</u>

Macrophyte data for the Vasse-Wonnerup Site is held by both GeoCatch and DEC, Busselton. Enquiries should be directed to either the Department of Environment and Conservation, 14 Queen Street, Busselton WA 6280, Australia (Tel: +61-8-9752-5555; Fax: +61-8-9752-1432), or Geographe Catchment Council, Unit 1A, 72 Duchess Street, Busselton, WA 6280, Australia (Tel: +61-8-9781-0111; Fax: +61-8-9754 4335).

Table 12. Phytoplankton and aquatic macrophytes recorded from the Vasse-Wonnerup catchment (sources: Lane *et al.* 1997, Paice 2001, Wilson *et al.* 2007).

Typically present	Lower Vasse River	Vasse Estuary	Lower Vasse Estuary	Wonnerup Estuary	Lower Wonnerup Estuary	Wonnerup Inlet	The Deadwater
Common phytoplankton (Microalgae)							
Chlorophytes (green algae) Diatoms *Rhizolenia* *Cerataulina* *Chaetoceros* *Cyclotella* Dinoflagellates *Katodinium* Cyanobacteria (blue-greens) *Oscillatoria* *Anabaenopsis* *Anabaena* *Lyngbya ?majuscula* *Microcystis* *Merismopedia* *Nodularia*	Dominated by blue-greens (*Anabaena* & *Microcystis* spp.) and green algae. **Persistent blooms of potentially toxic blue-greens.** Blue-greens frequently >100,000 cells/ml, with max. densities >500,000 cells/ml. Only low densities of diatoms and few dinoflagellates.	Dominated by blue-greens (*Anabaena, Lyngbya* & *Oscillatoria* spp.) and diatoms. **Persistent blooms of diatoms & potentially toxic blue-greens,** with relatively high densities in vicinity of Port Geographe development. Greens and dino-flagellates present at lower densities.	Blue-greens dominate. (*Anabaena, Lyngbya* & *Oscillatoria* spp.) **Severe toxic blue-green blooms often occur in summer** (>100,000 cells/ml). Low levels of greens, diatoms and dinoflagellates.	Blue-greens dominant. Levels typically lower than in Vasse Estuary. First report of ***Nodularia* bloom in Jan 2000** (99,000 cells/ml). Lower levels of greens and diatoms. Few dino-flagellates.	Blue-greens and diatoms dominant. Levels typically much lower than main Wonnerup lagoon. Several small diatom blooms. Low densities of green algae. Few dino-flagellates.	Algal growth relatively low, mainly blue-greens and diatoms. **One small diatom bloom in August 1999** (marine *Cyclotella* 25,810 cells/ml). Blue-greens usually <8,000 cells/ml Few greens or dinoflagellates.	Algal growth relatively low, mainly blue-greens and diatoms. **Diatom / green bloom in Aug 1999** associated with bloom in Wonnerup Inlet - 54,834 diatom cells/ml and 49,706 green cells/ml. Few dinoflagellates.
Macroalgae							
Stoneworts *Chara* spp. Filamentous green algae *Chaetomorpha* *Cladophora* *Rhizoclonium tortuosum* *Ulva clathrata* *Ulva* spp. Sea Lettuce *Ulva lactuca*	unknown	**Dominated by *Ulva***, (mainly *U. clathrata*) and particularly in mid reaches. Smaller amounts of *Rhizoclonium* in mid reaches. Little *Chara*, *Cladophora* or *Chaetomorpha*.	**Dominated by *Ulva***, (mainly *U. clathrata*). Macroalgal biomass higher than in main Vasse lagoon. **Blooms of sea lettuce and filamentous greens since 2000.** Little *Rhizoclonium*, *Chara*, *Cladophora* or *Chaetomorpha*.	***Chara* and *Ulva* co-dominant.** Macroalgal biomass lower than in Vasse Estuary. **Blooms of filamentous greens since 2000.** Smaller amounts of *Rhizoclonium* *Cladophora* in mid reaches. Little or *Chaetomorpha*.	***Chara* and *Ulva* co-dominant.** Macroalgal biomass lower than in main Wonnerup lagoon. Little *Rhizoclonium*, *Cladophora* or *Chaetomorpha*.	Few macrophytes. Large amounts of seaweed and seagrasses from Geographe Bay often swept in by winter storms.	unknown
Vascular Macrophytes							
Seagrasses *Lepilaena cylindrocarpa* *Ruppia megacarpa* *Ruppia ?polycarpa* Ribbonweed *Vallisneria americana*	**Ribbonweed** re-established in 2003/04	***Ruppia megacarpa* sub-dominant to macroalgae** (*Ulva*). Smaller amount of *Lepilaena*. Seagrass biomass greatest in mid reaches.	***Ruppia megacarpa* sub-dominant to macroalgae** (*Ulva*). Smaller amount of *Lepilaena*. Seagrass biomass much lower than in main lagoon.	***Ruppia megacarpa* sub-dominant to macroalgae** (*Ulva* and *Chara*). Smaller amount of *Lepilaena*. Seagrass biomass greatest in upper reaches.	***Ruppia megacarpa* co-dominant with macroalgae** (*Ulva* and *Chara*). Smaller amount of *Lepilaena*. Seagrass biomass much lower than in Wonnerup lagoon.	***Ruppia megacarpa dominant***. Smaller amount of *Lepilaena*. Seagrass biomass much lower than in estuary.	unknown

4.10 Fringing Vegetation

4.10.1 Fringing Wetland Vegetation

Most of the Vasse-Wonnerup Ramsar Site consists of broad expanses of open seasonal waters with large areas of low samphire (*Sarcocornia blackiana*, *Halosarcia pergranulata*) in the more shallow sections and fringed by taller mixed samphire, sea rush (*Juncus kraussii*) and sedges (*Lepidosperma* cf. *leptostachyum*, *Carex divisa*). In some areas, remnant paperbark (*Melaleuca rhaphiophylla*, *M. hamulos*, *M. cuticularis*) woodlands occur upslope from the samphire. These often have an understorey of Coast Saw Sedge (*Gahnia trifida*) and Pale Rush (*Juncus pallidus*) and grade into eucalypt (*Eucalyptus rudis*), peppermints (*Agonis flexuosa*) and casuarina woodlands at higher elevation and along tributary rivers. Vegetation of the dunes that lie between the Vasse-Wonnerup estuary and Geographe Bay is dominated by peppermints with an understorey of mainly pasture grasses and weeds with some remnant shrubs (*e.g. Acacia cyclopis*, *A. littoralis*, *Hibbertia cuneiformis*, *Eremophila glabra*, *Diplolaena dampieri*) and coast sword sedge (*Lepidosperma gladiatum*).

The natural vegetation of the system is fairly uniform, as other than samphire, most of the native understorey vegetation has been cleared for agriculture and urban development. Dense pasture grasses (*Paspalum* spp.) now dominate the understorey and have encroached on the margins of the estuaries. The floodgates have allowed much land to be reclaimed for pasture that would once have been inundated by seawater. Introduced Typha (*Typha orientalis*) and Arum Lily (*Zantedeschia aethiopica*) have become established along the Sabina, Abba and Vasse rivers. Table 13 provides estimates of percentage land clearing within the estuary catchment. Data are estimates for river sub-catchments taken from McAlpine *et al.* (1989) and GeoCatch (2000).

Table 13. Land clearing within the sub-catchments of the Vasse-Wonnerup Site. Unless otherwise indicated, data were sourced from McAlpine *et al.* (1989). 'Pre-European' and 'current' refers to the fact that inflow from these sub-catchments to the Vasse-Wonnerup wetlands has been partially or completely diverted by drain construction for agriculture.

River	Total catchment area (km^2)		Coastal Plain	
	pre-European	current	area (km^2)	% cleared
Vasse	213	19.5*	19.5*	91
Sabina	130	45	45	90
Abba	129	129	82	87
Ludlow	210	210	95	75
Capel	654	0	--	--
The Broadwater	29	0	--	--
Buayanyup & others	202	0	--	--
Total	**1567**	**403**	**241**	**86**

*from GeoCatch (2000).

To date, the most detailed surveys of the vegetation and flora of the area are those of Tingay and Tingay (1980) conducted for the (then) Department of Fisheries and Wildlife and by Froend *et al.* (2000) for DEC. The catchment was also included in the national Agricultural Land Cover Change Project which used satellite thermal imagery to estimate rates of vegetation clearing between 1990 and 2000 (Barson *et al.* 2000, Hamblin 2001). Other surveys of the area have comprised only the broader-scale mapping (1: 25 000); *i.e.* Smith (1973), Beard (1980) and Hill *et al.* (1996). Tingay and Tingay (1980) prepared vegetation maps at the 1:2 000, 1:5 000 and 1:10 000 scales covering the major (and associated) wetlands of Taylors Swamp, the Broadwater (river & lake), Long Swamp, New River, lower Vasse River (Old Butter Factory swamp), Vasse Estuary, The Deadwater and Wonnerup Estuary and Inlet. The surveys were conducted during March-April 1980 and consisted of 13 transects plus ground-truthing for interpretation of colour aerial photographs covering the entire study area. Resultant vegetation maps were lodged with DEC. In 2000, Froend *et al.* (2000) conducted transect surveys at ten shoreline sites in the northern half of Vasse Estuary upstream of the exit channel. These surveys were to establish a monitoring program for riparian vegetation affected by saltwater flooding and vegetation descriptions were based on those of Tingay and Tingay (1980). The final report included detailed transect profiles for each site together with vegetation maps at the 1:25 000 scale (lodged with DEC).

Some 106 species were identified by Tingay and Tingay (1980) and Froend *et al.* (2000). Flora was considered typical of the Drummond sub-district of the Darling Botanical District as described by Beard (1980). Table 14 provides an overview of the major vegetation associations described.

Table 14. Summary of remnant vegetation associations of the Vasse-Wonnerup Site and The Deadwater as identified by Tingay and Tingay (1980).

Region	Elevation	Vegetation Associations
Vasse Estuary	0 - 0.5m	Open heath of *Sarcocornia blackiana* grading into *Halosarcia pergranulata* at slightly higher elevation; backed by *Carex divisa* sedgelands.
	0.5 -1m	*Halosarcia pergranulata* open heath backed by low open forest of *Melaleuca rhaphiophylla* or low mixed forest of *M. hamulosa* and *M. cuticularis.*
	1 - 1.5m	*Juncus kraussii* open sedgeland.
	> 1.5m	*Eucalyptus rudis* woodland.
Sabina River Delta	0 - 0.5m	Open heath of *Sarcocornia blackiana* grading into *Halosarcia pergranulata* at slightly higher elevation.
	0.5 - 1.5m	*Halosarcia pergranulata* open heath and *Melaleuca cuticularis* low open woodlands mixed with *Juncus kraussii* sedgelands,
	> 1m	*Eucalyptus rudis* open forest with *Melaleuca rhaphiophylla* understorey.
Lower Sabina River	~ 1 - 2.5	*Eucalyptus rudis* open forest with *Melaleuca rhaphiophylla* understorey and introduced *Typha orientalis* and *Zantedeschia aethiopica.*
	> 2.5m	Tuart *Eucalyptus gomphocephala* high open woodland.
Abba River Delta	0 - 1m	Extensive open heath of *Sarcocornia blackiana* and *Halosarcia pergranulata* west of Malbup Creek, but otherwise uncommon.
	~1 - 2.5m	*Juncus kraussii* open sedgeland backed by *Melaleuca rhaphiophylla* low open forest or *Eucalyptus rudis* open forest with understorey of *M. rhaphiophylla*, *Agonis flexuosa* and pasture grasses.
Lower Abba River	<1m	Areas of *Typha orientalis* sedgeland and clumps of *Arum zealandicus* upstream from river mouth.
	~1 - 2.5m	*Juncus kraussii* open sedgeland backed by *Melaleuca rhaphiophylla* low open forest or *Eucalyptus rudis* open forest with understorey of *M. rhaphiophylla*, *Agonis flexuosa* and pasture grasses.
	> 2.5m	Tuart *Eucalyptus gomphocephala* high woodland.
Wonnerup estuary	0 - 1m	*Sarcocornia blackiana* and *Halosarcia pergranulata* open heath
	~1 - 1.5m	*Juncus kraussii* sedgelands or low shrublands of *Acacia cyclopis*, *Diplolaena dampieri*, *Hibbertia cuneiformis* and *Lepidosperma gladiatum*, backed by *Melaleuca rhaphiophylla* and *M. hamulosa* low open forest and *Juncus kraussii* sedgelands.
	1.5 - 2.5m	*Eucalyptus rudis* open woodland or mixed open forest of *E.rudis* and *Melaleuca rhaphiophylla*.
	> 2.5m	*Eucalyptus gomphocephala* high open woodland with understorey of pasture and scattered clumps of *Agonis flexuosa* and *Juncus kraussii.* This grades into Tuart high forest and pine plantations of the Ludlow State Forest.
Wonnerup Inlet	0 - 0.5m	*Sarcocornia blackiana* closed heath
	~ 0.5 - 1m	*Gahnia trifida* – *Juncus kraussii* sedgeland
	~ 1 - 2.5m	*Agonis flexuosa* low closed forest or open woodland and *Melaleuca hamulosa* low closed forest
	> 2.5m	Mixed closed heath of *Agonis flexuosa*, *Acacia cyclopis*, *Diplolaena dampieri*, *Hibbertia cuneiformis* and *Lepidosperma gladiatum* on dunes to the coast
The Deadwater	---	*Sarcocornia blackiana* closed heath, backed by *Juncus kraussii* closed sedgeland. At higher elevation are *Agonis flexuosa* low open forest with an understorey of *Lepidosperma gladiatum*, *Hibbertia cuneiformis*, *Diplolaena dampieri* and *Acacia cyclopis*.

The samphire heaths at the northern end of the Vasse Estuary and north and north-west sections of the Wonnerup Estuary have historically provided important annual nesting areas for Black Swans (Tingay & Tingay 1980). However, nesting by this species is now largely confined to the heaths of 'Swan Lake' (a cut off section of the Wonnerup Estuary) at the northern end of the Ramsar Site (Lane *et al.* 1997). Black-winged Stilts and White-fronted Chats are also known to nest among these heaths; the Chats preferring the taller *Halosarcia pergranulata* samphire (Tingay & Tingay 1980). Sacred Kingfishers have been observed nesting in casuarina groves along the Vasse Estuary. Research in other parts of the world suggests that tidal inundation of samphire creates a wide range of habitats that support diverse and abundant benthic invertebrate communities and provides habitat for juvenile fish (see Fortes 1994). Samphire flats may form a link between terrestrial communities and seagrass-macroalgal communities, with shared invertebrate communities facilitating exchange of nutrients and carbon (Levin *et al.* 2001).

Vegetation Maps

Vegetation data and vegetation maps for the Vasse-Wonnerup Site are held by DEC, Bunbury. Enquiries should be directed to Department of Environment and Conservation, South West Highway, Bunbury, WA 6230, Australia (Tel: +61-8-9725-4300; Fax: +61-8- 9725-4351).

Samphire flats at Wonnerup Inlet (courtesy Martin Pritchard, GeoCatch)

4.10.2 River Action Plans

GeoCatch and the Vasse-Wonnerup LCDCs have prepared river action plans for the Vasse, Sabina, Abba and Ludlow rivers, including those sections contained within the Ramsar Site boundaries (see GeoCatch 2000, 2002). The plans are part of integrated catchment management strategies aimed at improving water quality and river health. The plans are developed in consultation with local communities and detail techniques for rehabilitation of the river foreshores and help target priority areas for management action. Foreshore condition along the length of each river has been assessed following the method of Pen and Scott (1995). This rapid assessment technique categorises the rivers according to the health of the fringing native vegetation, degree of clearing and weed invasion, stock access, diversity of in-stream habitat and propensity for bank and bed erosion. Much of the surveying was conducted by local landholders during late autumn to late winter, at a time when problems of erosion and weed infestation could be most easily identified. Results are summarised in Tables 15 and 16.

The sections of the lower Sabina, Abba and Ludlow rivers contained within the Ramsar Site (between Tuart Drive and the estuary) were assessed as degraded, weedy and erosion prone (condition rating B-C). The understorey is predominantly pasture grasses (Cooch, Kikuyu, Buffalo Grass) and weeds with many declared plants such as Arum Lily, Apple of Sodom, and pest species such as Paddymelon and Bracken (GeoCatch 2002). There is extensive bank slumping and aggradation of channel pools in many sections. The entire section of the Sabina River downstream of Tuart Drive is contained within Reserve 3118, vested with DEC, and fencing and revegetation with native species has already begun (GeoCatch 2002). The lower Vasse River too is the subject of a major restoration and revegetation program, the Vasse River Cleanup Program (refer Paice 2005). The lower Abba River and delta lie within Reserve 40250 which forms part of the Tuart National Park. Revegetation and restoration of the lower Abba River and delta is planned under the Tuart National Park Management Plan (DEC 2006a).

Table 15. Summary of foreshore condition assessments of the Vasse, Sabina, Abba and Ludlow rivers (not including State forest in Whicher Range) (reproduced from GeoCatch 2000 and 2002).

Condition rating	Vasse River		Sabina River & Woddidup Creek		Abba River		Ludlow River & Tiger Gully	
	Total length (km)	Total %	Total length (km)	Total %	Total length (km)	Total %	Total length (km)	Total %
A (pristine)	4.3	15	4.7	12	2.2	6	1.7	5
B (weedy)	11	37	4.3	11	18.1	51	15.8	45
C (erosion prone)	11.5	39	9.2	24	7.7	22	12	33
D (ditch)	2.8	10	20.3	53	7.5	21	6	17

Table 16. Length of fenced areas along the Vasse, Sabina, Abba and Ludlow rivers (reproduced from GeoCatch 2000 and 2002).

	Vasse River		Sabina River & Woddidup Creek		Abba River		Ludlow River & Tiger Gully	
	Length (km)	% of length	Length (km)	% of length	Length (km)	% of length	Length (km)	% of length
West & south bank	20.5	69	3.8	9.9	2.6	6	4.9	13.8
East & north bank	18.1	61	2.9	7.6	1.8	4.1	1.4	3.9
Both sides			3.6	9.4	5.9	13.6	4.8	13.6
Total fenced			10.3	26.9	10.3	23.7	11.1	31.3

4.10.3 Tuart Forest National Park

Reserve 40250 of the Tuart Forest National Park was added to the Ramsar Site in 2001. The vegetation of Tuart Forest National Park is dominated by open high forest of mature Tuart *Eucalyptus gomphocephala* with an understorey of Peppermint *Agonis flexuosa*. The Tuart Forest National Park and Nature Reserves that were added to the Site in 2001 have contributed substantially to the conservation values of the Site by providing protected buffer zones for the Site's wetlands and some seasonal feeding habitat for waterbirds. Tree hollows in these areas provide important breeding sites for Australian Wood Duck, Australian Shelduck and possibly other duck species. Adult ducks have been observed moving their young from the forest to the wetlands.

4.11 Habitat Connectivity

While the Ramsar site plays an obvious role in maintaining habitat connectivity for international and national migratory bird species, there is little other information on the relative importance of the Site in maintaining habitat connectivity with the tuart forest ecosystem or with the marine ecosystem of Geographe Bay. Estuaries in general are considered important as transitional zones that connect terrestrial and freshwater habitats with the sea (Levin *et al.* 2001). River flood flows transport sediment, organic matter and nutrients from freshwater and estuarine ecosystems to nearshore marine habitats, enhancing biological productivity in coastal marine ecosystems (NRW 2006). Tides may transport sediments and nutrients into lower reaches of tributary rivers. Tides are believed to play a key role in many systems in transporting planktonic stages of marine and estuarine species inshore and upriver (NRW 2006).

In the Vasse-Wonnerup, at least seven species of marine fish are known to use the Site as nursery habitat. Of these, two at least (marine sea mullet, whitebait) may be dependent on the estuary. There is anecdotal evidence that fish stocks in the estuary are on the decline, but no data on how this has affected recruitment into marine populations. Reductions in recruitment and migration cues for fish would be expected to occur due to reduced freshwater inflows (NRW 2006). The consequences of reduced flood plumes, altered tidal regime and hence reduced sediment, nutrient and carbon exchange with Geographe Bay is not known. While overall fish abundances appear to have remained high, changes in abundance of individual species and in species diversity have not been studied. Nor is the relative importance of tidal saltmarshes as nursery areas for marine fishes and as foraging areas for terrestrial insects and fauna (other than birds) understood.

Wonnerup Inlet, Jan. 2007 (Andrew Storey)

4.12 Aquatic Invertebrates

Generally, both zooplankton and larger aquatic invertebrates (macroinvertebrates) play a pivotal role in freshwater and estuarine food-webs. They are an important food source for many waterbirds, fish and freshwater crayfish, as well as contributing to nutrient and carbon re-cycling. Macroinvertebrates play a critical role in the bioturbation[8] of estuarine sediments. In many Australian estuaries, high biodiversity and abundance of benthic (bottom-dwelling) invertebrates provides a rich food source which supports large resident and migratory waterbird populations, and productive commercial and recreational fisheries (NCTWR 2005).

To date, there have been no comprehensive surveys of the freshwater or estuarine invertebrate communities of the Ramsar Site. Davis (1989) conducted one-off surveys of midges (Chironomidae) at four sites in the Vasse Estuary as part of an environmental review for the Port Geographe marina and residential canal development. The survey found high larval midge populations, reflecting the very high nutrient status of the wetland system (Davis 1989). At least three of the midge species recorded are known pest species in the Perth region: *Chironomus australis*, *Polypedilum nubifer* and *Tanytarsus fuscithorax*. Of these, the most problematic is typically *P. nubifer*. In the Vasse Estuary, larvae of this species were recorded in densities well above those considered to result in nuisance swarms of adult midges, *i.e.* ≥ 2000 larvae/m² (Davis 1989).

There has been infrequent opportunistic collecting for marine and estuarine molluscs in Wonnerup Inlet by staff from the Western Australian Museum, though this has been insufficient to provide an adequate inventory of mollusc communities. While some of the species collected are likely to be of interest to science, their taxonomy requires further investigation (Shirley Slack-Smith, WAM, pers. com.).

There are also seven AusRivAS reference sites within the Vasse-Wonnerup catchment. All are located on tributary rivers (Vasse, Abba, Sabina and Ludlow rivers) outside the boundary of the Ramsar Site and include:

AusRivAS No.	River	River Name	SITE NAME
BUS12	Sabina	Sabina River	Sabina
BUS13	Ludlow	Ludlow River	Headwater
BUS14	Ludlow	Ludlow River	Reserve 18047-113
BUS15	Ludlow	Ludlow River	Colyoolup
BUS23	Abba	Abba River	Princefield Road.
BUS24	Capel	Layman Gully	Stirling Street
BUS25	Capel	Capel River	Capel Townsite

Site information and macroinvertebrate taxa lists are available from the Department of Environment and Conservation.

Results of more recent aquatic macroinvertebrate surveys in the Vasse and Ludlow rivers are also presented here as an indication of the type of macroinvertebrate communities to be expected in the Ramsar Site (Table 17). GeoCatch in association with the Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University, sampled macroinvertebrates at four sites in the lower Vasse River during spring 2001. This sampling formed part of monitoring for the Vasse Cleanup Program. Total numbers of species at each site ranged from 14 to 33 (Paice 2005) and community composition was generally dominated by species known to be tolerant of degraded conditions, *e.g.* amphipods (*Austrochiltonia subtenius*), water boatmen (*Micronecta* spp. & *Agraptocorixa* sp.), non-biting midge larvae (*Chironumus aff. alternans*), introduced aquatic snails (*Physa acuta*) and the caddis-fly larvae *Triplectides australicus* (Paice 2005). Relatively high numbers of water scavenger beetles (Family Hydrophillidae) were also present at the site with the least disturbed habitat conditions.

[8] Bioturbation = stirring or mixing of sediments by resident biota, particularly burrowing or boring animals. Bioturbation can play a major role in nutrient and carbon re-cycling through resuspension of sediments. It also enhances organic decomposition and redistribution of organic material, and enables deeper penetration of oxygenated waters into soil interstices (spaces between soil particles).

WRM (2006) conducted one-off surveys of eight sites in the mid and upper Ludlow River during spring 2005 as part of baseline surveys for the mineral sands mining company Iluka Resources Limited. 110 taxa were recorded and community composition found to be similar to other disturbed seasonal watercourses on the coastal plain. Numbers of species at each site varied from 25 to 69. In contrast to the Vasse River fauna, very few amphipods were recorded. Overall, the fauna was dominated by insects (~80%) with Chironomidae (non-biting midges) constituting ~20% of all insect taxa. Taxa normally associated with less disturbed ecosystems were rare or absent (*e.g.* Ephemeroptera, Odonata and many of the Trichoptera).

Most taxa were considered common, *i.e.* abundant and widespread throughout the State and occurring in other states/territories. Twenty-one taxa (19%) were south-west endemics. All insects recorded, were considered to be 'temporary' residents with highly mobile adult phases that would allow them to avoid adverse environmental conditions and reinvade from nearby permanent waterbodies, once conditions improved. A summary of species and relative abundances reported by WRM (2006) is provided in Appendix D Table D1.

Table 17. Dominant macroinvertebrate taxa recorded from tributary rivers of the Vasse-Wonnerup Estuary

River	Dominant Macroinvertebrates	
	Common name	Species name
Lower Vasse River	Amphipods Water boatmen Non-biting midge larvae Introduced freshwater snail Caddis-fly larvae Water scavenger beetles	*Austrochiltonia subtenius* *Micronecta* spp., *Agraptocorixa* sp. *Chironomus aff. alternans* *Physa acuta* *Triplectides australicus* Hydrophillidae *spp.*
Mid-upper Ludlow River	Aquatic worms Freshwater snail Freshwater limpet Seed shrimps & copepods Non-biting midge larvae Water boatmen (juveniles) Water beetles Water scavenger beetles	Oligochaete spp. *Glyptophysa* (*Glyptophysa*) sp. *Ferrisia petterdi* Ostracods, cyclopoid Copepoda *Chironomus aff. alternans*, *Tanytarsus* spp., *Paramerina levidensis*, *Thienemanniella* *Micronecta* spp., *Agraptocorixa* sp., *Sigara* sp. *Platynectes* spp. *Limnoxenus zealandicus* (Hydrophillidae)

The only other published information concerning invertebrates at the Ramsar Site, is that of Bunbury and Morrell (1930, cited in Lane *et al.* 1997) who reference Lieutenant H.W. Bunbury's comment during the late 1830s, that freshwater mussels ("Unios") were plentiful in permanent pools in the lower freshwater reaches of the seasonal Abba River. This mussel (*Westralunio carteri*) still occurs in the Vasse River and Diversion Drain (Gilbert Stokman, Dept. of Fisheries, pers. comm.) and in the Capel River to the north of the Ramsar Site (WRM 2006). It is considered to have an increasingly restricted distribution within the south-west and is listed as 'vulnerable' under the international IUCN Red List of Threatened Species (IUCN 2006). This listing indicates that whilst not currently threatened, mussel populations are fragmented and in need of monitoring. Population decline has been reported in many areas throughout the south-west and is likely related to secondary salinisation and heavy sedimentation/siltation of river beds and pools. Species such as freshwater mussels and freshwater crayfish are more at risk from environmental degradation as they are permanent residents with less capacity to escape adverse conditions.

4.12.1 Variation in Aquatic Invertebrate Communities

There have been no studies of spatial or temporal variation in aquatic invertebrate species richness or abundance at the Site. Like fish, invertebrate communities are known to exhibit large variation in response to seasonal changes in habitat and food availability, water quality (salinity, temperature, nutrients), predation pressures and annual recruitment success. Prior analyses of south-west riverine fauna have revealed a distinct seasonality in the invertebrate community structure, whereby summer/autumn fauna is typically distinct from winter/spring fauna (refer Bunn 1986, Bunn *et al.* 1986, 1988, Storey *et al.* 1990). This partly reflects emergence of species into terrestrial adult stages in summer/autumn as a mechanism to avoid desiccation when streams dry in summer, and the presence of fauna with drought-resistant stages in seasonal streams, resulting in inherent differences in the fauna of seasonal and perennial streams. Such seasonality is likely present in estuarine invertebrate communities but there is little documented information.

4.12.2 Functional Feeding Groups

The functional complexity and 'health' of a riverine or estuarine system is influenced by the diversity of aquatic invertebrate functional feeding groups, *i.e.* the obligate feeding mode of each species (Cummins 1974, Cummins & Klugg 1979) (Table 18). Current theories of functional organization of streams in the south-west (see Bunn 1985, 1986, 1988) predict relatively undisturbed, forested upland streams to be similarly dominated by collectors and predators, but with a high proportion of shredders. Proportions of each group are also expected to change seasonally and longitudinally within the catchment. Shredders would be expected to decrease downstream (*e.g.* coastal plain reaches and deltas) as the input of coarse particulate material decreases, while collectors and grazers would increase. Collectors are also likely to dominate lower reaches and in particular disturbed reaches where the input of fine particulate material is high.

Table 18. General examples for macroinvertebrate functional feeding groups.

Functional feeding Group	Diet	Example
Shredder	Coarse particulate matter (CPOM >1mm)	Some amphipods (*Austrochiltonia*), some leptocerid caddis flies (*Triplectides*)
Collector	Fine particulate matter (FPOM < 1mm)	Freshwater crayfish (decapods), aquatic worms (oligochaetes), some amphipods (*Perthia*), mosquito larvae (culicids), some non-biting midge larvae (*Chironomous* spp., *Polypedilum* spp.), some water boatmen (*Sigara*)
Filterers	Suspended particles from the water column and are often viewed as a subset of collectors	Water fleas (Cladocera), seed shrimps (Ostracods), copepods, black fly larvae (simulids), some non-biting midge larvae (*Tanytarsus* spp.)
Grazer / Scraper	Graze or scrape algae and diatoms attached to the substrate	Freshwater snails (*Glyptophysa*)and limpets (*Ferrissia petterdi*)
Predator	Capture live prey	Most aquatic beetles (Coleoptera) and bugs (Hemiptera), water mites (Acarina), some non-biting midge larvae (*Procladius* spp.), leeches (Hirudinea)

Though no information exists for the Vasse-Wonnerup, WRM (2006) provided an analysis of functional feeding groups for the Ludlow River and this is provided here as an example. WRM (2006) assigned each species to a functional feeding group based on available published literature: Williams 1980, Barnes 1987, Bunn 1988, Boulton 1989, Cartwright 1997, Davis and Christidis 1997, St Clair 2000, Gooderham and Tsyrlin 2002 and the University of Western Australia database. The proportion of each functional feeding group is shown in Figure 8.

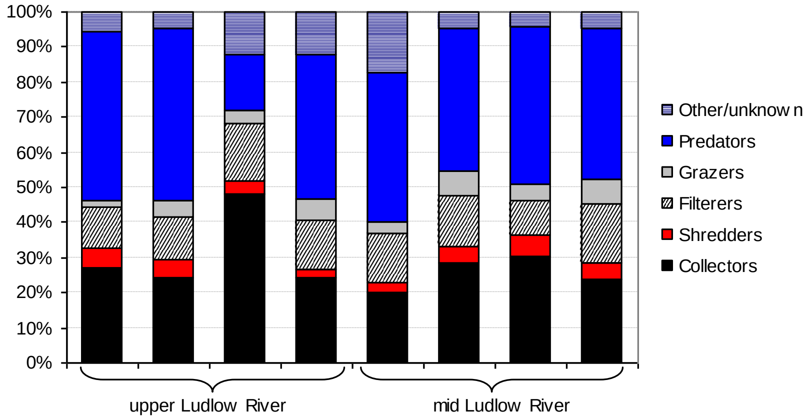


Figure 8. Example of functional feeding groups as determined for aquatic macroinvertebrates of the Ludlow River.

The mid and upper Ludlow River was found to have a high number of predators and collectors, with very few grazers or shredders. The paucity of shredders was linked to extensive clearing of riparian vegetation with few overhanging, fringing or aquatic plants and hence reduced coarse particulate matter on which shredders feed. In disturbed systems such as the Ludlow, an increase in grazers might also be expected due to nutrient enrichment, increased light and higher water temperatures all of which promote algal growth. However this did not appear to be the case, possibly due to seasonality of flows limiting permanent habitat for grazers and/or to unstable bed materials within the channels restricting algal and macrophyte growth and hence reducing availability of food sources for grazers.

4.13 Fish and Decapod Crustacea

Strictly speaking, decapod crustacea, such as crabs, prawns and crayfish, are invertebrates. They have been included here with fishes as they are generally viewed by the Department of Fisheries, and by the public, as recreational and commercial fisheries species.

At least twenty-nine fish, one crab, two prawn and four freshwater crayfish species are known to occur (or historically occurred) in the Vasse-Wonnerup estuary and tributary rivers (Table 19). These include three introduced freshwater fishes and one introduced crayfish (the Yabby). Most of these species occur or are likely to occur within the boundaries of the Ramsar Site, though there has been no comprehensive survey of the Site itself:

- 12 estuarine-marine fishes (including marine estuarine-opportunists), 5 estuarine fishes and at least 3 obligate freshwater fishes;
- 17 fish species that use the Site as a nursery area - estuarine and estuarine-marine species;
- 2 species - Black Bream and Mullet - that are fished commercially, as part of a small (2 to 3 active licences), restricted seasonal operation (refer Section 4.13.6);
- 1 introduced freshwater fish - Mosquitofish;
- 2 additional native fishes known to have historically been present that have not been recorded in recent years - freshwater Cobbler and marine-estuarine Tailor;
- 2 prawn species - Western School Prawn and (probably) Western King Prawn;
- 1 crab species - Blue Swimmer Crab - occasionally observed upstream of the floodgates;
- 2 freshwater crayfish - Koonacs and Gilgies - likely present in freshwater reaches of tributary rivers, but their presence within the Site is yet to be confirmed.

All of the native species recorded are south-west regional endemics. The Site contains no species that are considered rare or restricted in distribution. One fish species believed to have a restricted distribution has been recently recorded from headwater reaches of the Vasse River. This is the freshwater Mud Minnow, but it is unlikely to occur within the Site or in adjacent coastal waterbodies (see Section 4.13.3, below). The introduced Goldfish, Redfin Perch and Yabby are all pest species that to date have only been recorded from the Vasse River and Diversion Drain. However Goldfish and Yabbies have the potential to become more widely distributed if not checked.

Table 19. Fish and decapod crustacean species within the Vasse-Wonnerup catchment (sources: Bunbury & Morrell 1930 [cited in Lane *et al.* 1997], Lane *et al.* 1997, Morgan *et al.* 1998, White 1999, Morgan & Beatty 2004, Stewart 2003, WRM 2006, Gilbert Stokman & Mike Burgess, Dept. Fisheries, Busselton, pers comm.). Categorisation of species according to life-cycle (*e.g*. marine estuarine-opportunist) follows that of Young & Potter (2003a, b).

Codes: ✓ present; 🐟 nursery area; † historically present (may still be present); * introduced species.

Common Name	Scientific Name	Wonnerup Estuary	Vasse Estuary	Vasse River	Sabina River	Abba River	Ludlow River
Marine Estuarine-Opportunist Fishes (marine species that opportunistically use the estuary)							
Yellow Eye Mullet	*Aldrichetta forsteri*	✓ 🐟	✓ 🐟	✓ lower reaches			
Australian Herring	*Arripis georgianus*	?probably present	✓				
West Australian Salmon	*Arripis truttaceus*	✓ 🐟	✓ 🐟				
Whitebait	*Hyperlophus vittatus*	?probably present	✓ 🐟				
Sea Mullet	*Mugil cephalus*	✓	✓ 🐟	✓ lower reaches			
Tailor	*Pomatomus satatrix*	†	†				
Flounder	*Pseudorhombus* sp.	✓ 🐟	✓ 🐟				
Tarwhine (Silver bream)	*Rhabdosargus sarba*	✓ 🐟	✓ 🐟				
King George Whiting	*Sillaginodes punctata*	✓ 🐟	✓ 🐟				
Yellow-finned Whiting	*Sillago schomburgkii*	?probably present	✓ 🐟				
Marine and Estuarine Fishes (species that can complete their life cycle in either marine or estuarine environments)							
Yellowtail Trumpeter	*Amnaiataba caudivittata*	✓ 🐟	✓ 🐟				
Bridled Goby	*Amoya bifrenatus*	✓ 🐟	✓ 🐟				
Mulloway	*Argyrosomus japonicus*	✓ 🐟	✓ 🐟				
Cobbler (Estuary Catfish)	*Cnidoglanis macrocephalus*	✓ 🐟	✓ 🐟				
Bar Tailed Flathead	*Platycephalus endrachtensis*	✓ 🐟	✓ 🐟				
Western Sand Whiting	*Sillago ciliata*	✓ 🐟	✓ 🐟				
Common Blowfish	*Torquigener pleurogramma*	✓	✓				
Estuarine Fishes							
Black Bream	*Acanthopagrus butcheri*	✓ 🐟	✓ 🐟				
Elongate Hardyhead	*Atherinosoma elongata*	✓	✓				
Western Hardy Head	*Leptatherina wallacei*			✓ 🐟 lower reaches		✓ lower reaches	
Swan River Goby	*Pseudogobius olorum*	✓ 🐟	✓ 🐟	✓ 🐟 throughout river & Diversion Drain		✓ lower reaches	✓ lower reaches
Freshwater Fishes							
Nightfish	*Bostockia porosa*			✓ throughout		✓ throughout	✓ throughout
*Goldfish	*Carassius auratus*			✓ lower reaches & Diversion Drain			
Western Pygmy Perch	*Edelia vittata*			✓ throughout			✓ throughout
Mud Minnow	*Galaxiella munda*			✓ headwaters (Stuart Rd)			
Western Minnow	*Galaxia occidentalis*			✓ mid-upper reaches		✓ throughout	✓ throughout
*Mosquitofish	*Gambusia holbrooki*			✓ throughout		✓ throughout	✓ throughout
*Redfin Perch	*Perca fluviatalis*			✓			
Freshwater Cobbler	*Tandanus bostocki*					† lower fresh reaches (1830s)	
Crabs and Prawns							
Blue Swimmer Crabs	*Portunus pelagicus*	✓ occasionally above floodgates	✓ occasionally above floodgates				
Western School Prawn	*Metapenaeus dalli*	✓ 🐟	✓ 🐟				
Western King Prawn	*Penaeus latisulcatus*	?probably present	?probably present				
Freshwater Crayfish							
Marron	*Cherax cainii*			✓ upper reaches & Diversion Drain			
Koonacs	*Cherax plebejus*						✓ mid-upper reaches
Gilgies	*Cherax quinquecarinatus*			✓ Diversion Drain			✓ mid-upper reaches
*Yabby	*Cherax destructor*			✓ lower reaches & Diversion Drain			

Most Australian estuaries are species-rich (Loneragan *et al.* 1989); for example, the Swan River estuary supports at least 71 fish species, the Peel-Harvey Estuary has at least 47 species, the smaller Nornalup-Walpole estuary on the south-coast has 36 and the seasonally closed Wilson Inlet has 19 (Potter & Hyndes 1994, Young & Potter 2003). Estuaries that are permanently open to the sea tend to be dominated by marine fishes, while those that are seasonally closed are dominated by estuarine fishes (Potter *et al.* 1993, Potter & Hyndes 1994). The Vasse-Wonnerup is a seasonally closed estuary with an apparently high proportion of marine species.

Black Bream (courtesy Mark Maddern)

To further understand how relationships between species and physico-chemical/habitat variables may cause an increase or decrease in the abundance of individual species in the Ramsar Site, a greater knowledge of the life history requirements is needed.

4.13.1 Marine Fishes

Estuaries provide important nursery areas for marine fish species around Australia (Loneragan *et al.* 1986). They offer shallow protected habitat and abundant food sources for both juveniles and sub-adults. However, because estuaries are characterised by widely fluctuating environmental conditions (salinity, temperature *etc*), there are relatively few wholly estuarine-adapted species (Young & Potter 2003). Most spawn at sea and the larvae and pre-juveniles then migrate to estuaries where they inhabit shallow, warm nursery areas, before returning to marine environments as adults. Many species (*e.g.* Yellow-eye Mullet, Mulloway, Trumpeter, Yellow-finned Whiting, Western Sand and King George Whiting) can use marine embayments as well as estuaries as nursery areas. Larvae and juveniles of other species such as sea-mullet and whitebait are estuarine-dependent (Lenanton 1982, Potter *et al.* 2005). King George Whiting, Whitebait and Yellow-eye Mullet spend much of their life within estuaries and all can complete their whole life-cycle within the estuary if access to the sea is restricted (Potter *et al.* 2005). This is believed an adaptation to the seasonal closure or land-locking of many estuaries in Australia (Potter & Hyndes 1994).

Eight of the nine marine species that regularly occur within the Vasse-Wonnerup Site, are known to use the estuaries as nursery areas. The movement of marine species in and out of the Vasse and Wonnerup estuaries, their past and present distribution within the estuaries and triggers for breeding migration have not been studied. The Wardandi Noongar historically fished for juvenile Sea Mullet, Yellow-eye Mullet (pilch) and Black Bream (black snapper) in the estuaries. These species used the estuary as a nursery area, which was then more or less permanently open to the sea and would move far upstream into tributary rivers during winter (Vilma Webb, Busselton, pers. comm.). The extent to which the estuaries still provide nursery habitat has not been quantified.

4.13.2 Estuarine (Euryhaline) Fishes

There are four estuarine or euryhaline[9] fish species that occur within the Site. They include Black Bream, Swan River Goby, Western Hardyhead and Elongate Hardyhead. In other south-west estuaries, the life-cycle of Black Bream and Elongate Hardyheads is known to be confined to the estuary (Potter *et al.* 2005). Swan River GobY and Western Hardyhead can inhabit both estuarine and freshwater environments, often migrating far upstream in tributary rivers. Both species can complete their entire life-cycles in either estuarine or freshwater environments. Black Bream and Elongate Hardyhead however, remain within the estuaries, with bream showing a preference for the mid and upper sections (Lane *et al.* 1997). Black Bream typically spend their entire lives within the estuary in which they were born and recruitment is dependent on persistence of the estuarine environment (Chaplin *et al.* 1998, Sarre *et al.* 2000).

[9] Euryhaline species are those able to tolerate a wide range of salinities from fresh to saltwater.

Fish populations in general tend to show genetic differentiation between isolated catchments. This has been demonstrated for Black Bream populations in at least nine other Western Australian estuaries (Chaplin *et al.* 2005). Although individual black bream may be periodically flushed out to sea (*e.g.* by high freshwater flows in winter), there is very limited movement of fish between estuaries; most returning to the same estuary as soon as freshwater discharges decrease (Chaplin *et al.* 1998). Limited recruitment between estuaries means such species are particularly vulnerable to habitat degradation (and to over-fishing). Genetic research on gobies and Western Hardyhead would no doubt reveal a similarly restricted gene flow between south-west regional populations.

4.13.3 Obligate Freshwater Fishes

The seven freshwater fishes that occur within the Vasse-Wonnerup catchment tend to be restricted to the tributary rivers, though most are known tolerant of brackish conditions. With the exception of the lower Ludlow River study by Morgan *et al.* (1998) and the Vasse River study by Morgan and Beatty (2004), there have been no detailed surveys of the fish fauna in the tributary rivers.

The Western Pygmy Perch, Western Minnow and Nightfish are probably the most common native fish in both seasonal and perennial rivers throughout the south-west and southern regions of the State. Prior to European settlement, species such as Western Pygmy Perch, Western Minnow and Nightfish would have recolonised seasonal waterbodies each winter from permanent wetlands on the coastal plain, or from permanent pools within the river channels. The absence of river weirs and stop-boards would have allowed upstream migration of these species, in search of spawning habitat in small tributary creeks and flooded vegetation.


Freshwater cobbler (Andrew Storey)

Freshwater Cobbler were known to have historically been plentiful in larger rivers with well defined watercourses on the Swan Coastal Plain (Bradby 1997). Bunbury and Morrell (1930, cited in Lane *et al.* 1997) note Cobbler were plentiful in permanent pools in the lower freshwater reaches of the Abba River during the 1830's, but they have not been recorded in more recent surveys. Cobbler are widespread throughout the southwest and although abundant in some areas (often in reservoirs), they are considered locally threatened in others. Sedimentation of channel pools and loss of macrophyte beds is often implicated in the demise of Cobbler in many Coastal Plain river reaches.

The Mud Minnow which was only recently reported (Morgan & Beatty 2004) as present in the swampy, forested headwater reaches (Stuart Road waterpoint) of the Vasse River is believed restricted in distribution. Though common (and occasionally abundant) in coastal rivers between the Goodga River (near Albany) and Margaret River, elsewhere it is only known from small disjunct populations near Gingin (Morgan *et al.* 1998, Allen *et al.* 2002). The Mud Minnow is believed to have disappeared from much of its range due to habitat degradation and salinisation as a result of rural development. Predation by introduced fishes (*e.g.* Redfin Perch & trout) has also been implicated in population decline (Morgan *et al.* 1998, Allen *et al.* 2002). However, current data are insufficient to determine either the total population size or historical distribution and hence its nomination for listing under the EPBC Act was rejected in 2005, citing the need for quantifiable evidence of threatening processes. Mud Minnow have never been recorded from cleared agricultural areas and as such are considered unlikely to occur within the Ramsar Site or adjacent waterbodies.

The only introduced fishes recorded from the catchment are all freshwater species; Mosquitofish, Goldfish and Redfin Perch. Of these, only the Mosquitofish has been recorded from within the boundaries of the Ramsar Site. The presence of Goldfish and Redfin Perch could only be confirmed for the Vasse River and Diversion Drain, but both species reportedly (DEC 2006a) occur within the Tuart National Park which also encompasses lower reaches of the Abba, Sabina and Ludlow. The presence of all these species is considered detrimental to the ecology of native freshwater fishes and is discussed further in Section 5.6.4.

Like many estuarine fishes, freshwater fish populations may be distinct between catchments and even sub-catchments (Watts *et al.* 1995).


Western Minnow (Glenn Shiell)

4.13.4 Freshwater Crayfish

There have been no comprehensive surveys of freshwater crayfish within the Site. Morgan and Beatty (2004) recorded Gilgies and the introduced Yabby form the Vasse Diversion Drain, and WRM (2006) recorded Gilgies and Koonacs from the mid and upper sections of the tributary Ludlow River. Gilgies are typical of both seasonal and perennial waterbodies throughout the south-west. Koonacs tend to be associated more with seasonal systems in particular inland swamps and lakes. While it is possible that Gilgies and Koonacs are also present in lower freshwater reaches, they have yet to be reported. All freshwater crayfish have high conservation significance as icon[10] species (Nickoll & Horwitz 2000). Icon species are important ecologically because not only do they typically respond well to habitat restoration activities, but they also hold significant charismatic appeal. Generally, icon species are used to enhance public understanding of environmental issues. The elimination of any crayfish species from an area is considered to have significant conservation implications (refer Nickoll & Horwitz 2000).

4.13.5 Reproductive Migration

Details of spawning migration and reproductive behaviour of fishes within the Vasse-Wonnerup Site are not known. In other south-west estuaries and rivers, many fish species undertake spawning migrations. Fish may thus be categorised on the basis of reproductive behaviour:

i) diadromous species which migrate between fresh and estuarine or marine environments,
ii) species whose life-cycle can be completed entirely within estuaries,
iii) freshwater fish which migrate into upstream headwaters and tributaries to spawn.

Diadromous species include:

- anadromous fishes that live in estuaries or the sea as juveniles and/or adults but migrate into freshwaters to spawn, and
- catadromous fishes that live in freshwaters as juveniles or sub-adults, but migrate to estuaries or the sea to spawn.

None of the fishes so far recorded from the Vasse-Wonnerup estuary or tributary rivers are obligate diadromous species. Evidence from other south-west systems suggests that most of the marine species recorded in the Vasse-Wonnerup are capable of completing their lifecycles in inshore marine embayments, assuming suitable inshore habitat exists. Larvae of the estuarine Swan River Goby and Western Hardyhead are planktonic and are typically swept downstream into estuaries from where the juveniles migrate back into the rivers. However, if migration is restricted both these species can reproduce in freshwaters as well as estuarine.

Larvae and juveniles of estuarine Black Bream and of marine Sea Mullet and Whitebait are believed dependent on estuaries (Sarre *et al.* 2000, Potter *et al.* 2005). Summer survival rates and patterns of species distribution within the Vasse-Wonnerup estuaries have not been studied. Though Black Bream are believed to spawn in spring and summer when freshwater discharge into the Vasse-Wonnerup is at its lowest (Lane *et al.* 1997). They breed in reaches away from the estuary mouth.

[10] A priority conservation grouping similar to keystone, umbrella and indicator species or groups.

Of native freshwater species recorded in the Vasse-Wonnerup tributary rivers, Western Minnow, Western Pygmy Perch and Nightfish all migrate upstream to spawn in small tributary creeks and flooded vegetation. It is not known to what extent these species can utilise the flooded margins of the main river channel for breeding if upstream migration is prevented.

Timing of spawning and spawning migration varies between species. Most south-west fish species breed from spring to summer, though some spawn as early as late winter (*e.g.* Western Pygmy Perch) or as late as autumn (*e.g.* Swan River Goby). Cues for migration and spawning include breaking late autumn/early winter flood pulses and higher water levels, changes in flow and currents, changes in turbidity, water temperatures and photoperiod.

4.13.6 Variation in Fish and Decapod Crustacea Communities

There have been no quantitative studies of variation in fish, crab, prawn or freshwater crayfish species richness or abundance at the Site. DEC staff qualitatively assess fish numbers at the floodgates by visual observation over summer-autumn so that opening of the fish gates can be timed to prevent sudden mass fish deaths (refer White 1999, Elscot 2000). Actual abundance of marine and estuarine fishes is likely to be in the order of tens of thousands, given the numbers documented during sudden mass fish deaths that have occurred between 1905 and the most recent event in 2003. As many as 35,000 fish have been recorded congregating at the Vasse Estuary floodgates in summer (February 2000).

Throughout Western Australian, there have been only a limited number of studies on the relative distributions of marine, estuarine and freshwater fishes within estuaries and their tributary rivers. Exceptions are the Swan, Peel-Harvey and Nornalup-Walpole estuaries (refer Loneragan *et al.* 1989, Young & Potter 2003a, b) and Wilson Inlet (Potter & Hyndes 1994). Though no long-term catch data were available for the Vasse-Wonnerup, it is likely that fish communities exhibit large spatial and temporal variation in both abundances and species richness linked to changes in habitat and food availability, water quality (salinity, temperature), predation pressures and life-history stage.

The only quantitative surveys that have been carried out in the immediate vicinity of the Site are those of Morgan and Beatty (2004) in the Vasse River and Diversion Drain. These were commissioned by GeoCatch as part of the on-going Vasse River Cleanup Program. Morgan and Beatty (2004) recorded large spatial variation in fish fauna between nine sites sampled during December 2003 and March 2004. A total of 7,895 individuals were captured, 60% of which were introduced Mosquitofish. Abundances varied greatly between sites, from five to 2,285 individuals, while species richness varied from one to five species per site. Abundance and relative density of species caught is given in Appendix E. It is likely that similar surveys of river reaches within the Ramsar Site would reveal similarly high variation both between sites and seasons.

Freshwater crayfish tend to be less mobile than fish species, constructing burrows and defending small territories. Variation in abundances is thus more likely to be associated with mortality rate and recruitment success, than to movement in and out of a habitat.

4.13.6 Commercial and Recreational Fishing

The Vasse-Wonnerup wetlands system provides locally significant habitat for mullet and bream and a small commercial fishery for these species operates in the estuary from June to October/November. The catch is sold as 'crayfish bait' (Dept. of Fisheries, Busselton, pers comm.). The WA Department of Fisheries manages the operations as a Restricted Entry Fishery under licence (Condition 84 licence). Currently there are only five active licences covering some 13 vessels (dinghies). Fishing is restricted to set-nets (with operators to remain in attendance) and to the Vasse and Wonnerup exit channels above the floodgates. In practice, only two or three licensed operators continue to fish, primarily in the lower Vasse Estuary (Dept. of Fisheries, Busselton, pers comm.). Fishing is banned in Wonnerup Inlet and The Deadwater.

Since the 1960s, commercial netting has also been used to ameliorate the effects of sudden mass fish deaths by allowing commercial fishermen to harvest fish that would otherwise die over summer (Lane *et al.* 1997). Over the last few years, two fishermen have complained that odour and skin lesions caused by contact with the water prevent successful harvesting (Jim Lane, DEC, pers. comm.) (see also Section 10.2.1).

Recreational fishing is restricted to rod and line fishing in Wonnerup Inlet, The Deadwater and the Vasse Estuary exit channel below the floodgates (Lane *et al.* 1997). Recreational netting in the estuary was been banned since 1990 (Dept. of Fisheries, Busselton, pers comm.).

4.14 Waterbirds

The Vasse-Wonnerup Ramsar Site and the adjacent Broadwater, together provide one of the most significant coastal habitats for waterbirds in the south-west of Western Australia. Only the large Peel-Harvey Estuary, ca 100 km to the north, supports a greater number of waterbirds, but it covers an area nearly 13 times greater than the Vasse-Wonnerup. At least 17 migratory species (mostly shorebirds) regularly undertake annual migrations along the Flyway to spend their non-breeding season in the Vasse-Wonnerup. These species have international protection under the JAMBA (1974), CAMBA (1986) and/or ROKAMBA (2006) treaties.

The first surveys of waterbirds were annual waterfowl counts made during the 1960s and 1970s. Counts were conducted by air in September or October of each year as part of regional surveys to determine the duration of the duck-hunting season and bag limits in Western Australia (Halse *et al.* 1990). Duck shooting was permitted on at least part of the Vasse-Wonnerup wetlands until 1930, when it was banned on "the whole of the waters of Vasse River, Vasse Estuary and Wonnerup Estuary" (Jim Lane, pers. comm.). However, detailed and comprehensive surveys of waterbird abundance and diversity were not conducted until 1981, when the Royal Australian Ornithologists Union (RAOU; now Birds Australia), under contract to the Department of Fisheries and Wildlife (now DEC) began ground surveys of all waterbirds in the lower Sabina River, The Deadwater, Vasse Estuary and part of the Wonnerup Estuary, and many other reserved wetlands throughout south-western Australia (Lane 1981). These surveys continued till mid 1985 and were made in each season in each year, except winter 1981 - 1982, generally every 2 - 4 weeks (Jaensch *et al.* 1988).

Between 1986 and 1991/92, CALM and RAOU carried out joint investigations of waterfowl only, at some 1,247 wetlands across the south-west, including the Vasse-Wonnerup Site (Jaensch 1986, Jaensch & Vervest 1988a,b, Bamford & Bamford 1992, Halse *et al.* 1990, 1994, 1995). The 1986 - 1991 surveys were conducted over a 9-day period in March with additional November counts in 1989 - 1991 to enable the extent of breeding to be assessed, to compare distribution of breeding and post-breeding birds and to identify important moulting sites within the south-west (Halse *et al.* 1995). Surveys were conducted from the air and from the ground (or in some instances by canoe) using telescopes or binoculars. Aerial surveys were made over a 3-day period using a Cessna 182 flying at a height of 20 - 40 m. The aims of the surveys included monitoring of long-term trends in annual numbers of waterfowl and to examine regional distribution of species in relation to rainfall (Halse *et al.* 1990).

Bamford and Bamford (1995) surveyed the effect of disturbance on waterbird usage of the Vasse-Wonnerup Estuary floodplains. More recent surveys were made by Lane *et al.* (2007) between 1998 and 2000 and covered all except one ('Swan Lake') principal waterbird habitat within the Ramsar Site, including Wonnerup Inlet, Malbup Creek, The Deadwater and two locations on Lower Vasse River Wetlands (Ford Road & Peel Cove) which have potential for addition to the Ramsar Site. To ensure the majority of waterbird species would be included in the surveys, Lane *et al.* (2007) undertook the work in two phases:

1. Phase I All Species Counts – monthly surveys February 1998 - April 1998 and December 1998 - May 1999 to coincide with peak waterbird abundance. Limited attention was given to smaller waders during this phase as past surveys had shown several other waterbird species to be particularly sensitive to human disturbance and it would therefore be difficult to accurately count all species as part of a single survey;
2. Phase II Wader Counts – monthly surveys November 1999 - March 2000 to coincide with the main over-summering period of international migratory shorebirds.

Methods used by Lane *et al.* (2007) necessarily varied somewhat according to location, in particular estuary water level, shoreline exposure and accessibility. Surveys were conducted by two operators either on foot and/or from a kayak or vehicle using binoculars and/or telescopes with tripods. VHF radio and/or mobile phones were used to maintain contact between operators. Most monthly surveys were conducted over a period of two days (Lane *et al.* 2007). The principal aim of the survey was to assess current usage of Vasse-Wonnerup wetlands by waterbirds, in order to determine whether the Site continued to meet the Ramsar Criteria under which it was listed in 1990 as a Wetland of International Importance. The study report also compared current waterbird usage with RAOU 1981-1990 survey data as reported by Bamford and Bamford (1992) and Jaensch (1986).

Waterbird Data
All waterbird data for the Vasse-Wonnerup Site is maintained and updated by DEC, Busselton. Enquiries should be directed to Department of Environment and Conservation, 14 Queen Street, Busselton WA 6280, Australia, (Tel: +61-8-9752-5555; Fax: +61-8-9752-1432).

4.14.1 Species Diversity and Abundance

The Site supports peak numbers of 25,000 - 35,000 waterbirds in most years, of which some 12,000 are waterfowl (ducks & swans). The most recent census carried out between February 1998 and May 2000 (Lane *et al.* 2007), brings the total number of native species recorded to 83, with at least 60 of these occurring in most years. The total includes:

- 5 darters and cormorants,
- 13 herons and allies,
- 11 ducks and allies,
- 7 rails and water-hens,
- 30 shorebirds and
- 7 gulls and terns.

The most abundant of these are typically Grey Teal (14,000, Jan 1989), Australian Shelduck (6,108, Nov. 1989) and Black-winged Stilt (5,000, Jan. 1986). More than 34,500 waterbirds have been recorded in a single month (Dec. 1998) and 71 species have been recorded in a single season, including 23 species of wader (Jaensch 1986, Lane *et al.* 2007). One or two birds of domestic duck/geese species are also occasionally observed.

Table 20 lists all waterbird species that have been recorded. Three species not generally regarded as waterbirds (Whistling Kites, Swallow, Martin) have been included in this list as they make substantial use of the Site (Jim Lane, DEC, pers. obs.). The list includes:

- 40 species that have priority conservation status at a State, national or global level (including those listed under J/CAMBA, CMS);
- 39 species listed under the JAMBA, CAMBA and/or CMS treaties. Of these, 22 are international migratory species though only 17 occur regularly at the Site, *e.g.* Curlew Sandpiper, Sharp-tailed Sandpiper, Red-necked Stint, Long-toed Stint, Curlew Sandpiper, Wood Sandpiper and the Greenshank.
- 61 resident Australian species, the most abundant being the Australian Pelican, Great Egret, Yellow-billed Spoonbill, Eurasian Coot, Black-Winged Stilt and Red-necked Avocet.
- 4 species that regularly occur in numbers greater than or equal to 1% of the estimated relevant Ramsar populations; *i.e.* Black-winged Stilt, Red-necked Avocet, Australian Shelduck and Australasian Shoveler.
- 5 shorebird species that occur in numbers greater than 1% of the estimated SE Asia-Australasia Flyway population in some years; *i.e.* Wood Sandpiper, Sharp-tailed Sandpiper, Long-toed Stint, Curlew Sandpiper and Greenshank.

Table 20. Waterbirds recorded from the Vasse-Wonnerup Ramsar Site (source Lane 1997, Lane *et al.* 2007).

Code: Migratory = international migratory species; J/CAMBA, CMS = listed under international JAMBA, CAMBA and/or CMS treaties; M / V = international migratory species (M) and/or vagrant species (V); EN = listed as vulnerable on the IUCN (2006) Red list or DEC 2006 Declared Threatened Fauna list; VU = listed as vulnerable on the DEC 2006 Declared Threatened Fauna list, EPBC Act List of Threatened fauna and/or the IUCN (2006) Red list.

Common Name	Scientific Name	Max. Count 1981-2000	M / V	J/CAMBA, CMS	IUCN / EPBC / DEC Status	Breeds at Site
Ducks & allies (Family Anatidae)						
Blue-billed Duck	*Oxyura australis*	6		CMS		
Musk Duck	*Biziura lobata*	80				Yes
Black Swan	*Cygnus atratus*	3013				Yes
Australian Shelduck	*Tadorna tadornoides*	4536				Yes
Australasian Wood Duck	*Chenonetta jubata*	123				Yes
Pacific Black Duck	*Anas superciliosa*	4200				Yes
Australasian Shoveler	*Anas rhynchotis*	716				Yes
Grey Teal	*Anas gracilis*	14000				Yes
Chestnut Teal	*Anas castanea*	5				
Pink-eared Duck	*Malacorhynchus memranaceus*	66				
Hardhead	*Aythya australis*	200		CMS		Yes
Grebes (Family Podicipedidae)						
Hoary-headed Grebe	*Poliocephalus poliocephalus*	350				Yes
Darters (Family Anhingidae						
Darter	*Anhinga melanogaster*	21				
Cormorants (Family Phalacrocoracidae)						
Little Pied Cormorant	*Phalacrocorax melanoleucos*	296				
Pied Cormorant	*Phalacrocorax varius*	212				
Little Black Cormorant	*Phalacrocorax sulcirostris*	325				
Great Cormorant	*Phalacrocorax carbo*	60				
Pelicans (Family Pelecanidae)						
Australian Pelican	*Pelecanus conspicillatus*	750				
Herons, Egrets, Bitterns (Family Ardeidae)						
White-faced Heron	*Egretta novaehollandiae*	379				
Little Egret	*Egretta garzetta*	8				
Eastern Reef Egret	*Egretta sacra*	1	V	CAMBA		
White-necked Heron	*Ardea pacifica*	4				
Great Egret	*Casmerodius albus*	237		J/CAMBA, CMS		
Nankeen Night Heron	*Nycticorax caledonicus*	17				
Australasian Bittern	*Botaurus poiciloptilus*	1			VU (DEC); EN (IUCN)	
Ibis, Spoonbills (Family Threskiornithidae)						
Glossy Ibis	*Plegadis falcinellus*	14		CAMBA, CMS		
Australian White Ibis	*Threskiornis molucca*	279				Yes
Straw-necked Ibis	*Threskiornis spinicollis*	562				
Royal Spoonbill	*Platalea regia*	1	V			
Yellow-billed Spoonbill	*Platalea flavipes*	151				Yes
Osprey, Kites, sea Eagles, Harriers (Family Accipitridae)						
Osprey	*Pandion haliaetus*	2		CMS		Yes
Whistling Kite	*Haliastur sphenurus*	11		CMS		
White-bellied Sea Eagle	*Haliaeetus leucogaster*	1		CAMBA		Yes
Swamp Harrier	*Circus approximans*	5		CMS		
Rails, Crakes, Water-hens, Coots (Family Rallidae)						
Buff-banded Rail	*Gallirallus phillipensis*	4				Yes
Australian Spotted Crake	*Porzana fluminea*	5				
Spotless Crake	*Porzana tabuensis*	2				Yes
Purple Swamphen	*Porphyrio porphyrio*	25				Yes
Dusky Moorhen	*Gallinula tenebrosa*	14				Yes
Black-tailed Native Hen	*Gallinula ventralis*	4				
Eurasian Coot	*Fulica atra*	4000		CMS		

Table 20 continued.

Common Name	Scientific Name	Max. Count 1981-2000	M / V	J/CAMBA, CMS	IUCN / EPBC / DEC Status	Breeds at Site
Sandpipers, Knots, Stints & allies (Family Scolopacidae)						
Pin-tailed Snipe	*Capella stenura*	1	M,V	CAMBA, CMS		
Black-tailed Godwit	*Limosa limosa*	18	M	J/CAMBA, CMS		
Bar-tailed Godwit	*Limosa lapponica*	14	M	J/CAMBA, CMS		
Whimbrel	*Numenius phaeopus*	1	M	J/CAMBA, CMS		
Marsh Sandpiper	*Tringa stagnatilis*	8	M	CAMBA, CMS		
Common Greenshank	*Tringa nebularia*	300	M	J/CAMBA, CMS		
Wood Sandpiper	*Tringa glareola*	72	M	CMS		
Terek Sandpiper	*Xenus cinereus*	1	M	J/CAMBA, CMS		
Common Sandpiper	*Actitis hypoleucos*	11	M	J/CAMBA, CMS		
Grey-tailed Tattler	*Heteroscelis brevipes*	2	M	J/CAMBA, CMS		
Great Knot	*Calidris tenuirostris*	12	M	J/CAMBA, CMS		
Red Knot	*Calidris canutus*	9	M	J/CAMBA, CMS		
Red-necked Stint	*Calidris ruficollis*	2512	M	J/CAMBA, CMS		
Long-toed Stint	*Calidris subminuta*	24	M	CAMBA, CMS		
Pectoral Sandpiper	*Calidris melanotos*	7	M	J/CAMBA, CMS		
Sharp-tailed Sandpiper	*Calidris acuminata*	2300	M	J/CAMBA, CMS		
Curlew Sandpiper	*Calidris ferruginea*	2500	M	J/CAMBA, CMS		
Ruff	*Philomachus pugnax*	1	M,V	J/CAMBA, CMS		
Painted Snipe (Family Rostratulidae)						
Painted Snipe	*Rostratula benghalensis australis*	1	V	CMS	VU (DEC, EPBC)	
Oystercatches (Family Haematopodidae)						
Pied Oystercatcher	*Haematopus longirostris*	2				
Stilts, Avocets (Family Recurvirostridae)						
Black-winged Stilt	*Himantopus himantopus*	5000		CMS		Yes
Banded Stilt	*Cladorhynchus leucocephalus*	1137		CMS		
Red-necked Avocet	*Recurvirostra novaehollandiae*	4000		CMS		
Plovers, Dottrels (Family Charadriidae)						
Pacific golden Plover	*Pluvialis fulva*	73	M	CMS		
Grey Plover	*Pluvialis squatarola*	14	M	J/CAMBA, CMS		
Red-capped Plover	*Charadrius ruficapillus*	998				Yes
Greater sand Plover	*Charadrius leschenaultii*	6	M	CMS		
Black-fronted Dotterel	*Elseyornis melanops*	18				
Red-kneed Dotterel	*Erythrogonys cinctus*	2				
Banded Lapwing	*Vanellus tricolour*	8				
Gulls, terns (Family Laridae)						
Silver Gull	*Larus novaehollandiae*	3058				
Caspian Tern	*Hydropogne tschegrava*	15		CAMBA, CMS		
Crested Tern	*Sterna bergii*	25		JAMBA, CMS		
Fairy Tern	*Sterna nereis*	2				
Gull-billed Tern	*Sterna nilotica*	1	V			
Whiskered Tern	*Chldonias hybridus*	180				
White-winged Black Tern	*Chlidonias leucopterus*	70		CAMBA, CMS		
Honeyeaters, Australian Chats (family Meliphagidae)						
White-fronted Chat	*Ephthianura albifrons*	9				Yes
Swallows, Martins (Family Hirundinidae)						
Welcome Swallow	*Hirundo neoxena*	--				
Tree Martin	*Hirundo nigricans*	--				
Old World warblers (Family Sylviidae)						
Clamorous Reed-warbler	*Acrocephalus stentoreus*	1		CMS		
Little Grassbird	*Megalurus gramineus*	6				Yes

4.14.2 Waterbird Foraging Guilds

Waterbirds have evolved to exploit a wide variety of habitat types for both foraging and breeding purposes. Accordingly, waterbirds are often grouped into foraging/feeding guilds or nesting guilds as a useful classification for studying their ecology. Knowledge of habitat use is crucial when selecting appropriate species for assessment of habitat change. Species may be either generalist feeders or specialists. Specialists will often move between wetlands within the one complex in search of optimal conditions.

Foraging guilds described by Bamford and Bamford (2004) for the Creery Wetlands of the Peel-Yalgorup Ramsar Site, are also appropriate for the Vasse-Wonnerup (Table 21). The list includes species that are not strictly waterbirds but which are dependent on the waterbodies and associated vegetation of the Vasse-Wonnerup Site:

Table 21. Waterbird foraging guilds represented at the Vasse-Wonnerup Site.

Foraging Guild	Description	Number of Species
Waterfowl (swans & ducks)	Herbivores and omnivores feeding in sheltered shallow waters	11
Cormorants, darters, pelicans and grebes	Mostly fish-eating species that feed in the estuary in open, shallow water	7
Large waders (herons, egrets & ibis)	Forage on fish and invertebrates usually in shallow water	13
Raptors & kingfishers (swamp harriers, osprey & white-bellied sea-eagles, whistling kites)	Fish-eating birds of prey	4
Coots, rails and water-hens	Omnivores and insectivores foraging in dense vegetation on wetland margins	7
Shorebirds (*e.g.* oystercatchers, sandpipers, godwits, greenshank, plovers, stints & stilts)	Feed along shorelines, wet sandflats, mudflats, samphire and shallow waters	30
Scavenging seabirds (terns & gulls);	Feed in a wide variety of habitats; opportunistic	7
Small bush birds (*e.g.* white-fronted chat, little grassbird, clamorous reed warbler, swallows, martins)	Forage in reed beds, tussock grasses, samphire, fringing vegetation and over water	4

Even within guilds, each species has a unique mode of feeding dependent on their physique and on the spatial and temporal distribution of their preferred food (OzEstuaries 2007). As nutrition and calorie requirements vary over an individual's lifetime, food preferences will also differ between breeding and non-breeding birds and between adults and juveniles of the same species. A summary of general knowledge of preferred foraging habitat of various species is included in Appendix F. However there has been no research on specific diet of waterbirds at the Vasse-Wonnerup Site.

4.14.3 Waterbird Breeding Guilds

There are 21 species of waterbird known to breed at the Vasse-Wonnerup Site. It supports the largest known regular breeding colony of Black Swan in the State. Aggregations of 50 - 150 breeding pairs of swans occur annually in the samphire-covered basin ('Swan Lake') at the northern end of the Wonnerup Estuary (Environment Australia 2001). At least 20 pairs of swans also breed annually in the central Vasse Estuary. Other species known to breed regularly are Pacific Black Duck (large numbers), Grey Teal, Buff-banded Rail, Spotless Crake and Dusky Moorhen (ANCA 1996). It is thought samphire and sedgeland habitats may also provide breeding areas for the EPBC listed painted snipe, but this is yet to be confirmed. There have been occasional reports of breeding Australasian shoveler, Australian Shelduck, Musk Duck, Hardhead, Black-winged Stilt and Red-capped Plover (Jaensch *et al.* 1988) and sacred kingfishers *Halcyon sancta* have been observed nesting in casuarina trees fringing the Vasse Estuary (Jaensch 1986). Nesting guilds represented are listed in Table 22.

Table 22. Waterbird nesting guilds represented at the Vasse-Wonnerup Site.

Nesting Guilds	Description	Approx. Number of Species
Woodland (*e.g.* ducks, herons, egrets, cormorants, spoonbills, small bushbirds, kingfishers)	Nest in fringing trees, woodland, shrublands, bulrushes, tussocks.	12
Reed beds (*e.g.* coots, rails, swans, grebes)	Nest on reed beds, floating vegetation, submerged grasses and open water.	5
Open, sparse, short grassland (*e.g.* some shorebirds, Australasian shoveler)	Nests in open, sparse, short grassland and weeds or samphire	4
Bare-ground (*e.g.* some shorebirds)	Nests on bare-ground	1

A summary of general knowledge of preferred breeding habitat of various species is included in Appendix F. However, other than swans, there has been no research into specific nesting habits of waterbirds that breed at the Site. Access to much of the wetland is difficult and past attempts to systematically survey nests have proved unsatisfactory (Jim Lane, DEC, pers. comm.). There are also many birds which use the Site for food, but nest outside its boundary. For example two paperbark swamps on low-lying flats between the Vasse Estuary and Layman Road, (near Avocet Boulevard) are known to provide significant waterbird breeding and roosting habitats but are not part of the Ramsar Site. These are of particular conservation value as there are no other remnant wetlands of this type remaining on the Vasse-Wonnerup floodplain (WAPC 2005).

4.14.4 Variation in Waterbird Community

Greatest aggregations of individual birds and of bird species tend to occur in the Vasse Estuary and Sabina River delta (combined), followed by the Wonnerup Estuary, Malbup Creek, The Deadwater and Wonnerup Inlet (Jaensch *et al.* 1988, Lane *et al.* 2007). For example, during the most recent surveys of all species (Dec 1998 - May 1999), maximum waterbird counts ranged from ca 19, 000 in the Vasse Estuary to ca 14, 000 in the Wonnerup Estuary and down to 45 in Wonnerup Inlet (Lane *et al.* 2007). In 1999-2000, abundance of migratory shorebirds tended to be slightly higher in the Vasse Estuary (~1,400) than the Wonnerup (~1,200), with few shorebirds occurring in Malbup Creek, Wonnerup Inlet or The Deadwater (Lane *et al.* 2007). Of the total 61 waterbird species recorded during 1998 - 2000, 26 had maximum counts of less than 10 individuals.

The distribution of a species will change seasonally and annually in response to the condition of the habitat (Lane & Munro 1983). Species that occur mainly on coastal habitats will have a more stable distribution than species that use both coastal and inland wetlands and species that just use inland wetlands. Species that migrate or make use of additional breeding and/or foraging habitats outside the boundary of the Site will be subject to influences unrelated to Site conditions. In the Vasse-Wonnerup, Lane *et al.* (2007) recorded a maximum abundance for 1998 - 2000 of ca 34, 500 (Dec 1998) and a minimum of 5,047 (May 1999). They noted many species showed marked variation in seasonal or episodic abundance (Table 23).

The gathering of repeatable quantitative data on inter- and intra-annual variation in abundance and species richness is greatly hampered by access and by the Site's relatively large area and spatial complexity. Aerial surveys have been conducted in the past, but were always problematic (due principally to the configuration of the wetlands) and nowadays are impractical given the amount of recent housing construction near the Site (Jim Lane, pers. obs). In addition, annual surveys prior to 1998 were not always standardised by date or location, making statistical comparison of spatial and temporal variation difficult (Lane *et al.* 2007). For example, data collected by the RAOU between 1981 and 1985 was largely confined to the Vasse Estuary. The lack of a standardised approach stemmed from the fact that the aim of these earlier surveys was not to monitor changes in waterbird numbers, but to merely establish that the Site met Ramsar criteria for listing as a Wetland of International Importance.

Lane *et al.* (2007) also point out that timing of bird counts is critical if between-year comparisons are to be made. Past surveys have shown waterbirds to be most abundant between December and May, peaking December to February (Lane 1990). Lane *et al.* (2007) indicated that the 1997-1998 surveys were hampered by a delay in funding which meant waterbird surveys had to begin in February 1998 instead of the preferred December 1997 start data.

Gathering of quantitative water bird data may also be affected by the size of the survey team. In the 1998-2000 surveys there was potential for double-counting and under-counting due to possible movement of birds from the Vasse Estuary on one survey day to the Wonnerup Estuary on the next; as the number of skilled and available surveyors was insufficient to cover all waterbodies on the same day (Lane *et al.* 2007).

Table 23. 1997-98 and 1998-99 waterbird data, 1999-00 wader data, annual maxima of each species and total birds and species counted onVasse-Wonnerup Wetlands each year or part thereof (source Lane *et al.* 2007).

	1997-98				1998-99							1999-00						All Years
Species	Feb-98	Mar-98	Apr-98	Max	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Max	Nov-99	Dec-99	Jan-00	Feb-00	Mar-00	Max	Max
Black Swan	2	86	368	368	3013	149	5	29	44	459	3013	-	-	-	-	-	-	3013
Australian Pelican	0	1		1	281	354	182	10	6	5	354	-	-	-	-	-	-	354
White-faced Heron	46	36	27	46	220	379	146	34	53	106	379	-	-	-	-	-	-	379
Great Egret	0	2	2	2	86	108	13	4	11	2	108	-	-	-	-	-	-	108
Eurasian Coot	1	0	5	5	3570	29	0	1	2	0	3570	-	-	-	-	-	-	3570
Common Greenshank	34	18	9	34	94	300	176	92	14	4	300	67	89	102	123	33	123	300
Red-necked Stint	1064	758	166	1064	14	447	2512	746	238	0	2512	23	50	935	2118	1506	2118	2512
Sharp-tailed Sandpiper	170	0	0	170	112	372	391	2	2	0	391	340	432	331	281	0	432	432
Curlew Sandpiper	0	278	0	278	0	13	153	6	0	0	153	1	27	96	42	30	96	278
Black-winged Stilt	536	433	533	536	3371	2177	966	800	858	74	3371	515	3403	3494	2597	1072	3494	3494
Banded Stilt	1137	1034	197	1137	287	1124	887	155	0	0	1124	0	25	15	8	2	24	1137
Red-necked Avocet	36	1296	956	1296	2000	1013	735	18	0	0	2000	68	1220	1166	431	13	1220	2000
Pacific Golden Plover	0	0	0	0	0	71	39	14	0	0	71	23	73	11		19	73	73
Silver Gull	8	13	2	13	2564	3058	265	484	136	249	3058	-	-	-	-	-	-	3058

Data collected prior to 1998 is yet to be subjected to a rigorous quality assurance/quality control process. In the interim, Lane *et al.* (2007) have taken a knowledge-based, rather than statistical, approach to interpretation of changes in waterbird abundance and diversity between pre- and post-1998. They compared their data with data from the 12 'substantially complete' 1984-90 RAOU surveys reported by Bamford and Bamford (1992) and the 74 substantially complete or partial 1981-87 RAOU surveys reported by Jaensch (1987) (note that some survey data are common to both RAOU data sets). Lane *et al.* (2007) concluded:

1. Abundances of 28 of the 61 waterbirds recorded in 1998-2000 surveys were unchanged or greater than previous estimates. Species showing substantial increases in abundance were:
   - Silver Gull
   - Banded Stilt
   - Red-necked Stint
   - Black Swan
   - Red-capped Plover
   - Australian White Ibis
   - White-faced Heron
   - Little Black Cormorant
2. Abundances of 13 of the 61 waterbirds recorded in 1998 - 2000 surveys were less than previous estimates. For a few of these species, this was attributed to the fact that not all habitats were included in post-1998 (and pre-1998) surveys. For others, Lane *et al.* (2007) recommends closer investigation of historic data is needed to determine if apparent declines are indeed actual and not just artefacts of differences in areas surveyed or sampling techniques. Species of local and/or regional concern include:
   - Blue-billed Duck
   - Great Cormorant
   - Great Egret
   - Curlew sandpiper
   - Long-toed Stint
   - Wood Sandpiper

   Some of these species are reportedly in regional and/or national decline (*e.g.* Blue-billed Duck, Great Egret & Curlew Sandpiper) and apparent reduced abundances at the Vasse-Wonnerup Site may reflect this (Lane *et al.* 2007).

5. WETLAND PROCESSES

It was not possible to quantitatively define critical processes of the Vasse-Wonnerup Site due to the paucity of suitable baseline data. A summary list of key processes based on the limited available data and largely inferred from similar wetlands is given in Table 24. A brief discussion of each is presented in the following sub-sections, and highlights knowledge gaps for the Vasse-Wonnerup Site.

Table 24. Key ecosystem processes in the Vasse-Wonnerup Wetlands.

Process Type	Process
Geomorphologic and fluvial processes	Sand bar Sediment regime - erosion, transport and deposition Habitat availability
Hydrological regime	Floodgates Surface Flows - frequency, magnitude, duration, seasonality Water balance - water flowing in, evaporation, water flowing out Estuary water residence time Salinity regimes
Circulation processes	Wind driven
Energy and nutrient dynamics	Nutrient and carbon cycling Physico-chemical interactions - carbon, nutrients, dissolved oxygen, salinity, sulphate, iron and temperature, silica Interactions between physico-chemical components and biota
Processes which maintain animal and plant populations	Migration (waterbirds, fish) Reproduction (waterbirds, fish)
Species interactions	Phytoplankton and macrophyte successional dynamics Macrophyte and samphire communities - food source, nursery habitat Predation and herbivory Competition - fish, waterbirds - introduced plants and animals

5.1 Geomorphic and Fluvial Processes

The natural processes of erosion and deposition that shape estuaries result in a complex distribution of sediments with different grain sizes, varying chemical and organic matter content and hence varying nutrient concentrations. Increased rates of erosion due to land clearing and catchment disturbance can alter the distribution and character of deposited sediments and alter or even infill habitats. The amount of deposited organic matter has a major influence on dissolved oxygen (DO) levels in the water column as micro-organisms use DO as they decompose the organic material. Organic matter in sediments contains carbon and nutrients and thus erosion and deposition processes contribute to external loadings of carbon and nutrients to the estuary. The type of soils eroded and deposited is also important. Fine-grained sediments more readily adsorb organic matter and thus deposition of muds and clays, rather than sand and gravel, can increase soil carbon and nutrient concentrations. In most estuaries, there is generally a positive correlation between total nitrogen or total organic carbon and percentage mud (Anderson *et al.* 1981). Fine sediments and muds accumulate in deposition zones. In estuaries, these typically occur in calmer areas where wave or water energy is low, *e.g.* central basins, intertidal flats, samphire heathland and seagrass beds. In tributary rivers, deposition is greatest in pools and inner meander bends of lowland reaches. In-filling of lowland river pools has lead to the loss of much freshwater fish habitat throughout the south-west.

In estuaries such as the Vasse-Wonnerup, organic matter loads are likely high due to catchment clearing and agricultural land use. Reduced river and tidal flushing means relatively little of this material is washed out to sea (refer Sections 4.1 & 4.4.1). High retention rates and long residence times increase carbon and nutrient re-cycling within the estuary. In natural systems, this has a positive effect on ecosystems by providing abundant energy and nutrient sources that support large populations of plants and animals (*i.e.* high primary and secondary productivity). However, there is no available data on water residence times, erosion/deposition rates, zones of deposition, sediment nutrient stores or sediment infauna and epifauna within the Vasse-Wonnerup Ramsar Site. Soil biota in general is considered integral to nutrient fluxes (Levin *et al.* 2001, De Roach 2006). For example, invertebrate feeding guilds such as shredders assist the breakdown and decomposition of organic matter, while benthic filter feeders transport nutrients and sediments across the sediment-water interface (Levin *et al.* 2001). Physical movement of animals burrowing across or within sediments (*e.g.* polychaetes) results in aeration and transport of organic matter. The physical characteristics of soils and sediments will determine the type of fauna present.

The shallow estuary basins, restricted inlet and sand bar formation at the mouth, naturally provide a sheltered environment with reduced wave energy and high light conditions favourable to algal and seagrass growth and thus invertebrate, fish and waterbird communities. Opening of the sand bar determines habitat connectivity with the marine environment of Geographe Bay and influences salinity in the estuary. This habitat connectivity is particularly important to maintain local populations of marine fishes that spawn at sea. While longer-lasting openings of the bar probably historically, permanent opening of the bar today would have uncertain and possibly adverse consequences for waterbird and fringing vegetation communities adapted to existing hydrological regimes. There is a current proposal under the Port Geographe canal and residential development to translocate 50,000 cubic metres of sand from an area west of and immediately adjacent to the mouth of Wonnerup Inlet. It is expected this removal would affect an area some 600 m long and significantly alter the beach profile (Mark Close, Shire of Busselton, pers. comm.). The sand would be used to replace that lost to coastal erosion between groynes constructed further west. Under the EPBC Act, any such proposal must be referred to the Australian Government Environment Minister for approval.

Wonnerup Inlet and open sandbar (Google Earth, downloaded Nov. 2006).

5.2 Hydrological Regime

The seasonal shallow and partial drying of the estuary attracts waterbirds which feed on exposed mud flats and the spatial distribution of birds will change as waters retreat and more foraging areas are made available. Thus time taken for waters to retreat may influence number of birds that can be supported at any one time (see Priest *et al*. 2002).

In spring, estuary waters are regulated to achieve an optimum level of 0.4 m AHD in order to retain freshwater for as long as possible. This facilitates breeding of Black Swan (see also discussion on salinity in Section 5.4.3). Water levels need to be managed to provide freshwater for cygnets and to prevent water levels rising too high and flooding nests or falling too low and allowing foxes to access the nest mounds (Lane *et al.* 1997). Maintaining reasonably stable water levels during the nesting season is therefore seen as a priority. Levels slowly fall to around -0.1 m AHD in the Vasse Estuary and -0.4 m AHD in the Wonnerup Estuary with evaporative loss over summer-autumn. Prevention of rapid changes in water level in spring will also likely protect both fringing vegetation and submerged aquatic plants (*e.g.* seagrasses) from damage, either directly through excessive exposure/inundation or by altering potential cues for seed set. There has been no investigation of water level and duration of spring flooding needed to sustain plant communities. Similarly, the effects of winter-spring water levels and flows on life-cycles of fish and invertebrate within the estuary is unknown. High freshwater discharges are believed to be an important controlling factor in phytoplankton bloom dynamics. In the Swan River estuary for example, high winter-spring discharges and reduced residence times (~0.3 days) appear to control even the fastest growing phytoplankton taxa, breaking cells up and/or flushing them from the estuary before blooms can occur (Chan & Hamilton 2001). Under lower discharge, phytoplankton growth rate (cell multiplication) and water quality factors have more influence.

Since 1988, the Vasse-Wonnerup Estuary floodgates have been artificially opened for varying periods over summer-autumn in order to improve water quality, limit fish deaths and maintain a water level of -0.1 m AHD (refer Section 4.4.1). Ninox (1989) postulated that relatively rapid seawater inflow during at least one summer opening, may have been the cause of an apparent decline in bird numbers; *i.e.* 10,470 birds in February 1989, down from 26,000 birds three weeks earlier. However, no quantitative surveys were commissioned to investigate intra- and inter-annual variation and substantiate this theory. Past surveys indicate waterbird numbers are highest as waters recede over summer and autumn (Lane 1990). Lane *et al.* (1997) suggested increased summer-autumn water levels may directly affect bird communities by preventing access to and destroying food sources, of at least some species. Loss of fringing vegetation would reduce habitat for food, nesting and roosting. Lane *et al.* (1997) recommended regular quantitative surveys needed to be conducted to investigate the potential adverse effects of continued summer-autumn openings of the Vasse Estuary floodgates.

The hydrodynamics of the system, *i.e.* the relative contribution of surface, groundwater and tidal inflows, internal circulation and water depths will ultimately determine water quality to a large extent. The fact that the wetlands are surface expressions of the underlying groundwater table means they are particularly vulnerable to the effects of dissolved nutrients moving through the sandy soils of the catchment (refer McComb & Davis 1993). The predictive modelling by DoW, under the Vasse-Geographe CCI Water Quality Improvement Plan, will begin by developing a hydrodynamic model of water depth, volume and discharge (Christian Zammit, DoW, pers. comm.; refer Section 4.3). Effect of climate change will also be incorporated. This will then be used for the next phase in modelling nutrient and salinity dynamics. Finally temperature variables and wind circulation will be added.

5.3 Circulation Process

Water circulation within the wide, shallow Vasse-Wonnerup Estuary is driven primarily by wind and secondarily by freshwater inflow in winter and tidal movements when the floodgates are open in summer-autumn. Salinity/density gradients across salt-freshwater interfaces will also contribute to a lesser degree. These gradients occur because saline waters are denser and sink below freshwater layers as seawater enters into the estuary. Vertical mixing across these gradients (haloclines) is restricted and can lead to hypoxic or anoxic conditions if exchange of DO between aerated surface waters and depleted bottom waters, is halted. In waters that are not well mixed there can be large variations in water quality, both vertically and horizontally. Circulation is important for resuspension and effective transport and recycling of nutrients and carbon between zones of high and low productivity. It increases availability of bottom water nutrients that would otherwise be inaccessible due to stratification. Reductions in river discharge and marine water inflow will reduce circulation as well as flushing. A layer of salt water appears to be occasionally maintained in winter in the Vasse-Wonnerup Estuary exit channels immediately upstream of the floodgates (Paice 2001). Duration of the halocline is not known, but circulation would seem inadequate for effective mixing in these deeper channels. Anoxic conditions have been reported to accompany halocline formation (Paice 2001). A permanent salt layer of anoxic water would be expected to increase sediment nutrient input and ultimately algal blooms.

5.4 Energy and Nutrient Dynamics

Energy and nutrient dynamics within the Site have not been studied. Knowledge of general interactions between carbon, nutrients, dissolved oxygen, sulphate, iron and temperature are described below, including water-sediment interactions and desorption/adsorption of nutrients. The role of these physico-chemical processes in structuring plant and animal communities is also discussed.

5.4.1 Nutrients

To some degree, the Vasse-Wonnerup Estuary would have undergone natural nutrient-enrichment and eutrophication due to geomorphologic processes, low hydrodynamic energy and accumulation of suspended and deposited organic materials. Nutrient enrichment can be beneficial, leading to increased primary productivity (algae & seagrasses) and associated increases in abundance of invertebrates, fish and waterbirds (McComb & Davis 1993. However, excessive nutrient loadings (either external or internal) can have detrimental effects on ecosystem functioning resulting in persistent, severe toxic phytoplankton blooms, proliferation of opportunistic macroalgae (*e.g.* *Ulva*, *Chaetomorpha*, *Rhizoclonium*, *Cladophora*) loss of vascular plants, turbid and foul smelling (mephitic) water, oxygen depletion and associated mass mortality of animals (de Jong *et al.* 2002). The chronic direct effects of medium to high nutrient loads on waterbirds, fish and invertebrates in the Vasse-Wonnerup Site are unknown. Ammonia and nitrite are both known to be acutely toxic to fish. Even nitrate is toxic at very high concentration.

To protect aquatic ecosystems from N-toxicity, ANZECC/ARMCANZ (2001) recommend maximum trigger values of:

	Freshwaters	Marine water
NH_3	< 2.3 mg/L	< 1.7 mg/L
NO_2	none	none
NO_3	< 0.7 mg/L	< 0.7 mg/L
PO_4	none	none

Nutrient enriched water bodies typically harbour significant stores of nitrogen (N) and phosphorus (P) within organic matter in sediments and additionally, adsorbed to suspended particulate materials. The bioavailability (whether they have the potential for biological use) of these stores depends on complex interrelationships with the overall water chemistry of the water body. For example, certain forms of nutrient (mostly phosphate and ammonia) are released under anoxic conditions and re-circulated to the water column. In the Vasse-Wonnerup, this most likely occurs over summer in shallow mixed waters of the lagoons, but could also occur in winter following the breakdown of seasonal haloclines (salinity stratification) near the floodgates. In other south-west wetlands, seasonal drying of sediments over summer-autumn can also result in increased P release on re-flooding. This is thought to result in significant increase of internal P loading under both aerobic and anaerobic conditions (refer Qui & McComb 1994). In the Vasse-Wonnerup Estuary, the relative contribution of the various point and diffuse sources is unknown, but accumulation of leached N and P in the estuary sediments is believed a major contributor to the eutrophication (McAlpine *et al.* 1989, Innes Zagoui, DoW, pers. comm. 2007). Cycles of phytoplankton blooms and decay will also contribute significantly to internal loadings of bioavailable nutrients. Vast numbers of invertebrate consumers (*e.g.* zooplankton and amphipods) often accompany increased plant biomass and these may also contribute to internal loadings.

Factors that determine effects of nutrient enrichment include turnover time (*i.e.* residence time, flushing rate & sand bar closure), wind circulation of estuary waters, proportion of high/low energy areas (determined by geomorphology) which in turn affect sediment-water interrelationships and biogeochemical processes (N, P, carbon, silica cycling/dynamics) and carrying capacity for fishes and birds (nursery, migration and feeding). The relative availability of both N and P determines productivity as both nutrients are required for plant growth. Even under high N loading, increased algal and macrophyte growth will not occur if P is limiting. Even then, productivity will be determined by the bioavailability of N and P which depends on forms, fluxes and transformations within the wetland (Harris 2001). Types of N and P that occur in waterbodies are (OzEstuaries 2007):

- Inorganic N - comprising oxidised species (nitrate NO_3 and nitrite NO_2) and reduced species (ammonium NH_4, ammonia NH_3) and nitrogen gas (N_2);
- Dissolved inorganic N (DIN) - consists of NO_3, NO_2 and NH_4;
- Dissolved organic N - which occurs as complexes within amino acids, proteins, urea and humic acids;
- Particulate nitrogen - found in plants and animals and ammonia adsorbed onto sediment;
- Dissolved inorganic P (DIP) - orthophosphate (HPO_4, PO_4 forms); measured as filterable reactive phosphorus (FRP);
- Dissolved organic P (DOP) - organic compounds that contain P;
- Particulate P – found in plants and animals, in minerals and adsorbed onto iron compounds (oxyhydroxides) in sediments.

The most common biologically available forms of N and P are nitrates (NO_3), ammonia (NH_4) and ortho-phosphates (PO_4). Estuary sediments and their micro-organisms play an important role in the cycle of energy (carbon) and nutrients through aquatic food webs. Decomposition of organic matter by soil microbes (mineralisation) releases nutrients and carbon into the water column in the form of DIN, DON, DIP, DOP, dissolved organic carbon (DOC) and CO_2 gas. The three major nutrient recycling processes involve N (BRMB 1998):

i). ammonification - breakdown of NH_3 in organic compounds to form ammonia (NH_4),

ii). nitrification - oxidation of NH_4 to NO_3, and

iii). denitrification - microbial conversion of NO_3 to NO_2 and then to nitrous oxides (NO, N_2O) and finally nitrogen gas (N_2); particularly important as it removes bioavailable N from the system. The NO_3 used in this process comes from either dissolved NO_3 in water column or from the nitrification process.

All these processes are influenced by dissolved oxygen concentration, temperature and pH. Rates of mineralisation typically decrease as temperature, DO and pH decrease. Rate of NH_3 conversion to NH_4 increases as pH shifts from alkaline (> 7.0) to acidic (< 7.0). This process has biological implications for aquatic fauna (macroinvertebrates & fish), as ammonium is not considered harmful but conversely ammonia is acutely toxic at relatively low concentrations. Denitrification is also of importance as it can significantly reduce eutrophication by reducing the bioavailable pool of NO_3 (Harris 2001), however it is also recognised as a source of ozone depleting N_xO_x gases and a contributing agent to global warming (Verhoeven *et al.* 2006) (see also Section 3, above). Zones of deposited muds and fine silts typically display high rates of denitrification as they contain greater quantities of organic matter and hence have higher rates of microbial decomposition. Denitrification is typically enhanced by long water residence times (see Figure 9) and by the presence of abundant emergent and submerged vegetation whose roots and stems provide large surface areas of biofilms that are key sites of microbial activity (Palmer *et al.* 2000, Harris 2001).

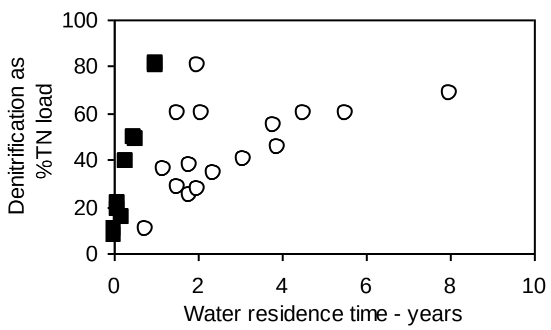


Figure 9. Relationship between water residence time and denitrification efficiency in eastern Australian estuaries and lakes; ■ estuaries, ○ lakes (reproduced from Harris 2001).

The ratio of $N_2O:N_2$ produced in wetlands will be higher under conditions that are sub-optimal for denitrification; *i.e.* where the reduction of nitrate to N_2 is incomplete. However, significantly higher N_2O:N2 ratios have also been recorded in overseas wetlands with high nitrate loads (Verhoeven *et al.* 2006). Denitrification will also be inhibited if organic matter and carbon loads increase beyond a critical amount. Rates will continue to decrease as the estuary moves from eutrophic to hyper-eutrophic and more and more nitrogen is recycled in bioavailable forms (such as ammonium). This is due to more hypoxic-anoxic events associated with increased productivity, decomposition and DO consumption. Though denitrifying microbes are anaerobic they use NO_3 produced from aerobic nitrification processes.

Hydrogen sulphide gas (rotten egg gas H_2S) produced by anaerobic sulphate-reducing bacteria, also reduces denitrification efficiency. This gas is acutely toxic to many aquatic organisms. Chronic exposure at low concentrations can cause illness in people and can be lethal at higher concentrations (Hicks & Lamontagne 2006). Other pungent sulphur gases released from wetlands include sulphur dioxide (SO_2) and volatile organic sulphur compounds (VOSC). Chronic exposure to SO_2 is also harmful and while there have been no measurements the types of VOSC compounds emitted from Australian wetlands, overseas studies indicate many are toxic (Hicks & Lamontagne 2006). Increased foul odour is often associated with drying wetland sediments. Factors controlling the rates of emission are believed to include sediment texture, organic matter content, sulfide content, water content, salinity, pH, time of day and temperature (Hicks & Lamontagne 2006). Bioavailable NH_4 is also released during sulphate reduction.

TP is usually correlated with iron (Fe) concentrations as most P is bound up in insoluble Fe-P complexes such as iron oxyhydroxides (Harris 2001). High concentrations of P in the water column will occur when loadings exceed the rate at which plants can take it up or particulates in soils and water column can adsorb it. P release can occur when iron oxyhydroxides are converted to iron sulfides during sulfate reduction. Cycles of wetting and drying of sediments also lead to increased P release. This is probably due to both accumulation of soluble inorganic P caused by breakdown of organic material during the drying phase and a decrease in phosphate sorption (Qui & McComb 1994).

Sustained TP concentrations > 0.05 mg/L (50 μg/L) in the water column are known to promote a switch from clear water-macrophyte (*e.g.* seagrass, ribbongrass) dominated communities to turbid-phytoplankton dominated ones (Sheffer 1990, Novak & Chambers 2005). Turbidity is caused by the amount of particulate matter in the water column (including phytoplankton) which is also associated with nutrient load. Harris (2001) similarly calculated that in estuaries where agricultural TP loads are very high, TN loads greater than 1.6 tonnes/km²/year will release N limitation and result in saturation of primary production, leading to abundant algal blooms and loss of seagrasses (Figure 10). In the northern hemisphere, research conducted on a large number of wetlands in temperate zones has lead to the proposal of critical loading rates of 2.5 tonnes TN/ km²/year and 1 tonne TP/ km²/year (Verhoeven *et al.* 2006). These critical loads are defined as the loading rate above which the system displays "sudden, drastic changes, including a shift in species dominance and species composition and a major change in ecosystem functioning, in terms of carbon and nutrient outputs, trophic interactions and/or nutrient cycling rates". A more conservative threshold, such as the 1.6 tonnes TN/km²/year proposed by Harris (2001) is perhaps more applicable to estuaries of the south-west, whose ecosystems are most likely pre-adapted to nutrient-poor soils. Based on DoE (2004a) figures for total catchment export to the estuaries, loadings to the Vasse-Wonnerup Site (1,115 ha) were estimated to be ca. 19 tonnes TN/km²/year and 1.3 tonnes TP/km²/year.

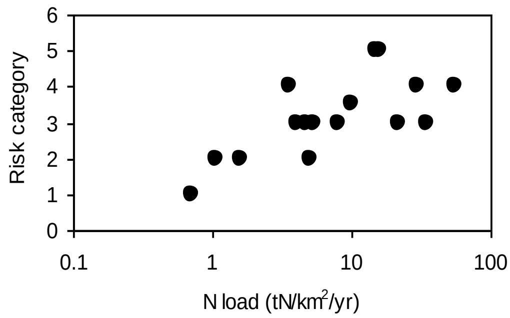


Figure 10. Harris (2001) risk assessment of NSW coastal lagoons, where 1 = pristine and 6 = severely impacted by eutrophication.

Progressive eutrophication of estuaries can result in the inhibition of nitrification and thus decreased denitrification, giving rise to large internal loads of ammonia which are believed a significant factor in the switch in stable state from macrophyte to phytoplankton-dominated (OzEstuaries 2007). At a critical nutrient load, phytoplankton and/or other algae concentration is so dense that it prevents enough light reaching vascular macrophyte beds. The vascular macrophyte population collapses, fuelling further phytoplankton growth and a change in state with "blooms of one or two micro and macroalgal species affecting the integrity of the system" (WRC, River Science, Issue 3, 2005). This change is often abrupt and shows strong hysteresis, that is, it is highly resistant to switching back even if nutrients are reduced below the critical load (Sheffer 1990, Harris 2001, Morris *et al.* 2003). The recent anecdotal reports of increasing macroalgal blooms in both estuaries and of blue-green blooms in the Wonnerup estuary are of concern as, if correct, may signal a trend toward a shift in stable state.

Unlike most algae, blooms of the toxic cyanobacterium *Lyngbya* do not appear to be directly linked to elevated N and P. General literature and studies of *Lyngbya majuscula* in Moreton Bay, Qld, indicate elevated levels of bioavailable Fe as well as P are needed to stimulate growth in this species (Ahern 2006) (refer also Figure 15 in Section 7.2). Increased Fe is often associated with acid sulphate soil drainage or from disturbed areas, and to a lesser degree from groundwaters in contact with coffee rock. The fact that Wilson *et al.* (2007) noted largest blooms of *Lyngbya* in the vicinity of the Port Geographe development warrants further investigation to determine if the development is contributing to bloom formation of *Lyngbya* species in the Vasse-Wonnerup.

The Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University is already investigating top down approaches to conceptual models of nutrient dynamics in the lower Vasse River. The aim is to determine predictors of macrophyte/phytoplankton succession with the focus on nutrients. GeoCatch, in partnership with DEC, also contracted MAFRL to conduct a one-off investigation into seagrasses and macroalgae in the Vasse-Wonnerup Estuary with the aid of SWCC funding (refer Section 4.9). DEC and GeoCatch hope that this investigation will be repeated/expanded subject to further funding. This would also offer a good opportunity to expand the conceptual models to include the estuary.

5.4.2 Dissolved Oxygen

Nutrient enrichment together with a highly regulated hydrological regime has resulted in increased primary productivity within the Vasse-Wonnerup wetlands. This in turn has likely lead to increased aquatic invertebrate abundance and provided food resources to support large fish and waterbird populations. However, continued nutrient input from the surrounding catchment has fuelled frequent, large phytoplankton blooms which deplete dissolved oxygen during night-time respiration. Bloom collapse and subsequent microbial decomposition leads to low day-night DO levels, often lethal to fish and most likely zooplankton and many benthic invertebrates. Very high DO can be as much a problem for fish as very low DO. Supersaturated DO concentrations (*i.e.* >100%) can cause the formation of gas bubbles inside blood vessels (gas embolism) leading to the death of fish. The tiny air bubbles released by phytoplankton (particularly during algal blooms) are believed most problematic to fish, rather than larger bubbles released by macrophytes.

Most of the sudden mass fish deaths recorded between 1905 and 2003, have occurred in the Vasse Estuary exit channel (upstream of the floodgates) or in Wonnerup Inlet (between the floodgates and the sand bar) with only infrequent occurrences in the Wonnerup estuary and The Deadwater (Lane *et al.* 1997, White 1999). While the floodgates, which were installed in 1908, are not the cause, they have contributed (till 2003) to an increased frequency in sudden mass fish deaths. The deaths are believed mostly due to night-time anoxia associated with algal blooms and possibly toxins released by decaying algae and macrophytes (Lane *et al.* 1997). High day-time temperatures in the shallow, unshaded waters of the exit channels and Inlet are thought to contribute to fish deaths. Thousands of fish have died during single events. Only a few of the sudden mass death events appear to have been associated with reduced salinities following high rainfall (Paice 2001). However, there has been no detailed quantitative study of environmental conditions or types of algal species present at the time of events.

Dissolved oxygen levels are influenced by temperature, pH and salinity which affect the solubility of oxygen in water. For example, solubility is typically greater in cold, saline water than in fresh, warm waters. Temperature, pH and salinity also have a direct effect on algal (and macrophyte) growth and productivity, as do turbidity and light penetration. Dissolved oxygen is typically expressed in terms of concentration (mg/L or ppm) or percent saturation (%). Percent saturation is independent of temperature and salinity, making it a useful measure if comparing between greatly varying waterbodies. In order to protect aquatic biota, previous ANZECC guidelines recommended day-night DO levels should not be permitted to fall below 60% saturation. Current more conservative trigger values[11] are given for day-time only with a minimum of 80 - 90% saturation and maximum of 110 - 120% (ANZECC/ARMCANZ 2000).

Hypoxia and anoxia not only causes the localized extinction of fauna, but also results in desorption (release) of nutrients (*e.g.* P & NH_4) and heavy metals (*e.g.* from fertilizers) from sediments causing further water quality problems. Mobilisation of nutrients from the sediment (particularly phosphorous) contributes to successive algal blooms. In well-aerated waters, many metals readily adsorb (bond) to suspended matter (*e.g.* clay or organic particles suspended in the water column) and to river bed substrates, thereby reducing their bioavailability. Under conditions of low or zero DO, heavy metals and nutrients are released from the sediments into the water column. The toxicity of many compounds such as copper, lead, zinc, cyanide and ammonia is thereby increased

[11] ANZECC/ARMCANZ (2000) trigger values are an interim guideline to be used in the absence of site-specific guidelines. Site specific guidelines for seasonal maxima and minima should be developed from the 20th and 80th percentiles of data collected over a minimum 2 year period. This should also incorporate day-night (24 hour) variation in DO levels.

as they become increasingly biologically available. Acute toxicity of many metals doubles as DO levels decrease from 10 mg/L to 5 mg/L (ANZECC/ARMCANZ 2000). The pH, dissolved organic carbon (DOC) and suspended particulate matter have a major influence on the bioavailability of heavy metals (ANZECC/ ARMCANZ 2000).

5.4.3 Salinity

Salinity regimes within the site are highly regulated by floodgate operation, diversion of tributary rivers and by natural sand bar formation at the mouth of the estuary which reduces tidal influence. Most species that inhabit estuaries are either tolerant of a wide range of salinities or show behavioural avoidance, inhabiting only those zones where salinities are optimal. Salinity tolerance can also vary with life history phase and for those species, breeding and migration cycles coincide with seasonal changes in salinity regime. Many juvenile waterfowl (swans and ducks) for example, cannot osmoregulate saline waters and need fresh water to survive. Goodsell (1990) studied distribution of broods of 39 species of waterbird across 121 south-west wetlands and found proximity to freshwater sources such as farm dams and tributary rivers appeared equally important as salinity level within the wetland. Ninety percent of all broods occurred in waters with salinity < 15,300 mg/L TDS (Goodsell 1990). Though adult waterfowl may be more salt tolerant than their chicks, many species still need to drink fresh water regularly when feeding at saline sites (*e.g.* Pacific Black Duck, Blue-billed Duck, Hardheads). For other birds the influence of salinity on vegetation that provides nesting sites may be more important (*e.g.* cormorants, darters, Yellow-billed Spoonbill, the great egrets, herons & ibis).

Salinity will also affect the type and abundance of zooplankton and benthic invertebrates that form a large part of the diet of many waterbirds and of many fishes. In general, as salinity increases from fresh through saline to hypersaline, invertebrate community composition will change with "the steady substitute of salt sensitive taxa by opportunistic and salt tolerant taxa" (Horrigan *et al.* 2005). In brackish waters community composition is changed, but species richness may remain more or less the same. While in saline to hypersaline waters, macroinvertebrate communities tend to be dominated by fewer species but much greater abundances.

Estuarine fish are tolerant of a wide range of salinities from fresh to hypersaline but typically cannot tolerate salinities > 60,000 mg/L TDS (Geddes 2000, Boon 2000). In the Vasse Estuary, black bream, show a preference for the less saline mid and upper sections (Lane *et al.* 1997) and in other south-west estuaries sea mullet and yellow-eye mullet show a similar preference (Potter & Hyndes 1994). The link between salinity and habitat preferences has not been investigated for populations of these species in the south-west and preference may in fact be for other riverine characteristics (Potter & Hyndes 1994). Reduced salinities over winter-spring however, are a known cue for many estuarine fishes to spawn and for migration of marine species into and out of estuaries (Young & Potter 2003a,b). Other south-west estuaries that are permanently open to the sea tend to have greater abundance and diversity of marine fishes than do those that are seasonally open. Salinity is believed a major factor influencing the distribution of marine teleosts in estuaries (Weinstein *et al.* 1980; Allen 1982). In the Peel Inlet, Loneragan *et al.* (1986) considered differences between the fish fauna of the Inlet and its tributary rivers were related to differences in salinity regime. Loneragan *et al.* (1986) suggested conditions conducive for marine fishes to spend protracted periods in estuaries were year round salinities of > 15,000 mg/L TDS, small tidal action and wide basins that offer protection from flushing effects of freshwater discharge. By contrast riverine fish communities were subjected to much more variable and lower minimum salinities (Loneragan *et al.* 1986). Most adult freshwater fishes of the south-west cannot tolerate salinities > 8,000 - 10,000 mg/L (Boon 2000). Tolerances of juvenile fish are not known.

Salinity also strongly influences the structure of aquatic and fringing plant communities and recruitment success. Growth of freshwater macrophytes such as *Vallisneria* is restricted to lower salinity tributary rivers. In the Vasse-Wonnerup Estuary and lower Vasse River, the spring-autumn blooms are caused by a succession of different types of phytoplankton and macroalgae determined by changes in salinity as well as nutrient cycling. The species involved in successional dynamics have not been identified. In other estuaries, fast growing chlorophytes (green algae) dominate spring blooms when salinity is low. As spring progresses into summer, calmer conditions, long days and higher water temperatures favour slower-growing cyanobacterial (blue-green) blooms. Cyanobacteria are not tolerant of high salinities and are replaced by diatom blooms over summer-autumn. Small diatom blooms may also occur in brackish waters during spring if silica and nutrient concentrations are high from rainfall run-off (WRC, River Science Issue 3, 2005). Diatoms require silica in order to build their cell walls.

While most estuarine inhabitants are adapted to fluctuating salinity, there is little published information on the sensitivity of Western Australian organisms to rapid unseasonal fluctuations and few studies on sub-lethal or long-term effects on more sensitive life stages. As noted above, a few of the sudden mass death events that have occurred in the Vasse-Wonnerup appear to have been associated with reduced salinities following high rainfall (Paice 2001). Rapid salinity fluctuations have also been linked to declines in some *Ruppia* communities overseas. Verhoeven (1979) found salinity increases of 18,000 mg/L over a period of less than a month resulted in high mortality in most European *Ruppia* species. In Western Australia *Ruppia megacarpa* has been recorded from some saline lakes with salinities up to 210,000 mg/L. However, growth and reproductive success is likely to be limited at high salinity > 50,000 mg/L (Nicol 2005).

Froend *et al.* (2000) found fringing wetland vegetation of the Vasse Estuary to be adversely affected by salinisation, as well as physical disturbance in the form trampling and removal by humans and stock. Spot measurements revealed elevated soil conductivities, which were considered the result of the influx of seawater caused by prolonged summer-autumn openings of the floodgates post-1988. Effects of seawater were most obvious in paperbarks and eucalypts where significant proportions of the local population had died or showed reduced crown vigour. Samphire also appeared to be spreading to higher elevations.

5.4.4 Turbidity

There is little long term data on water clarity, turbidity or levels of total suspended solids in the Ramsar Site. Under natural conditions, turbidity would be expected to be low, as low wave energy would limit re-suspension of deposited sediments and organics except during winter storms and/or periods of high river discharge. Anecdotal evidence suggests that water clarity and water depths in the estuary and tributary rivers have declined over the past 40 - 50 years. This is possible due to increased sediment and organic loads in winter and wind re-suspension of particulates across the shallow estuary at other times of year. Phytoplankton blooms will contribute to turbidity and reduced water clarity.

Because turbidity limits light penetration it has a controlling effect on vascular macrophytes. Many species of alga (*e.g.* cyanobacteria) are able to control their buoyancy and remain near the surface where light penetration is greatest (Barsanti & Gualtieri 2006). Such species have a competitive advantage in turbid waters. Wilson *et al.* (2007) commented that even in the relatively shallow waters of the Vasse-Wonnerup estuary, there appeared to be an association between depth and water quality and macrophyte species dominance with little or no seagrass occurring in deeper (~1 m) waters immediately upstream of the floodgates or in the narrow channels that criss-cross the main basins. Research on other Australian estuaries suggests water transparency depths of no less than 90 cm are needed to maintain healthy *Ruppia megacarpa* communities (Phillips & Muller 2006). Overseas, most species of *Ruppia* appear reduced or absent in water with sustained Secchi depth < 1m and/or TSS >55 mg/L and turbidities > 60 NTU (Kantrude 1991). In the Peel-Harvey Estuary, a change in species dominance has been recorded over the years. Increased turbidity and deteriorating light conditions have favoured *Chaetomorpha* and *Ulva* over certain *Cladophora* species, and *Ruppia megacarpa* has all but been replaced by macroalgae (McComb & Davis 1993).

Wind induced turbidity can also affect growth and distribution in shallow estuaries. Many species of phytoplankton and macrophyte will naturally die off over winter when river flows, water depths and turbidity are high and light penetration and temperature low. Growth will re-commence in spring and summer depending on nutrient availability.

Current ANZECC/ARMCANZ (2000) guidelines acknowledge that natural turbidity and TSS is highly variable and dependent on geomorphology, soils and seasonal rainfall runoff. Once baseline data are available, then area-specific triggers should be developed for each 'season' (*e.g.* winter-spring and summer-autumn) using 80th percentile (80%ile) values. In this case, ANZECC/ARMCANZ (2000) recommend that data collected under high flow conditions or during periods of inflow to the receiving environment, should be used to develop the trigger(s). Median turbidity concentrations monitored under high flow conditions should be used to monitor any departures from trigger values.

5.5 Processes Maintaining Plant and Animal Populations

5.5.1 Fish Migration and Reproduction

Fish migration and breeding within the Vasse-Wonnerup Site has not been researched (refer Section 4.13). Of species known to currently occur, only estuarine black bream and marine sea mullet and whitebait are likely dependent on the Site for breeding (refer Section 4.13.2). Black bream are believed to spawn in spring and summer when freshwater discharge into the Vasse-Wonnerup is at its lowest (Lane *et al.* 1997). They breed in reaches away from the estuary mouth. Cues for spawning, and breeding area preferences of sea mullet and whitebait are unknown. Hydrological regimes that maintain brackish waters coupled with availability of aquatic plants for food and shelter are likely important to preserve populations of these fishes within the Site.

Diversity of fishes within the Site is however dependent on maintenance of connectivity with the ocean. Available data indicates the fish community to be dominated by marine species that spawn at sea but enter the estuary for food and shelter, likely remaining for protracted periods. The effect that loss of fish diversity would have on waterbird diversity is not known. Fish-eating waterbirds that require sheltered habitat for feeding would presumably be at most risk.

5.5.2 Waterbird Migration and Reproduction

There are 21 Australian resident waterbird species known to breed at the Site and 17 transequatorial migrants that regularly use the Site as a spring-summer feeding area (refer Section 4.14). These migratory species travel thousands of kilometres from breeding areas in the northern hemisphere (some as far as eastern Siberia) to spring-summer feeding areas in Australia and New Zealand. Shorebirds visiting the Vasse-Wonnerup Site rely on the good feeding conditions (abundant invertebrates) and safe roosting sites prior to their return migration. Typically the adults arrive at Australian sites between June and October, while their offspring from the previous breeding season arrive some two months later (Priest *et al.* 2002). The adults start their return northward migration the following March - June, but the young birds may remain in Australia for two to four years depending on the species.

Waterbird abundance and species richness in the Vasse-Wonnerup Site naturally fluctuates due to seasonal and environmental events and (likely) to human pressure. Responses may be in relation to changes in local, regional or overseas conditions, or to all three. Resident Australian species may also move out of the area in response to rainfall inundation of other regional waterbodies. This can result in large year-to-year variations in numbers as bird populations spread out to take advantage of increased food and habitat availability (Halse *et al.* 1992; Halse *et al.* 1995).

The Site supports the largest known regular breeding colony of Black Swan in the State. Waterbirds breed in south-western Australia mostly during spring and early summer when there is abundant freshwater and warmer temperatures to promote growth of aquatic plants, invertebrates and fish (Lane & Munro 1983). High rainfall years typically show greater breeding rates. Nest construction and egg laying commence in early June and continue to November/December. For most species, peak nesting occurs during August/September with the majority of broods recorded from September to November. Most birds have fledged by January, thus waterbird numbers typically peak early in the new year (Lane & Munro 1983). Ecosystem components and processes important to waterbird breeding success have been discussed in previous sections, they include freshwater flows and suitable nesting (*e.g.* samphire heathlands, fringing trees) and foraging sites (*e.g. Ruppia* beds) (see also Appendix F).

Detailed surveys of waterbird breeding behaviour at the Site have only been conducted on Black Swans, but even these did not record breeding and recruitment success or correlated factors. Swan numbers typically begin to increase around May-June when first rains provide suitable habitat (Tingay *et al.* 1977). The preceding year's rainfall also likely affects habitat availability. Nesting commences in June and both colonial and solitary nest mounds are established. Water depth appears to be an important factor in nest site selection with maximum depths at the base of mounds ≤ 0.4 m. Water levels that rise too early may flood nests, while rapidly dropping levels may interfere with breeding behaviour and food resources. In the nearby Broadwater, Tingay *et al.* (1977) observed that clearing or damage by stock can limit the amount of nesting material available for swans, particularly during flood years. Limited material means swans are not able to raise their nest mounds above high-water level. These observations have relevance for floodgate operation and flood control in the Vasse-Wonnerup Ramsar Site. Cygnets hatch during August and September and colonial-nesting birds remain on the nest for only about two days after hatching. Birds that build solitary nests will defend a relatively large territory and continue to use their mounds as resting sites for the remainder of the season (Tingay *et al.* 1977). Most young are fully fledged by late November-December when the estuaries, and in particular 'Swan Lake', begin to dry up.

5.6 Species Interactions

5.6.1 Phytoplankton – Macrophyte Interactions

Wilson *et al.* 2007 has recommended baseline research into phytoplankton-macrophyte interactions within the Vasse-Wonnerup Estuary, similar to work already commenced for the tributary lower Vasse River. In general, algae are important for oxygenation and nutrient cycling in the water column and in supporting aquatic food webs, providing organic matter (carbon) at the base of the food chain (WRC, River Science Issue 3 2005). Spring blooms are a natural occurrence in estuaries and offer a significant food resource for waterbirds, fish and invertebrates (Carstensen *et al.* 2007). Vascular macrophytes too play an important role in providing food sources and sheltered habitat for fauna, supporting denitrifying biofilms, stabilising soils and recycling nutrients between water column and sediments. Actively growing vascular macrophytes and macroalgae can limit phytoplankton growth by shading and competition for soil and water column nutrients (WRC, River Science Issue 9 2002). In Wilson Inlet, studies by Dudley and Walker (2000) found *Ruppia megacarpa* was integral to the natural control of phytoplankton blooms. *Ruppia* competes directly with phytoplankton by its ability to take up water column nutrients through its leaves. It also competes indirectly by providing a substratum for the growth of epiphytic plants which take up water column nutrients.

However, decay of macrophyte/macroalgal can also fuel phytoplankton blooms through release of nutrients. Large biomass of micro- and macroalgal blooms competes with vascular macrophytes for light and nutrients. Drifts or banks of floating algae together with prolific growth of epiphytic algae may physically smother seagrasses and fringing saltmarsh plants. In shallow estuaries, wind-induced suspension may bring benthic microalgae to the surface adding to 'phytoplankton' blooms (McComb & Davis 1993).

As inflow of DIN decreases with decreasing river flow over spring, denitrification and rapid uptake by phytoplankton, macroalgae and vascular macrophytes can lower N:P ratios in the water column and nitrogen becomes limiting for plant growth. Under these conditions there is an increased risk of potentially toxic cyanobacterial blooms which fix nitrogen. Bloom growth is eventually limited when demand for P or C (for example) cannot be met by availability (WRC, River Science Issue 9 2002). As these blooms breakdown, they release bioavailable N triggering a succession of micro- and macroalgal blooms. The blooms are typically dominated by one or two species dependent on salinity, temperature, light and flow conditions. Phytoplankton have the ability to take up and accumulate nutrients (*i.e.* 'luxury uptake') for later use when nutrient water column levels are reduced or when growing conditions are more favourable (McComb & Davis 1993).

5.6.2 Plant – Fauna Interactions

Plant-fauna interactions in the Vasse-Wonnerup Site have not been investigated. In other south-west estuaries, large increases in zooplankton and amphipods often accompany increased blooms of planktonic algae and diatoms in south-west estuaries (McComb & Davis 1993). Zooplankton in particular are believed an important factor controlling bloom size (WRC, River Science Issue 3 2005). Macrophytes can indirectly suppress phytoplankton growth by providing habitat for zooplankton and benthic invertebrates which feed on phytoplankton. In turn, high zooplankton and macroinvertebrate biomass feeds many fish and waterbird species. In the Vasse-Wonnerup, high invertebrate populations, including larvae of nuisance midges, are believed the result of high nutrient status (EPA 1989b, Davis 1989) and give the estuary system its high waterbird carrying capacity (EPA 1989b). The EPA has previously stated that "in so far as a high value is placed on the estuary as a waterbird habitat, the Authority and the Department of Conservation and Land management (now DEC) both consider high midge populations as an essential characteristic of the Vasse-Wonnerup estuary environment" (EPA 1989b).

Fish too are an important food source for predatory fishes and some water birds. The relative contribution of the various fish and invertebrate species to waterbird diet in the Vasse-Wonnerup is not known (refer Section 4.14.2). Preferences of waterbirds are likely to change with life history stage as nutrition and calorie requirements vary, *e.g.* breeding versus non-breeding birds and adults versus juveniles and chicks.

Invertebrates and fish play a critical role in the re-cycling of nutrients and carbon through aquatic food-webs. In the lower Vasse River, populations of introduced Goldfish population are considered likely to contribute to algal blooms through feeding behaviour and stimulation of algae in passage through their digestive systems (Morgan & Beatty 2004).

Low dissolved oxygen levels and toxins associated with algal blooms cause the death of fish and invertebrates (particularly larger predatory macroinvertebrates). Loss of predators and related change in proportions of invertebrate functional feeding groups disrupts food chains and can lead to increases in nuisance species such as midges. Detritus from decaying blooms also provides an abundant food supply for midge larvae and for amphipods, which in turn add to detrital loads once dead. Algal blooms may physically interfere with waterbird feeding and foraging. In the Vasse-Wonnerup during 1981 - 1982, Jaensch *et al.* (1988) noted mudflats and shallows normally used for feeding by thousands of waders were sometimes covered by (extensive) algal mats.

High levels of decomposing organic matter (and decomposing carcasses) coupled with hypoxia/anoxia and warm water temperatures provide suitable conditions for outbreaks of botulism in waterbirds. Botulism is a disease caused by the neurotoxin botulinum produced by actively growing *Clostridium botulinum* bacteria. It is most prevalent during warmer months and frequently fatal. Birds ingest the bacterium while feeding, become paralysed, cannot fly and often drown. Many different species of waterbird are susceptible through accidental ingestion of contaminated plant material, filtering muds (often a favoured habitat of the bacterium) or eating fish or fly maggots that have fed on contaminated detritus. Some overseas studies indicate salinity to be a controlling factor with maximum growth of the bacterium occurring at ca. 20,000 - 30,000 mg/L TDS (USGS 2002). However this is yet to be conclusively demonstrated. Though there are no documented reports or suspected occurrences of botulism in the Vasse-Wonnerup Site, it is a common feature of shallow wetlands in the State's urban areas over summer (McComb & Davis 1993).

Macrophytes form a large part of the diet of some fish and waterbird species. Diet of Black Bream generally is known to include *Cladophora*, *Chaetomorpha* and *Ruppia megacarpa* as well as macroinvertebrates (amphipods, polychaete worms, bivalves, crabs) and small fish (Sarre *et al.* 2000). In the Peel-Harvey Estuary, decline in macroalgal abundance following the Dawesville Cut has been linked with declines in commercial fish stocks of Yellow-eye Mullet, Sea Mullet and Catfish (*Cnidoglanis macrocephalus*). Though this is believed principally due to loss of sheltering habitat which protected juvenile fish from predation (Young & Potter 2003). *Ruppia* is a favoured food of swans and cygnets in the Vasse-Wonnerup Estuary (Tingay *et al.* 1977, Jim Lane, DEC, pers. obs.). On the other hand, Tingay *et al.* (1977) concluded that nesting swans in the Vasse-Wonnerup appeared to have a food preference for inundated pasture grasses such as *Paspalum*. In other Australian estuaries *Ruppia* is also eaten by ducks, plovers, sandpipers, stints, stilts and avocets, while *Lepilaena* and *Vallisneria* are also eaten by swans and ducks (Brearley 2005, Phillips & Muller 2006). If persistent algal blooms lead to a significant loss of such macrophytes in the Vasse-Wonnerup it would most likely result in substantial declines in waterfowl numbers.

Studies overseas also indicate large populations of migratory waterbirds can play a significant role in nutrient fluxes in many wetlands and lagoons (Tamisier & Boudouresque 1994). They add to nutrient loads through their excrement but can also remove nutrients by eating vast quantities of macrophytes, plankton and macroinvertebrates and then migrating from the site. Thus waterbirds may actually prevent eutrophication, even in wetlands that are somewhat nutrient-enriched, if they can fully exploit the aquatic plant biomass.

Though much of the fringing wetland vegetation of the Vasse-Wonnerup Site has been cleared, emergent sedges and reeds, samphire heath and remnant trees provide nesting and roosting habitat for waterbirds. Samphire provides important nesting material for swans (in 'Swan Lake') and when inundated may also offer nursery habitat for fish. Shorebirds may roost in samphire or behind low shrubs, or on exposed sands and mudflats, or in low open grassland. There is anecdotal evidence that the long history of cattle grazing around the shoreline of the estuary has helped to maintain a diversity of habitats for waterbirds (McAlpine *et al.* 1989). Grazing prevents encroachment of tall dense pasture grasses that are not suitable as waterbird habitat. Pugging and trampling also creates holes and divots across exposed sands and mudflats, within and behind which shorebirds can shelter and roost. While general wisdom might dictate exclusion of livestock and revegetation of the estuary foreshore, selective grazing of fringing lands (which on some parts of the Site is ongoing) should be investigated as to its importance maintaining the diversity of waterbird habitat.

5.6.3 Fauna – Fauna Interactions

In the Vasse-Wonnerup, high invertebrate populations, including nuisance midge larvae, are believed the result of high nutrient status (EPA 1989a, Davis 1989) and to give the estuary system its high waterbird carrying capacity (EPA 1989a). The EPA has previously stated that "in so far as a high value is placed on the estuary as a waterbird habitat, the Authority and the Department of Conservation and Land management (now DEC) both consider high midge populations as an essential characteristic of the Vasse-Wonnerup estuary environment" (EPA 1989b). Fish too are an important food source for both predatory fishes and fish-eating waterbirds. The relative contribution of the various fish and invertebrate species to waterbird diet in the Vasse-Wonnerup is not known (refer Section 4.14.2). Preferences of waterbirds are likely to change with life history stage as nutrition and calorie requirements vary, *e.g.* breeding versus non-breeding birds and adults versus juveniles and chicks.

Predation and competition between fish species is known to be important in structuring communities and determining spatial distribution of fishes within estuaries. The availability and diversity of habitats will affect the numbers of predators and prey that can co-exist. For example, deeper water areas are important for larger, deeper bodied fish. Shallow waters and weed beds protect small fish and juveniles from large bodied predators. Turbidity may also offer some protection for fish from visual predators including waterbirds. Declines in availability of food and shelter for fishes may also affect fish eating birds. The dynamics of fish populations within the Vasse-Wonnerup Site and likely impacts to fish eating birds is not understood.

Competition between waterbird species for available foraging, roosting and nesting resources will ultimately determine the maximum number of waterbirds the Site, or specific locations within the Site, can sustain. In higher rainfall years, birds may migrate between local or even regional wetlands in search of optimal habitats, easing competitive pressures (see Section 4.14.4). During years when locally available foods are in short supply, birds that can travel long distances in search of suitable food for themselves and their young will have a competitive advantage.

5.6.4 Introduced Species

Introduced *Typha* (bullrush) is utilised by a few waterbird species for nest sites. However *Typha*, is invasive and has the potential to rapidly colonise large areas in some parts of the Site, exclude native plant species and ultimately reduce the diversity of foraging and nesting habitats. Control (if not eradication) of introduced plants, including others such as Arum Lily and pasture grasses, is important to maintain the biodiversity of the site. Introduced animal species such as foxes and cats are known to prey on waterbirds and chicks, though the impact of such predation at the Site has not been quantified.

As noted in Section 5.6.4, introduced Goldfish are thought to contribute to water quality problems in the lower Vasse River. They are also known carriers of disease (Morgan & Beatty 2004). Other introduced freshwater fish and crayfish species have also been recorded from tributary rivers of the Site (refer Table 19, Section 4.13). These include Mosquitofish, Redfin Perch and the Yabby. Mosquitofish are considered a pest species because they occur in high densities, competing with local species for food, resources and space. They are prodigious breeders and able to rapidly increase numbers. To date, there has been only one successful management activity to reduce numbers of Mosquitofish in south-western Australia wetlands and this was their recent physical removal from Bull Creek (Morgan & Beatty 2006). If ever eradicated from a waterbody, it is very likely that it will soon reinvade unless that waterbody is isolated. The Mosquitofish is often either dominant, or the only species present in situations in which a diversity of habitats no longer exists (Pusey *et al.* 1989, Morgan & Beatty 2006, WRM 2006). Low flows and anoxic conditions over summer tend to favour proliferation of Mosquitofish and a concomittant loss of endemics (Pusey *et al.* 1989, WRM 2006). Redfin Perch are aggressive piscivores and can cause the decline of native fish populations through competition and predation. They also predate on invertebrates including freshwater crayfish. If caught, neither Redfin Perch nor Mosquitofish should be returned live to the water. The release of Redfin Perch into natural waterways should be discouraged. The presence of yabbies in natural aquatic systems is of concern owing to its highly aggressive nature and superior competitive ability (Lynas *et al*. 2004; Lynas *et al*. 2006) in comparison with native freshwater crayfish such as the Gilgie. This species is also tolerant of a wide range of environmental conditions (particularly low oxygen) and has the ability to exploit a wide variety of different aquatic habitats, including semi-permanent swamps, drain and irrigation channels, and seasonal rivers (Austin 1985). It also produces a large number of offspring. Yabbies are burrowing crayfish adapted to long-term population survival in the fluctuating environments of impermanent wetlands. It's extended spawning period, early age at first maturity and rapid growth rate give it a competitive advantage over native freshwater crayfish species (Morgan & Beatty 2004).

Though it is recommended that control of introduced fish and crayfish be considered in any final management plans for the Site, they are not considered likely to threaten the biological integrity of the Site as a whole.

6. WETLAND BENEFITS / SERVICES

A summary list of key wetland benefits/services of the Vasse-Wonnerup Wetlands is given in Table 25 and a brief discussion of each presented in the following sub-sections. As with ecosystem processes, ecosystem services were not quantified owing to lack of baseline data.

Table 25. Ecosystem benefits/services of the Vasse Wonnerup Wetlands.

Benefits / Services Type	Benefit / Service
Maintenance of hydrological stability	Flood control - protection of agricultural land and built assets
Sediment and nutrient retention Water purification	Sediment and nutrient deposition Removal and dilution of wastewaters from irrigation areas, urban areas
Recreation and Tourism	Recreational fishing Bushwalking Nature observation
Cultural value	Aesthetic values Cultural heritage (historical and archaeological) Spiritual and religious - sacred sites Sense of place Educational values
Food web support	Nutrient & carbon cycling Primary production
Ecological value	Waterbirds - supports high abundance (>20,000) and richness (>60 species) of waterbirds - supports significant proportions (≥1%) of the relevant Ramsar populations of Black-winged Stilt, Red-necked Avocet, Australian Shelduck and Australasian Shoveler - supports the largest known regular breeding colony of Black Swan in the State (50-150 pairs)

6.1 Maintenance of Hydrological Stability

The site is used as a compensating basin for discharge from four rivers; the Vasse, Abba, Sabina and Ludlow rivers (Environment Australia 2001). Floodgates on the exit channels of the Vasse and Wonnerup estuaries are used to manipulate water levels in the estuaries. Levels are lowered during winter to provide storage capacity for river floodwaters, when high sea levels would otherwise prevent their discharge. Floodgates prevent storm surges[12] from causing saltwater inundation of low lying coastal lands adjacent to the estuaries and in Busselton township (Lane *et al.* 1997). This is likely to be of increasing importance given current predictions for increasing storm surges associated with climate change (IPCC 2007). Sea water has overtopped (+1.65 m AHD) the former (pre-2004) floodgate structures on some occasions, mostly associated with cyclones: June 1919 (severe winter storm); +1.94 m in Feb 1937 (unnamed cyclone); +1.79 in April 1978 (cyclone Alby); +1.70 in April 1991 (cyclone Fifi) (Lane *et al.* 1997).

[12] Large rises in sea level due to strong on-shore winds and low barometric pressures.

6.2 Sediment – Nutrient Retention and Water Purification

Like most south-west estuaries, geomorphology, long residence times and high productivity of the Vasse-Wonnerup Estuary prevents nutrients, sediments, pesticides and other pollutants in wastewaters and agricultural run-off from being transported directly to Geographe Bay (refer Sections 5.1 & 5.3). Estuaries regulate the fluxes of nutrients, water, particulates and organisms to and from land, rivers and the sea (Levin *et al.* 2001). The rate and extent of transport from the Vasse-Wonnerup Estuary to the Bay has not been studied. Rates of primary production and plant uptake of water column nutrients during periods of active growth can significantly reduce nutrient export. In systems such as the Vasse-Wonnerup where loadings of both N and P are high, it is important that any management activities to reduce nutrient loads address N and P both, rather than just one supposedly limiting nutrient (Davis & Kloop 2006). For example a reduction in P load without a corresponding reduction in N load may lead to reduced primary productivity due to P-limitation and potential increased export of N to Geographe Bay. It should also be noted that existing sediment stores in the estuaries may pose a greater potential problem to management than external loadings. This will be dependent on the adsorptive/desorptive properties of the sediments and oxygen conditions at the sediment-water column interface (Davis & Kloop 2006).

6.3 Recreation and Tourism

The Site is important for tourism and recreation, including bushwalking and nature observation. Recreational fishing is now largely confined to line fishing in the estuary exit channels and Wonnerup Inlet (recreational netting for fish has been banned since 1990). Tourism is a significant industry in the Shire of Busselton. Environmental assets such as the Ramsar Site, nearby wetlands and adjoining Tuart Forest play a considerable role in attracting visitors and tourists. The Shire, with guidance from DEC, other agencies and the community, has recently commenced planning for a major 'Wetlands Experience' tourism attraction, including a Busselton Bird Observatory and Wetlands Centre on the New River and walk trails providing guided access to the wetlands and Tuart Forest.

The annual economic benefit of this project to the Shire has been estimated at $698,000, equating to almost $7m over ten years and generating 60 additional jobs (Evolve Solutions 2007). This was based on a claimed conservative estimate of 50,000 visitors annually and 2% growth thereafter. Projections indicate that 85,000 people could visit the Busselton Bird Observatory and Wetland Experience Centre annually. The Shire expects the Centre will cost up to $5.25m to build with funding coming mostly from Government grants and business. A less expensive option is currently being examined.

Factors contributing significantly to tourist and visitor perceptions of wetland health are:

- water clarity, colour, odour and freedom from 'choking' aquatic plant growth,
- water depth,
- frequency and duration of inundation,
- sudden mass fish deaths,
- waterbird abundance and diversity and
- fringing and emergent vegetation health.

6.4 Cultural Value

The wetlands system, including the Ramsar Site, and adjoining Tuart Forest National Park are particularly valued for their "sense of place" by the local community. The Shire of Busselton has described the Site as having outstanding aesthetic value. The Shire would also like to foster collaborative teaching and research between the Busselton Bird Observatory / Wetlands Centre and the Capel Eco Discovery Centre at Iluka Resources Limited Capel mine site, some 20 km north of Busselton (see Section 14.1).

The Tuart Forest is of historical interest because it was among the first areas to be gazetted as State Forest in Western Australia, and was the site of the first formal training school for forest managers in the State. Several historic buildings are situated beside the Site, notably Wonnerup House (National Trust). The replacement timber floodgates installed on the estuaries in 1928 are also recognised as having heritage value. Prior to their replacement in 2004, their construction was documented and photographed and parts were saved for inclusion in the proposed interpretive centre (Sinclair Knight Merz 2003).

Part of the Site (and the adjoining Tuart National Park) is listed on the Register of the National Estate, on the basis of its significant conservation and heritage value. This listing covers the Wonnerup Estuary and the north-eastern half of the Vasse Estuary, including farmland between the wetlands and the Tuart National Park. As such, all development proposals must be referred to the Heritage Commission under the Australian *Heritage Council Act 2003*. Non-aboriginal heritage sites listed on the Municipal heritage Inventory and located within or near the Ramsar Site include:

- 025 Ford Road Causeway, Ford Road;
- 066 Ballarat Timber Mill Site, Layman Road Wonnerup, near the Floodgates;
- 079 Chapman's Mill (Inlet Park Farm), Wonnerup SL 2 Tuart Drive;
- 085 Geographe Longboat Sinking Site, Wonnerup Inlet;
- 094 Lockeville Farmhouse and St Mary's Church Hall, Wonnerup - Layman Road, Lot 26;
- 112 Rushleigh (Dwelling), Rushleigh Road, Wonnerup;
- 114 Pidgeon Grove Homestead, Wonnerup - Barracks Road, Lot 21;
- 123 Ballarat Railway Bridge, Layman Road, Wonnerup;
- 131 The Shipwreck Site, Wonnerup Inlet - The Deadwater *via* Forrest Beach Road;
- 138 Vasse River, Busselton Shire;
- 148 Wonnerup Wetlands;
- 160 Broadwater Wetlands;
- 164 Richardson's Cottage, Layman Road;

There are also 97 Aboriginal heritage sites listed by DIA as occurring within the Shire (O'Brien 2006). Sixteen of these are located within or close to the Ramsar Site, including the Wonnerup Scarred/Shield trees, Massacre Site and Corroboree Ground (Centre for Cultural Research 1997, WAPC 2005). The Sabina and Abba Rivers in their entirety are listed as important mythological Aboriginal heritage sites associated with the Waugal and specially protected by the Western Australian *Aboriginal Heritage Act (1972)*. All Crown land encompassed by the Ramsar Site is currently included within two registered native title claims: the Harris family and the South-West Boojarah family, for whom the Noongar Land Council is the representative Aboriginal Body. The Busselton-Wonnerup area is relatively rich in archaeological sites containing around 21% of all known artefact assemblages in the Busselton-Narrogin-Walpole Region[13] (O'Connor *et al.* 1995). Of these, the most frequent locations are around estuaries, rivers, wetlands and coastal dunes. Prior to European contact, coastal lake chains including the Vasse-Wonnerup Estuary were an important source of food for Aboriginal people, particularly over the summer months. O'Connor *et al.* (1995) stated that the "region's (Busselton-Narrogin-Walpole) waterways were the main focus of Aboriginal traditional life from the viewpoint of food and drink, living areas and highways along which seasonal migrations occurred". The Wardandi Noongar are the traditional custodians of lands bounded by Capel, Nannup and Cape Leeuwin, including the Busselton-Wonnerup area (Tindale 1974). The coastal wetlands and Geographe Bay are of great social, cultural and spiritual importance to the Wardandi (Vilma Webb, Busselton, pers. comm.). Historically, the wetlands, estuary and Bay were a major food source for local peoples. The Wardandi built fish traps (mungas) of stakes at the entrance to Wonnerup Inlet (Marchant 1982). Other food resources exploited included waterfowl, eggs, long-necked turtles, frogs, crayfish and reed roots. The foreshore and adjacent forest were sites of seasonal ceremonial and social gatherings as evidenced by the Coroboree Ground and semi-circular earthwork or "religious grove" described by Péron during the 1801 Baudin expedition (Marchant 1982). There is also "an unbroken link with the past" through the descendents of Sam (Yebble) Isaacs (O'Connor *et al.* 1995). Sam Isaacs, together with Grace Bussell is renowned for his part in the sea rescue of passengers and crew from the wrecked schooner *S.S. Georgette* in 1876. His bravery was recognised by the Royal Humane Society which awarded him a bronze medal in 1878 and by the Western Australian

[13] The Busselton-Narrogin-Walpole region covers an area of ca. 35,000 km2 bounded by the towns of Capel, Busselton, Dunsborough, Augusta, Walpole, Kojonup, Katanning, Nyabing, Harrismith, Narrogin, Darkan, Boyup Brook, Balingup as described by O'Connor *et al.* 1995.

Government who awarded him 100 acres (~40.5 ha) of land. Many of the descendents of Sam Isaacs still live in the Busselton area, *i.e.* members of the Webb family.

The Wardandi traditionally buried their dead in the coastal dunes between the Vasse-Wonnerup Estuary and Geographe Bay (Vilma Webb, Busselton, pers. comm.). Skeletal remains have been discovered eroding from sand dunes or following disturbance by earthworks for housing and infrastructure. Ethnographic and archaeological information suggests two large burial grounds existed in the area, however to date, only isolated single internments have been discovered (Stephen Corsini, Consultant Archaeologist, pers. comm.). A model of burial site location is currently being developed for DIA based on GIS and locations of discovered remains. The model will include all known south-west ethnographic and archaeological sites. The aim is to predict occurrences and aid in protection of sites during future developments (Stephen Corsini, Consultant Archaeologist, pers. comm.).

The area is also infamous for the massacre of at least nine Wardandi people by European settlers at Wonnerup in February 1841 (O'Connor *et al.* 1995). The massacre occurred to the north of the Ramsar Site, on the north side of the Capel River (White & Comer 1999). The Wonnerup area is the second site in Busselton where settlers met Noongar people. It is named after an Aboriginal term meaning "(Aboriginal) woman's digging stick" and was traditionally a place of "women's gathering".

The Australian Government Resource Assessment Commission's Coastal Zone Inquiry of 1993 (RAC 1993) noted "the presence of early Aboriginal people is evident and widespread throughout the south-west in thousands of archaeological and ethnographic sites which form an intrinsic part of the character of the region. These sites are protected by the *Aboriginal Heritage Act 1972* and together with many buildings and sites which bear witness to the early years of European settlement, form an important legacy of human settlement in the Region".

6.5 Food Web Support

The Site provides for vital nutrient and carbon cycling which supports abundant primary production and consequently large populations of fish and waterbirds. The Site provides essential ecological functions and is fundamental to the food web which supports the values of Ramsar significance. Further detail of specific components and processes likely important to food web support is given in preceding Sections 5.4 to 5.6.

6.6 Ecological Value

The ecological value of the wetlands here refers primarily to values of Ramsar significance as discussed in Sections 2.4 and 4.14. Values for which the Site is already listed include:

- "regularly" supports high abundance (> 20,000) and richness (at least 60 species) of waterbirds,
- "regularly" supports significant proportions (≥ 1%) of the relevant Ramsar populations of Black-winged Stilt, Red-necked Avocet, Australian Shelduck and Australasian Shoveler.

In addition, the Site supports significant proportions (≥ 1%) of Flyway populations of the following species in some years:

- Wood Sandpiper,
- Sharp-tailed Sandpiper,
- Long toed Stint,
- Curlew Sandpiper, and
- Greenshank.

At the time of last survey in 1998 - 2000, the Red-capped Plover were also present in numbers ≥ 1% of the Australian population.

The Site also supports the largest known regular breeding colony of Black Swan in the State; between 50 and 150 pairs of swans nest there annually (note that this is not a large colony nationally).

It is possible the Site may also qualify against other Ramsar criteria, but this could not be confirmed with currently available data. These other ecological values include:

- Criterion 3 as applied to waterbirds, *i.e.* "a wetland should be considered internationally important if it supports populations of (waterbird) species important for maintaining the biological diversity of a particular biogeographic region".
- Criteria 7, as applied to fish, *i.e.* "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".
- Criteria 8 as applied to fish, *i.e.* "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".
- Criteria 9 as applied to fish, *i.e.* "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".

7. SUMMARY OF ECOSYSTEM COMPONENTS, PROCESSES AND SERVICES

7.1 Summary Table

Table 26, overpage, provides a synopsis of the Vasse-Wonnerup Ramsar Site components, processes and benefits/services discussed in the preceding sections. The table is ordered by wetland type. It indicates which components or processes directly support specific ecosystem services. For example, the critical components and processes required to annually support 50 - 100 breeding pairs of Black Swan are likely to be water regime, salinity regime, nesting resources (samphire), breeding habitat ('Swan Lake') and primary productivity (*e.g. Ruppia*). However, due to the limited empirical data, the supporting components and processes could not be quantified for most services. For breeding swans, the required aspects of supporting components and processes may include:

- a specific volume and rate of freshwater inflow (ML/day or GL/month) in May-July to induce breeding and maintain salinity levels below 15,300 mg/L,
- a specific area (hectares) of inundation to provide ample nesting habitat,
- reasonably stable water levels of ca. $^{+}$0.4 m AHD - this is the target level for the Vasse and Wonnerup estuaries; the precise level for 'Swan Lake' has not been determined but is likely to be similar (Jim Lane pers. comm.) - from July to September to prevent flooding or access by terrestrial predators, with a gradual recession to December to prevent abandonment of nests,
- a specific biomass and aerial coverage (hectares) of samphire heathland for adequate supply of nesting material, and
- a specific biomass and aerial coverage (hectares) of mature *Ruppia* to feed nesting swans.

Further consideration of the specific aspects of components and processes needed to support wetland services is given in Section 8 'Limits of Acceptable Change'.

Black Swans on Malbup Creek (courtesy Martin Pritchard, GeoCatch)

Table 26. Summary of wetland benefits/services and the ecosystem components and processes that directly support them.

*Wetland types within Vasse-Wonnerup Ramsar Site (refer Section 2.2):

i = Seasonal / brackish saline lagoons,
ii = Estuarine mud flats,
iii = Freshwater / brackish deltas (mouths of the Ludlow, Abba & Sabina rivers),
iv = Freshwater swamps and channels of tributary streams (lower reaches of the Abba & Sabina rivers).

<table>
<tr><th rowspan="2">Benefit / Service</th><th colspan="4">Wetland Type</th><th rowspan="2">Key Components</th><th rowspan="2">Related Components & Processes</th></tr>
<tr><th>i</th><th>ii</th><th>iii</th><th>iv</th></tr>
<tr><td>Maintenance of hydrological stability
Compensation basin for flood control</td><td>✓</td><td></td><td></td><td></td><td>Geomorphology & Hydrology :
▪ depth and area of the estuary basins;
▪ seasonal freshwater inflows.</td><td>Climate and rainfall;
Rate of sedimentation, erosion & sand bar formation;
Floodgate operation & restricted tidal flushing; seawater level; frequency & magnitude of storm surges;
Frequency, magnitude & duration of surface and groundwater inflow.</td></tr>
<tr><td>Sediment & nutrient retention</td><td>✓</td><td>✓</td><td>✓</td><td></td><td>Geomorphology & Soils :
▪ depth and area of the estuary basins (wetland type i);
▪ soil & sediment types;
▪ carbon loads - concentrations in estuary sediments & water column.
Hydrology:
▪ seasonal freshwater inflows.
Nutrients:
▪ concentrations in estuary sediments & water column.
Seagrass & Samphire:
▪ aerial extent of seagrass beds - provide low energy areas for deposition of particulates & support biofilms (i);
▪ aerial extent of samphire heath - provide low energy areas for deposition of particulates (ii).</td><td>Climate & rainfall;
Connectivity with the ocean & sand/weed bar formation at the estuary mouth;
Floodgate operation & restricted tidal flushing (wetland types i & ii);
Wind-driven internal water circulation and water residence time;
Frequency, magnitude & duration of surface and groundwater inflow;
Rate of N, P & C re-cycling;
Aerial extent of deposition zones, e.g. seagrass beds, organic muds, & rates of de-nitrification. Shallow mudflats & seagrass beds typically important zones of denitrification.</td></tr>
<tr><td>Recreation & Tourism</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>Geomorphology & Hydrology:
▪ water depth and aerial extent of large expanse of open water in the Wonnerup & Vasse Estuaries (i & ii);
▪ permanent seawater in Wonnerup Inlet & in exit channels downstream of the floodgates (i).
Nutrients, Turbidity, DO: i.e. water quality.
Samphire & Riparian Vegetation:
▪ aerial extent & health of samphire heath, sedgelands and fringing paperbark, peppermint & eucalypt communities (ii, iii & iv).
Habitat Connectivity:
▪ between Ramsar Site, other wetlands & with Tuart Forest National Park - vegetation type, composition & health (ii, iii & iv)
Fish:
▪ abundance & diversity of recreational fish stocks (i & ii).
Waterbirds:
▪ abundance, diversity & composition of waterbird populations that use the lagoons, mudflats & samphire (i, ii & iii).</td><td>Frequency, depth and duration of estuary inundation - dependent on rainfall, surface & groundwater regimes, floodgate operation & tidal inflow (i, ii & iii);
Connectivity with Wonnerup Inlet and the ocean; sand / weed bar formation (i & ii);
Hydrological regime - frequency, magnitude & duration of surface freshwater inflows - dependent on rainfall & groundwater regimes;
Peppermint & eucalypt woodland dependent on surface flows & water table level & frequency & duration of tree root inundation (iv);
Frequency, severity & extent of toxic & nuisance algal bloom formation (i, ii & iii);
Rates of primary & secondary (invertebrates & fish) production that support abundant waterbirds;
Biomass & aerial extent of macrophyte beds that offer food & shelter to waterbirds and fish stocks (I, ii & iii);
Aerial extent of exposed sand/mud flats & riparian vegetation communities that provide roosting & nesting habitat for waterbirds.</td></tr>
</table>

Table 26 continued.

Benefit / Service	Wetland Type i	ii	iii	iv	Key Components	Related Components & Processes
Cultural value Aesthetic	✓	✓	✓	✓	As above.	As above.
Cultural heritage; 'Sense of place'	✓	✓	✓	✓	As above. Sabina & Abba rivers are important mythological Aboriginal heritage sites associated with the Waugal.	As above.
Educational values - ecosystem function - waterbirds		✓	✓		As above.	As above.
Food web support	✓	✓	✓	✓	**Geomorphology & Hydrology**: ▪ depth and area of the estuary basins (i); ▪ aerial extent of the mudflats (ii) & deposition zones (iii); ▪ habitat connectivity with the ocean; ▪ seasonal freshwater inflows; ▪ water quality (salinity, turbidity, DO); ▪ carbon loads & concentrations in estuary sediments & water column. **Nutrients**: ▪ concentrations in estuary sediments & water column. **Phytoplankton, Macroalgae & Seagrass**: ▪ diversity, abundance & biomass (i, ii, & iii). **Samphire & Riparian vegetation**: ▪ aerial extent of samphire (ii), sedgeland & paperbark communities (iii & iv); ▪ vegetation type, vegetation composition & health (iv). **Habitat connectivity**: ▪ between Ramsar Site & floodplain & with Tuart Forest National Park (iv). **Aquatic Invertebrates**: ▪ diversity, abundance, biomass & community composition. **Fish**: ▪ diversity, abundance, biomass & community composition.	Geomorphic & fluvial processes that maintain morphology of the Site - rates of sedimentation, erosion; Habitat connectivity with the ocean important for marine migratory species (i, ii & iii); Wind-driven internal water circulation and water residence time (i, ii & iii); Hydrological regime - frequency, depth and duration of estuary inundation. Dependent on rainfall, surface & groundwater regimes, floodgate operation & tidal inflow; Frequency, magnitude & duration of surface freshwater inflows - dependent on rainfall & groundwater regimes; Physico-chemical interactions that affect water quality - salinity, turbidity, DO, pH, temperature, internal & external loads of N, P & C; Nutrient & carbon dynamics; Rates of primary & secondary (invertebrates & fish) production.
Ecological value Supports peak numbers of 25,000-35,000 waterbirds in most years	✓	✓	✓		**Geomorphology, Soils, Hydrology & fringing Vegetation**: ▪ frequency, depth and duration of estuary inundation, particularly December to February; ▪ aerial extent of the lagoons, mudflats shallows, samphire and other fringing vegetation communities add to the diversity of habitats contained within the Site. The deeper waters of the lagoons likely provide habitat for larger estuarine & marine fishes and foraging areas for diving & fish-eating birds; ▪ aerial extent of mudflats, shallows & samphire heath likely provide seasonal habitat for fish & invertebrates when inundated, and foraging & nesting habitat for waterbirds, including migratory shorebirds;	Climate and rainfall; Geomorphic & fluvial processes that maintain morphology of the Site - rates of sedimentation, erosion; Habitat connectivity with the ocean important for marine migratory fishes; Hydrological regime - frequency, depth and duration of estuary inundation May to February. Dependent on rainfall, surface & groundwater regimes, floodgate operation & restricted tidal inflow; Physico-chemical interactions that affect water quality (particularly July - February) - internal & external loads of N, P & C, inter- & intra-annual variations in salinity, turbidity pH, temperature & DO levels; Salinity regime May – January (i, ii & iii);

Table 26 continued.

Benefit / Service	**Wetland Type** i	ii	iii	iv	**Key Components**	**Related Components & Processes**
					▪ aerial extent, composition & structure of fringing overstorey vegetation that provides roosting and nesting sites for many waterbirds. **Macrophytes**: ▪ diversity, abundance & biomass - waterbird food resource. **Aquatic Invertebrate**: ▪ diversity, abundance & biomass - waterbird food resources. **Fish**: ▪ diversity, abundance & biomass.	Nutrient & carbon dynamics; Primary productivity, biomass & aerial extent of macrophyte beds that supply food, shelter & nursery habitat to fish populations (i, ii & iii); Secondary productivity of invertebrate and fish food resources for waterbirds (i, ii & iii); From a management perspective, the main waterbird areas / zones of the Site are the Vasse Estuary, Wonnerup Estuary, Malbup Creek and Wonnerup Inlet.
Regularly supports 60 species in any one year	✓	✓	✓	✓	as above; more specific data not available.	As above; more specific data not available. From a management perspective, the main waterbird areas / zones of the Site are the Vasse Estuary, Wonnerup Estuary, Malbup Creek and Wonnerup Inlet.
Species regularly present in numbers > 1% of relevant Ramsar population: Black-winged Stilt (annual peak numbers ~3,000-4,000 birds)		✓			**Geomorphology, Hydrology, Macrophytes, Fringing Vegetation & Aquatic Invertebrates**: ▪ prefers to forage in shallow water, open or surrounded by dense vegetation or emergents; ▪ abundance, diversity & biomass of preferred foods (*e.g.* invertebrates, vegetative matter & seeds); ▪ availability of roosting habitat dependent on aerial extent of exposed sands & mudflats, shallows, samphire & short grasses.	As above; more specific data not available.
Species regularly present in numbers > 1% of relevant Ramsar population: Red-necked Avocet (annual peak numbers ~1,000-2,000 birds)		✓			**Geomorphology, Hydrology, Macrophytes, Fringing Vegetation & Aquatic Invertebrates**: ▪ prefers to forage in shallow waters in soft muds; ▪ abundance, diversity & biomass of preferred foods (*e.g.* invertebrates, vegetative matter, seeds & occasionally small fish); ▪ availability of roosting habitat dependent on aerial extent of shallows.	As above; more specific data not available.
Species regularly present in numbers > 1% of relevant Ramsar population: Australian Shelduck (annual peak numbers ~2,500-3,500)	✓	✓	✓		**Geomorphology, Hydrology, Macrophytes, Fringing Vegetation & Aquatic Invertebrates**. Specific data not available, but based on other systems: ▪ prefers to forage in open bare margins; ▪ abundance, diversity & biomass of preferred foods (*e.g.* invertebrates, & plants); ▪ availability of roosting & nesting habitat dependent on aerial extent of samphire, short grasses, fringing shrubs & trees.	As above; more specific data not available.
Species regularly present in numbers > 1% of relevant Ramsar population: Australasian Shoveler (annual peak numbers ~300-700)	✓		✓		**Geomorphology, Hydrology, Macrophytes, Fringing Vegetation & Aquatic Invertebrates**. Specific data not available, but based on other systems: ▪ forages in inundated grass, macrophyte beds, open water & bare margins;	As above; more specific data not available.

Table 26 continued.

Benefit / Service	Wetland Type				Key Components	Related Components & Processes
	i	ii	iii	iv		
					▪ abundance, diversity & biomass of preferred foods (*e.g*. invertebrates, & plants); ▪ availability of roosting & nesting habitat dependent on aerial extent of samphire, short grasses.	
Annually supports ~50-150 pairs of nesting Black Swan in 'Swan Lake'	✓		✓		**Geomorphology & Hydrology**: ▪ sufficient volume and rate of freshwater inflow (ML/day or GL/month) in May-July to induce breeding and maintain salinity levels below 15,300 mg/L; ▪ sufficient area (hectares) of inundation to provide nesting habitat; ▪ reasonably stable water levels of ca. +0.4 m AHD (precise level to be determined) July - September to prevent flooding or access by terrestrial predators, with a gradual recession to December to prevent abandonment of nests. **Samphire**: ▪ sufficient biomass and aerial coverage of samphire heathland for adequate supply of nesting material. **Macrophytes**: ▪ sufficient biomass and aerial coverage (hectares) of mature *Ruppia* to feed nesting swans.	As above, except, from a management perspective, the main areas / zone is 'Swan Lake' at the northern end of Wonnerup Estuary; Phytoplankton - direct & indirect effects of bloom formation unknown, *e.g.* toxicity; smothering of nesting & foraging habitat; impede movement.

7.2 Conceptual Models

This section presents conceptual models of the components, processes and benefits/services (where applicable) for the Ramsar Site (Figures 11 - 16). It must be noted that with little or no baseline data, models are theoretical based on generic estuarine models (*e.g.* OzEstuaries 2007) and models of other Australian estuaries (*i.e.* WRC, River Science Issue 9 2002, Cox *et al.* 2004, Healthy Waterways 2007). Nonetheless, the models serve to illustrate likely interrelationships between key ecosystem components, processes and services, highlight knowledge gaps and help to decide most appropriate indicators of change within the Site. It is important that the complexity of the ecosystem is understood if management is to be successful. The Vasse-Wonnerup Estuary is highly modified compared to historical condition and will need to be managed to an altered state.

Conceptual model(s) for the Site have been designed to illustrate:

1. Historic condition pre-1830:
   - wave-dominated estuary,
   - intermittently closed by sandbar,
   - winter flooding due to relatively high freshwater input from tributary rivers,
   - some C, N and P loading from catchment,
   - summer seawater inundation of tidal mudflats,
   - saltwater/freshwater interaction and flushing with greater freshwater flushing than saltwater = positive hydrology, and
   - occasional sudden mass fish deaths related to natural algal bloom formation over summer and natural closure of the sandbar.
2. Condition at time of Ramsar listing in 1990:
   - significantly reduced freshwater inflow from tributary rivers,
   - reduced winter flooding,
   - reduced area of seawater inundation over summer,
   - more frequent closing and opening of the sandbar,
   - significantly increased sediment loads from overland run-off → decrease in water depth,
   - significantly increased internal and external C, N and P loads → increase in nuisance algal blooms and fish deaths, and
   - seasonal drying and increased nutrient levels → increase in primary and secondary production → better bird habitat.

The models also demonstrate the difficulties in setting appropriate indicators and targets for ecosystem change in the absence of empirical baseline data. For example, which water quality parameters will be the most useful and cost-effective predictors of algal bloom initiation? Will water column N and P concentrations suffice or must a range of water and sediment parameters be included (*e.g.* salinity, turbidity, temperature, Fe, DO)? Should a bottom-up approach to monitoring (*e.g.* nutrient loadings) be taken, or a top-down approach (*e.g.* macrophyte biomass, waterbird abundance and diversity)? Both approaches would seem warranted. For management purposes it is not sufficient that potential change in only one component (*e.g.* waterbirds) be monitored. The cause and implications (beneficial or adverse) of that change must also be understood and will require concurrent monitoring of a number of inter-related physico-chemical and biological metrics. Changes in waterbird numbers may be due to any number of causes in all or only part of the Site - changes in water or salinity regime, changes in food sources (macrophytes, invertebrates, fish), toxic algal blooms, disease, sub-lethal effects of pesticides/metals and human disturbance, or off-Site influences (*e.g.* rainfall).

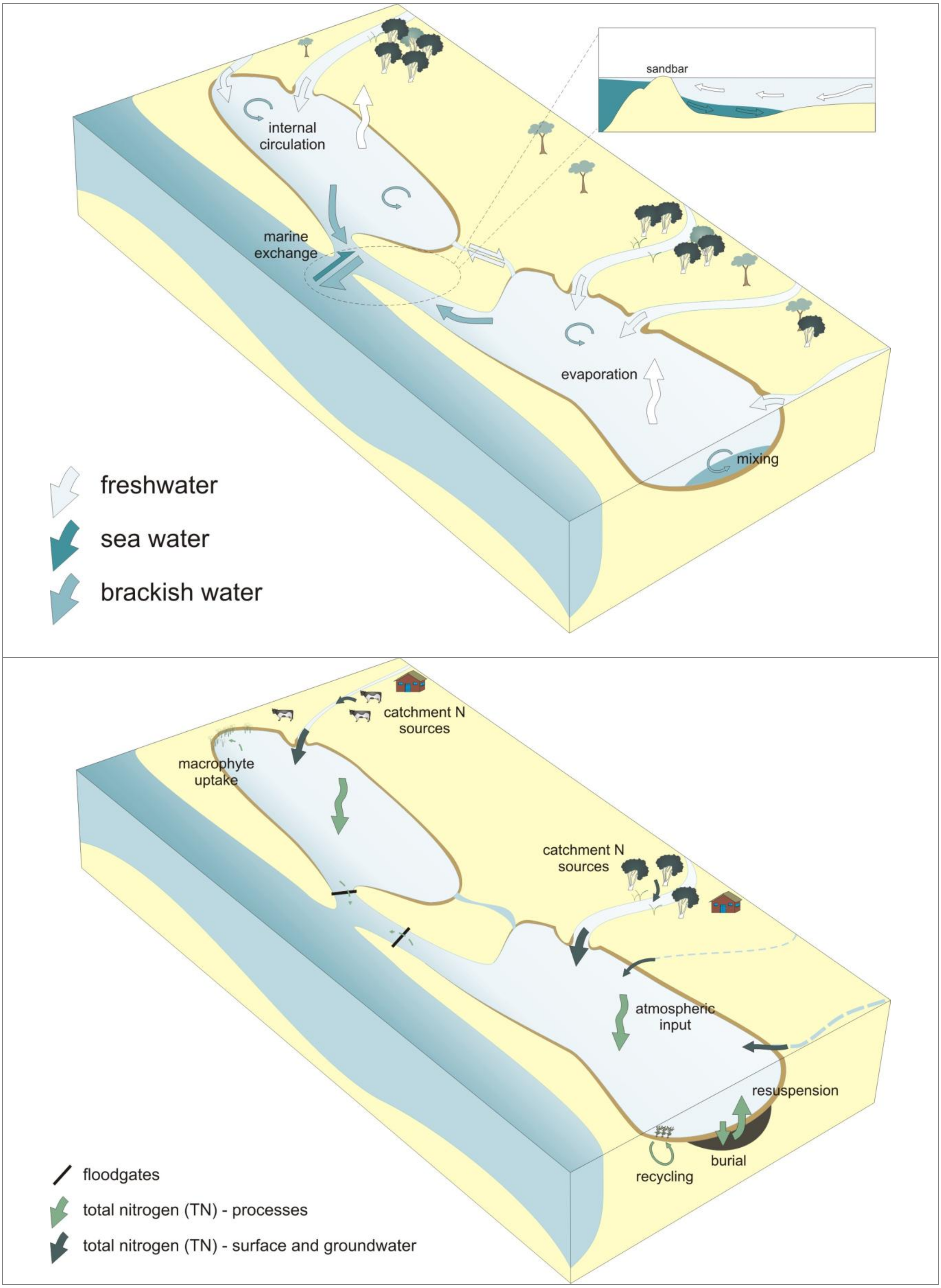


Figure 11. Theoretical conceptual model of hydrology; (top) historic winter condition and (bottom) winter condition at time of Ramsar listing.

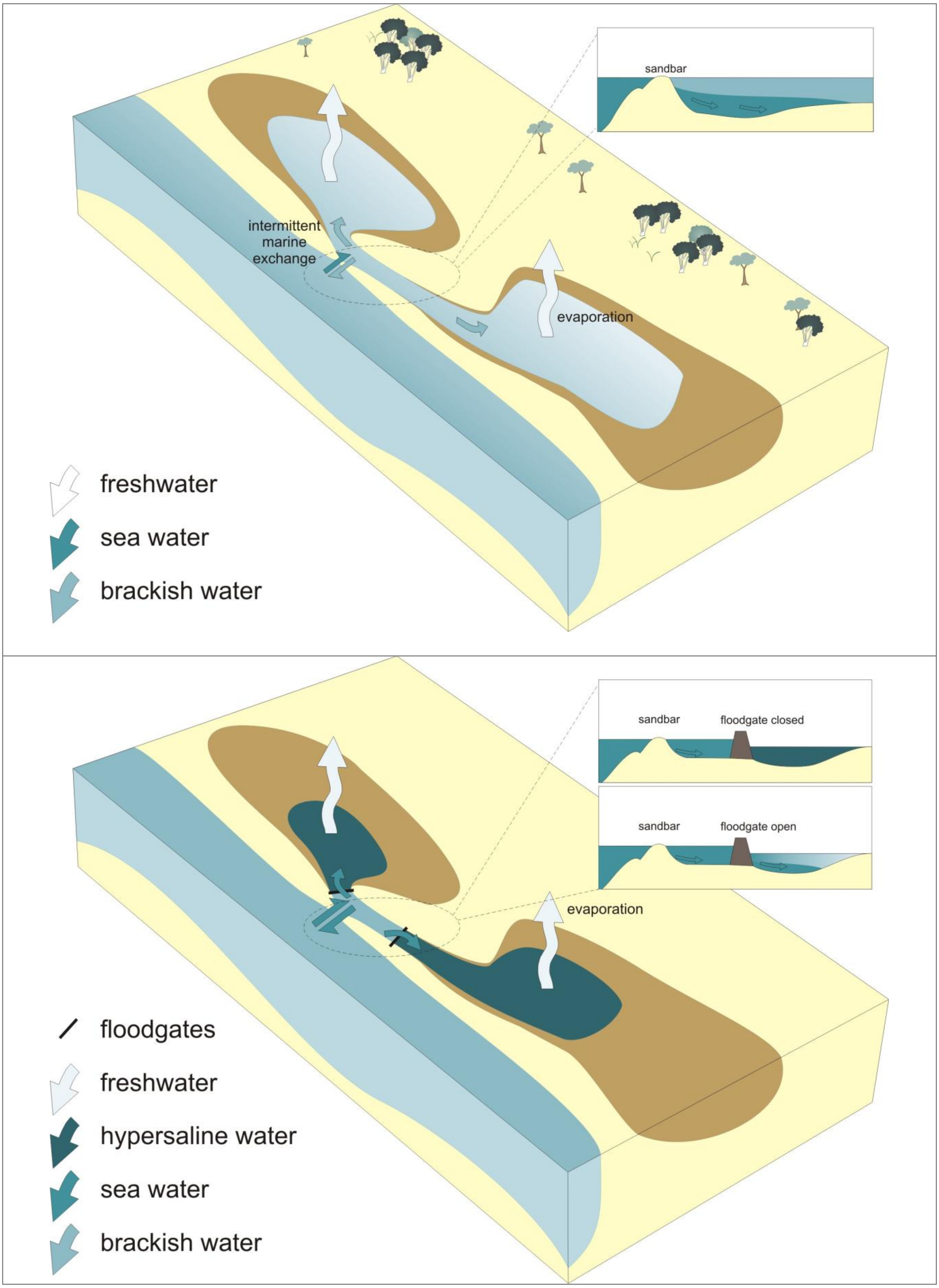


Figure 12. Theoretical conceptual model of hydrology; (top) historic summer condition and (bottom) summer condition at time of Ramsar listing.

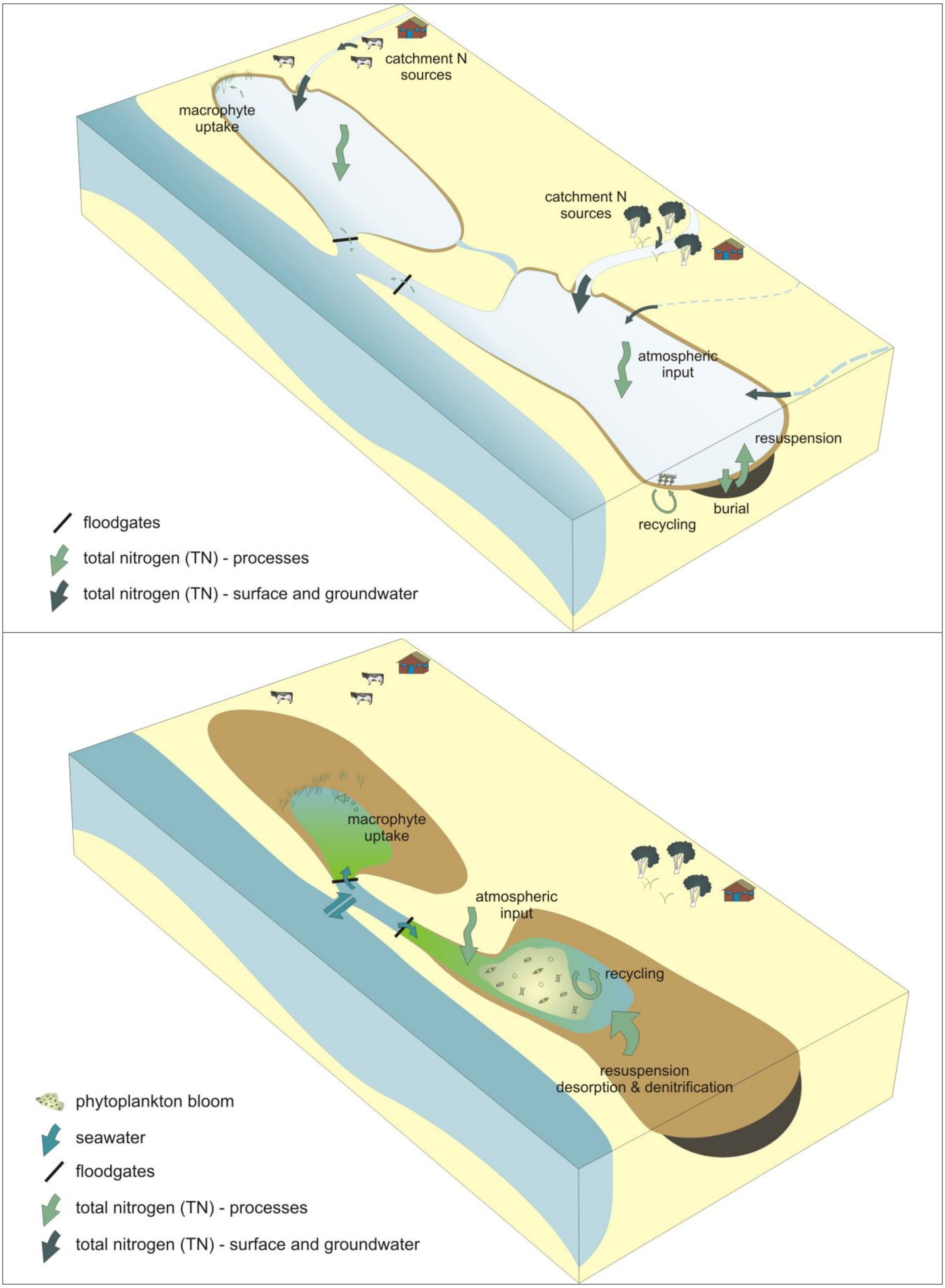


Figure 13. Theorised Vasse-Wonnerup Estuary nutrient dynamics; winter (top) and summer (bottom) conditions at time of Ramsar listing.

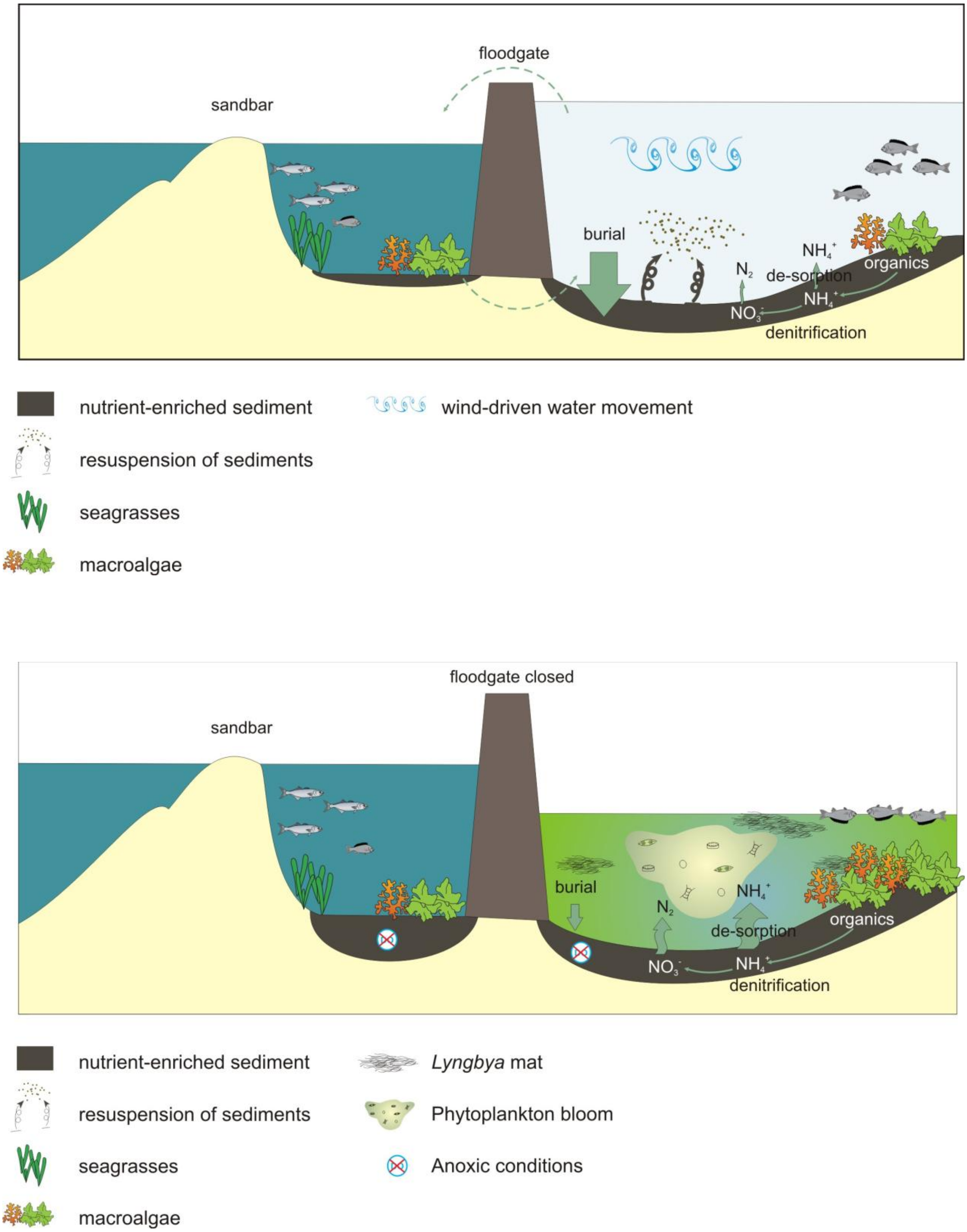


Figure 14. Detail of theorised Vasse-Wonnerup Estuary nutrient dynamics; winter (top) and summer (bottom) conditions at time of Ramsar listing.

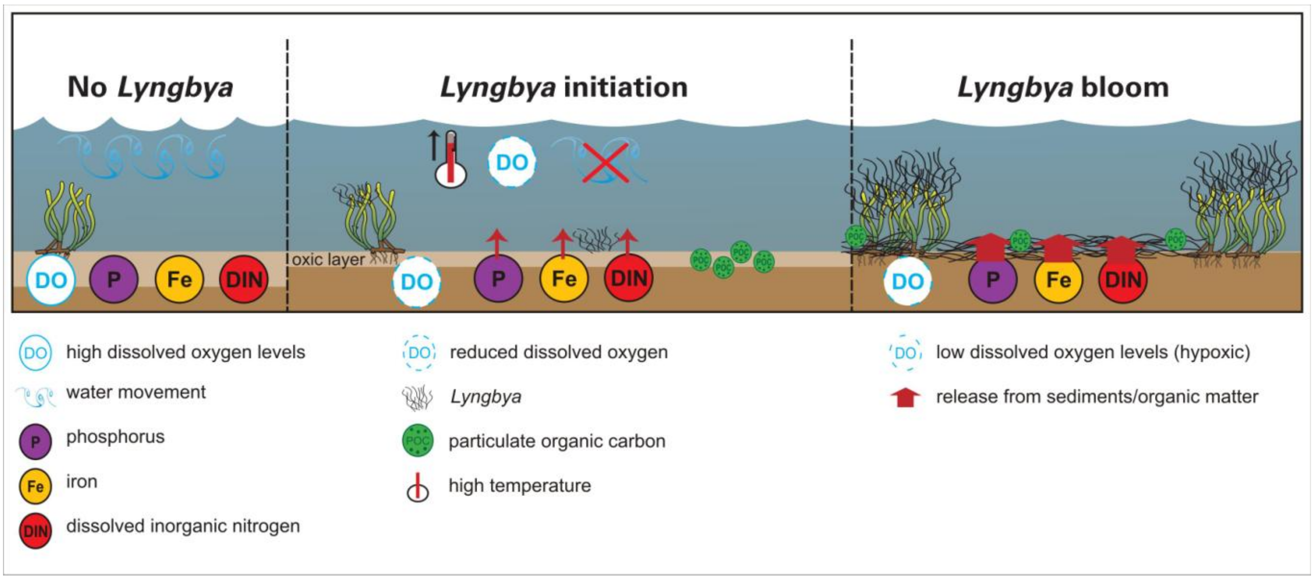


Figure 15. Generalised conceptual models of *Lyngbya* blooms (reproduced from Healthy Waterways 2007 - Moreton Bay, SE Queensland). This has been included based on the finding of Wilson *et al*. (2007) that, in November 2006, the abundance of the potentially toxic blue-green *Lyngbya* was highest in the vicinity of the Port Geographe canal development and that increased Fe concentrations are often associated with acid sulphate soil drainage and/or disturbed areas (refer Sections 4.9.1 & 5.4).

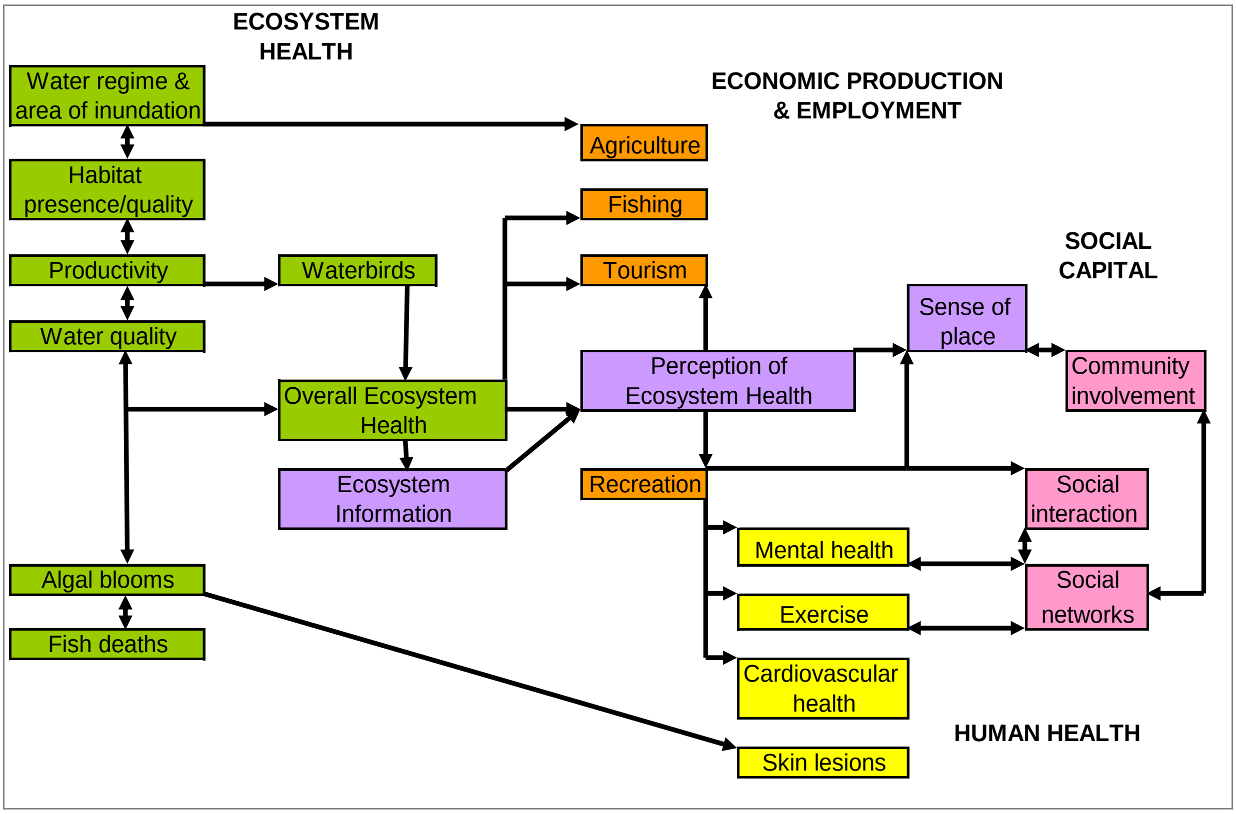


Figure 16. Conceptual model of relationships between key ecosystem components, processes and services and human health (adapted from Cox *et al.* 2004).

7.3 Perspectives of the Local Community

Seventeen long-term local and indigenous community representatives were contacted by phone and/or written correspondence for their 'insight' into how the Vasse-Wonnerup wetlands, tributary rivers and surrounding lands had changed in recent years and over the past 40 - 50 years (or more). Their collective knowledge provides valuable anecdotal evidence on the changing 'health' of the system. Community involvement is also seen as crucial to the development of effective catchment-scale management and monitoring plans. This ECD should be viewed as the first step only in the community consultation process. As part of the ECD, community representatives were asked to respond to a questionnaire (Appendix G). The questionnaire contained open questions meant to be used as a starting point for respondents to comment on the value of the wetlands, changes over time, issues of concern and on future community consultation. Only 50% of people responded. Many believed that informal meetings held locally may have resulted in greater participation, rather than phone or written correspondence.

Major views and concerns expressed were:

- The Ramsar Site, adjoining wetlands and remnant woodlands are highly valued by the local community for its wildlife (particularly birds, possums and frogs), aesthetics, heritage significance and as a peaceful and quiet location for recreation.
- The frequency and duration of nuisance algal blooms is on the increase.
- River flows (particularly in the Vasse River) have declined in recent years.
- An increase in the severity of repugnant odours emitted from drying sediments ("sludge") of the lower Vasse Estuary during the summers of 2005/06 and 2006/07. Odours were particularly noxious along Estuary View Drive and down to the floodgates, with some residents experiencing feelings of nausea when outdoors or even if their house windows were open. Amenity is greatly affected by this.
- Waters in the Vasse Estuary channel and in Wonnerup Inlet were much deeper and water clarity much better during the 1940s than they are today. Algal blooms were far less frequent even though much more water is believed to have remained in the estuaries over summer. Seaweed now often chokes the Inlet. Upstream of the floodgates, people would fish for Mullet (Sea Mullet), Pilch (yellow-eye mullet) and Black Snapper (Black Bream). In Wonnerup Inlet and The Deadwater there was once recreational fishing for Sand Whiting, King George Whiting, Tailor, Bream (Black Bream), Cobbler, Flounder and Mulloway (large Kingies).
- The wetlands are important to the Wardandi indigenous community who used to swim and hunt there for eggs, birds, turtles, fish, crayfish and mussels. The Wardandi would use the tide to help trap fish in the estuary and Deadwater channels. Fish traps of sticks and paperbark were built in the estuary and Inlet to catch fish moving downstream on the ebb tide. They would hunt for swan and duck eggs. Waterbirds traditionally bred in great numbers around the estuary and would continue to do so even if the floodgates were removed so long as the fringing native vegetation was allowed to re-establish.
- The local community together with GeoCatch and DEC Busselton, is putting a lot of effort into addressing water quality and land clearing issues within the catchment. Some farmers are extensively replanting tuarts, peppermints, rushes and sedges on lands bordering the Wonnerup Estuary. While much has been achieved there is still much to be done.
- A very positive attitude toward work being done by GeoCatch and DEC Busselton, but staff and resources already appear stretched to capacity. More help is needed.
- With the rapid growth in residential and industrial development within the Busselton area, there is urgent need to produce specific management plans for the Ramsar Site and adjoining Tuart Forest National Park.
- Scepticism that adequate State and Australian Government funding will be made available to effectively implement any long-term monitoring or management programs. Some residents believe the only solution to problem algal blooms and mass fish deaths is to remove the floodgates altogether.
- The proposal by Port Geographe developers to 'borrow' sand from the mouth of the estuary will have detrimental effects on the ecology of the Ramsar Site and on surrounding agricultural lands if the sand bar remains permanently open. There was concern that the proposal by Port Geographe developers to

'borrowing' sand from the mouth of the estuary had not been referred to the Federal Minister for consideration under the EPBC Act.

- Group meeting(s) or workshop would be helpful for community representatives to discuss individual views and concerns. This would help provide more unified/cohesive and comprehensive community input to the development of management plans.

8. LIMITS OF ACCEPTABLE CHANGE - INDICATORS & TARGETS

The current lack of robust empirical data made it difficult to set definitive limits of acceptable change (LOAC) for many key ecological features. Where sufficient knowledge existed, LOAC have been proposed as an interim measure until adequate quantifiable baseline data can be gathered. These are presented in Table 27. For some features, such as waterbird diversity, the limit of acceptable change will be no change from the 1990 condition, taking into account natural seasonal and year-to-year variation. For others, such as water quality, an improvement over conditions at the time of Ramsar listing is desirable. As discussed in Section 7.2, once adequate baseline data are available it may be possible to use only a sub-set of the listed 'key ecological features' as indicators for monitoring future change in ecological character of the Site.

Objective selection of indicators is considered a significant task in itself (Browne *et al.* 2007). In theory, the final suite of indicators should cover a variety of aspects of ecosystem health, including both components (biodiversity, species composition, water quality parameters, metal levels *etc*) and processes (primary production, nutrient cycling) (Rapport *et al.* 1998, Bunn & Davies 2000). In practice, indicators are often selected with regard to specific management objectives. For example, if the goal is to reduce the frequency and severity of problem algal blooms, then appropriate indicators may include TN, TP, DO and chlorophyll-a (DoE 2004b). If the goal is to protect wader feeding habitat, then appropriate indicators should include the aerial extent of inundation of the estuaries as a measure of the availability of shallow water and mud-flat foraging areas. Depending on the goals, a considerable range of potential indicators may still be required, covering physical, chemical and biological parameters (MEWG 2006). Indicators must be well defined, have sound scientific meaning (knowledge of cause-effect pathways), be readily understood and have a practical means of measurement (Browne *et al.* 2007). Targets for any particular indicator in one wetland type within the Site may need to be quite different to those in another wetland type.

Indicators and targets have already been set for another of the State's nutrient-enriched estuaries; the Swan-Canning system near Perth. Funding through the Swan River Trust as part of the Swan-Canning Cleanup Program (SCCP), lead to the development of catchment runoff and nutrient models (DoE 2004b). Gathering of baseline data for the models included weekly sampling for a range of water quality parameters (refer also Section 12.3). Results of the modelling enabled target TN, TP, DO and chlorophyll-a levels to be set for individual reaches of the Swan-Canning system, including tributary rivers. Targets included short-term (0 - 5 years) "Management Action Targets", long-term (10 - 20years) "Resource Condition Targets" and "Aspirational Targets" (>50 years) (DoE 2004b). Methods employed to set targets were based on a statistical approach (percentiles from baseline data, collected over a number of years) together with consideration of current ANZECC/ARMCANZ (2000) guidelines for water quality. Indicators chosen were based on goals relating largely to problematic algal blooms and their impact on public health and amenity. Indicators included DO, chlorophyll-a, phytoplankton cell counts, TN, DIN, TP & DIP).

The same approach is appropriate for the Vasse-Wonnerup Site and could be readily incorporated into the existing Vasse-Geographe CCI Water Quality Improvement Plan (refer DoW 2006).

Table 27. Interim limits of acceptable change (LOAC) for key ecological features of the Vasse-Wonnerup Ramsar Site.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Geomorphology			
Winter aerial extent of inundation	Important to provide freshwater in spring for waterfowl chicks - needs to be < 15,300 mg/L to allow successful recruitment. Winter aerial extent of inundation is a key determinant of the carrying capacity for nesting swans. Flooded pasture grasses believed to be an important early-season food source for nesting swans – needs seasonal flooding. No baseline data on aerial extent or duration of inundation. Need to maintain current aerial extent in each winter month.	Insufficient data - need to define current inter-annual variability in aerial extent of inundation in each winter month to define allowable change. Baseline data should be gathered over a minimum 2-3 year period. Winter maximum aerial extent (ha) in each wetland to be determined from current median coverage, once baseline data are gathered. Winter minimum aerial extent of inundation to be similarly determined to avoid reduction in wetland habitat/carrying capacity.	As for short-term target.
Summer aerial extent of inundation	Many waterbirds forage on the mudflats that are exposed by seasonal drying. Summer aerial extent of inundation determines waterbird carrying capacity. No baseline data on summer maximum water level/aerial extent of seawater inundation required to avoid adversely effecting riparian vegetation through salinity.	Insufficient data - need to define current inter-annual variability in aerial extent of inundation in each summer month to define allowable change. Baseline data should be gathered over a minimum 2-3 year period. Summer maximum aerial extent (ha) in each wetland to be determined from current median coverage, once baseline data are gathered. Summer minimum aerial extent of inundation to be similarly determined to avoid reduction in wetland habitat/carrying capacity.	As for short-term target.
Water depth and floodgate operation	Operation of floodgates on estuary exit channels used to manipulate water levels: i) for winter flood control, ii) for maintenance of freshwater over spring for breeding waterfowl, iii) to maintain reasonably stable water levels for swan nesting, iv) to limit saltwater inundation of summer grazing pastures, v) to facilitate some tidal flushing over summer to prevent fish deaths associated with anoxia due to algal blooms. No bathymetry maps to indicate current seasonal and spatial variations in water depth.	No departure from existing strategy, which uses remote and automatic operation to respond to changes in water levels, water quality and fish movements. Operational guidelines recommend a stable winter-spring level of +0.4 m AHD for swan broods, gradually reducing to a summer maximum of -0.1m AHD to prevent flooding of grazing land and loss of remnant vegetation. Same type of rule needed for winter to determine maximum level (AHD) to prevent flooding of surrounding farmlands.	As for short-term target.
Sand bar opening	Sand bar (& often weed bar) at the mouth of Wonnerup Inlet is strategically opened over summer-autumn to allow tidal flushing of the lower estuaries (predominantly the Vasse Estuary) to help reduce frequency and severity of fish kills. At present, the bar naturally opens most winters, except if large storms result in greater accumulation of sand and seaweed.	No departure from existing operational strategy, which requires manual opening of the bar to correspond with floodgate openings. Width of bar opening >13 m, depth 2 m.	As for short-term target.

Table 27 continued.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Soils and Sediments			
Salinity Vertical and longitudinal soil profiles on lands adjacent to the estuary and tributary rivers	No current data on seasonal or spatial trends. Soil salinity likely to vary dramatically at low elevation close to the estuary dependent on seasonal water regime. Salinity has a major influence on the structuring of vegetation communities and increased salinisation has lead to some changes in fringing vegetation.	Insufficient data. Site specific minima and maxima should be developed for each Ramsar wetland type and each 'season' using 20%ile and 80%ile values from baseline data (*sensu* ANZECC[c]) collected over a minimum 2-3 year period.	As for short-term target.
Nutrients and Acidity Nutrient concentration, pH	No baseline data on soil / sediment chemistry. Wetland sediments can act as both sources and sinks of nutrients. Shallow flooded muds and margins are typically important zones of denitrification. High risk of acid sulphate soil drainage.	Insufficient data. Site specific minima and maxima for nutrients and pH should be developed for each Ramsar wetland type and each 'season' using 20%ile and 80%ile values from baseline data (*sensu* ANZECC[c]) collected over a minimum 2-3 year period.	As for short-term target.
Sedimentation Erosion / deposition rate	No baseline data on rates of sedimentation or erosion. Natural sedimentation and erosion processes are important in shaping the estuaries and river deltas and in deposition of mud flats which provide important habitat for biota. Artificially high rates, however, can lead to excessive infilling, loss of habitat and reduced water clarity.	Data insufficient at this time.	Data insufficient at this time.
Metals, Oils, Petroleum Hydrocabons, Pesticides, Herbicides	No baseline data on levels of residual contaminants or bioavailability.	ANZECC trigger values should be used as LOAC where available.	As for short-term target.
Hydrology / Hydrogeology			
Groundwater inflows Discharge Frequency Duration Water table level	Groundwater inflows believed to be a major contributor to freshwater inflows to the wetlands, but there is no water balance model and no data on hydraulic gradients. No information on the relative contribution of groundwater to fresh-water inflow in winter.	Data insufficient at this time to specify monthly inflow volumes, frequency, duration or drawdown. Need to maintain freshwater inflows sufficient to sustain current salinity regime.	As for short-term target.
Surface water inflows Discharge Frequency Duration	Insufficient data. No water balance models. No data on residence times. Freshwater surface inflow important to inundate estuary during winter-spring. Important in maintaining salinity regime and thus estuarine biota. Important to support estuarine fish breeding (*e.g.* black bream) and possibly *Ruppia* recruitment.	Data insufficient at this time to specify monthly volumes, frequency or duration. However, once understood, the potential exists to manipulate timing and extent of freshwater inflows in winter months using existing bypass channels and drain system.	As for short-term target.

Table 27 continued.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Water Quality			
Nutrients Concentration (μg/L or mg/L) TN, DON, NO_2, NO_3, NH_3, TP, PO_4 Nutrient loads (per unit area or per unit volume)	Historic data inadequate/unavailable to determine trends. No baseline data on spatial and seasonal bioavailability of NO_3, NH_4, PO_4. No data on current nutrient loads, sediment stores, residence times, re-cycling or denitrification rates. No data on relative contributions of various point and diffuse sources to nutrient loads. No data describing relationship between waterbird (or invertebrate) abundance and nutrient concentrations. No data on maxima or minima to protect waterbird (or invertebrate) populations.	Insufficient data. Need to develop achievable short-term "Management Action" targets (*sensu* DoE 2004b), based on baseline data to be collected fortnightly over a minimum 2-3 year period. It is desirable that at a minimum, there be no statistically significant upward trend in the median 'seasonal' nutrient concentration in the water column or in median 'seasonal' nutrient loads to the Site (as determined by linear regression or an equivalent procedure on future baseline data).	Maximum TP < 50 μg/L to prevent switch from macrophyte (*Chara* / seagrass) dominated to phytoplankton/ macroalgal (*Ulva/ Cladophora*) dominated system. TN loads < 1.6 tonnes/ km^2/year to prevent release of N limitation and saturation of primary production. Insufficient data on other parameters.
Dissolved Oxygen Concentration (mg/L and % saturation)	Insufficient data on seasonal or spatial variation. DO naturally fluctuates over the course of the day in response to levels of aquatic community respiration and photosynthesis. Low levels (<50%) may occur naturally in highly productive waterbodies such as estuaries, particularly at night. Super-saturated levels (>100%) also harmful to fish due to formation of gas bubbles inside blood vessels. Tiny air bubbles released by phytoplankton blooms are believed most problematic to fish, rather than larger bubbles released by macrophytes. Anoxia reduces denitrification efficiency of sediments, which then become a source rather than a sink for nitrogen. Phosphorus is also likely released under anaerobic conditions.	Insufficient data - need to develop Site specific minima and maxima for each 'season' using 20%ile and 80%ile values from baseline data to be collected fortnightly over a minimum 2-3 year period. In the absence of Site-specific data for estuary, use a day-night range of 50 - 110% saturation for the protection of fish and macro-invertebrates. % saturation not to exceed upper or lower range. For daytime only, use ANZECC[c] trigger range of 90 - 110%.	As for short-term target.
pH (pH units)	Insufficient baseline data. Changes in pH are both a direct and an indirect ecological stressor (pH effects the availability of toxicants such as NH_3 & heavy metals). Has a high natural variability. Influenced by the effect of algal growth on dissolved CO_2 and by run-off/leaching from disturbed acid sulphate soil. Low pH water associated with ASS is the result of sulphuric acid formation and can generate serious heavy metal pollution.	Insufficient data - need to develop Site specific minima and maxima for each 'season' using 20%ile and 80%ile values from baseline data to be collected fortnightly over a minimum 2-3 year period. In the interim, use ANZECC[c] trigger range of 7.5 - 8.5.	As for short-term target.

Table 27 continued.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Sulphate and Iron Concentration of dissolved SO_4 and Fe (mg/L)	No baseline data. Elevated levels may be indicative of acid sulphate soil (caused by iron sulphides) and agricultural fertiliser (zinc sulphate) run-off. Pulses of acidic water from acid sulphate soils are a common cause of fish kills in other parts of Australia. If waters are of high alkalinity this may afford increased buffering capacity against acid drainage, but there is still the risk of increased anoxia if sulphidic minerals are exposed by either physical disturbance or through lowered water tables. Interactions between Fe, SO_4 and PO_4 are thought to influence *Lyngbya majuscula* bloom formation in particular.	Insufficient data - Site specific maxima should be developed for each 'season' using 80%ile from baseline data collected fortnightly from target sites. Advice required on duration of sampling. There are no ANZECC[c] trigger values for SO_4 or Fe.	As for short-term target.
Total Suspended Sediment and Turbidity Concentration of TSS (mg/L) and/or turbidity (NTU) Secchi depth (cm)	No current data on seasonal or spatial trends in turbidity or TSS. Turbidity and TSS can be expected to vary with freshwater inflows, wind and tidal actions. Part of natural sedimentation and erosion processes. Artificially high levels can affect aquatic plant growth by reducing light penetration and physically smother aquatic biota. In other wetland systems, Secchi depth ≥ 90cm is believed necessary to maintain seagrass communities (Phillips & Muller 2006).	Insufficient data - Site specific maxima for turbidity and TSS should be developed for each Ramsar wetland type and 'season' using 80%ile values from baseline data, to be collected fortnightly over a minimum 2-3 year period. It is desirable that at a minimum, there be no statistically significant upward trend in the median 'seasonal', TSS levels in the water column (as determined by linear regression or an equivalent procedure on future baseline data).	As for short-term target.
Salinity Concentration of total dissolved solids (mg/L) and/or conductivity (mS/cm)	Insufficient data on spatial and temporal variability. Salinity varies dramatically spatially and over seasonal water regime cycles from fresh to hypersaline. Salinity has a major influence on the structuring of aquatic plant and animal communities. Excessive salinity in spring (>15,300 mg/L) can result in duckling mortality as they are unable to osmoregulate salt until past a certain developmental stage. Rapid increases in salinity may reduce *Ruppia* recruitment.	Insufficient data - Site specific minima and maxima should be developed for each Ramsar wetland type and each 'season' using 20%ile and 80%ile from baseline data, to be collected fortnightly over a minimum 2-3 year period. Maximum salinity target for winter-spring should be determined from 80%ile of baseline data. Duration (months, weeks) to be determined once baseline data are available. Maximum winter-spring level should remain below sensitive thresholds for juvenile waterfowl.	As for short-term target.
Temperature	Insufficient data on spatial and temporal variability. Influence on algal bloom dynamics needs to be understood. Climate change and warmer water temperatures may lead to algal blooms occurring earlier in the year.	Data insufficient at this time- need to collect data to establish spatial and temporal variability before deciding if temperature would be a useful indicator.	Data insufficient at this time.
Metals, Oils, Petroleum Hydrocabons, Pesticides, Herbicides	No baseline data on levels of contaminants or bioavailability.	ANZECC[c] trigger values should be used as LOAC (where available).	As for short-term target.

Table 27 continued.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Flora			
Phytoplankton Community structure (type and number of species present)	Several genera of chlorophyte, diatom, dinoflagellate and cyanophyte have been identified. Little information on species present. No data on seasonal or spatial variation	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability. It is desirable that at a minimum, there be no net increase in the proportion of nuisance algae - to be determined following analysis of future baseline data (multivariate analysis should be used to derive a community 'similarity' approach).	As for short-term target.
Biomass (dry weight grams per unit area) and/or cell counts (No. of cells/ml)	There are persistent, severe blooms of potentially toxic cyanobacteria associated with high nutrient levels. No data on successional dynamics or distribution. No data on the role of salinity, TSS, temperature, dissolved iron and silica and wind action in bloom formation. A reduction in bloom formation is desirable (in particular potentially toxic algal blooms), however, mini-blooms are beneficial to food-webs.	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability in biomass / cell counts. It is desirable that at a minimum, there be no statistically significant upward trend in the median 'seasonal' values for total biomass / cell counts (as determined by linear regression or an equivalent procedure on future baseline data).	Maximum cell count of <15,000-20,000 cells/ml for nuisance algae. Insufficient data on other parameters.
Chlorophyll and phaeophytin (concentration μg/L or mg/L)	No data on seasonal or spatial variation. May be too spatially and temporally variable to use as an indicator. Chlorophyll is an indicator of phytoplankton biomass, but can vary widely dependent on light regime (which affects chlorophyll production) and phytoplankton health. Phaeophytin is a breakdown product of chlorophyll degradation.	Data for estuary insufficient at this time - need to collect data to establish spatial and temporal variability before deciding if chl-a would be a useful indicator. Base-line data to be collected fortnightly over a minimum 2-3 year period. For tributary rivers use ANZECC[c] trigger value of 3-5 μg/L chl-a.	As for short-term target.
Macro-algae Community structure (type and number of species present)	Several genera of macro-algae have been identified - *Ulva*, *Chara*, *Cladophora*, *Rhizoclonium*, *Chaetomorpha*. Little information on species present or spatial and temporal variation in species composition.	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability. It is desirable that at a minimum, there be no net increase in the proportion of nuisance algae - to be determined following analysis of future baseline data (multivariate analysis should be used to derive a community 'similarity' approach).	As for short-term target.
Biomass (dry weight grams per unit area)	Recent trend of increasing nuisance blooms of *Ulva* and *Cladophora* species. Only one-season's data on spatial distribution (Wilson *et al.* 2007) and no data on temporal trends. No data on the role of salinity, TSS, temperature and wind action in bloom formation. A reduction in nuisance bloom formation is desirable, however mini-blooms are beneficial to food-webs. Beds of *Chara* may provide important food source for waterfowl and important habitat for fish and macroinvertebrates.	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability in biomass. It is desirable that at a minimum, there be no statistically significant upward trend in the median seasonal values for biomass of nuisance algae (as determined by linear regression or an equivalent procedure on future baseline data).	Once seasonal and annual distributions are known, an upper and lower limit to the aerial extent can be specified.

Table 27 continued.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Seagrasses Community structure Aerial extent	At least 3 species of seagrass are known to occur - *Ruppia megacarpa*, *Ruppia ?polycarpa*, *Lepilaena cylindrocarpa*. No data on aerial extent Only one-season's data on spatial distribution (Wilson*et al.* 2007) and no data on temporal trends. Seagrass beds are an important food and habitat source for waterfowl and likely also fish and macro-invertebrates. They support biofilms on their roots and stems which play can play an important role in denitrification. The importance of seagrasses to ecosystem function in the Site is unknown	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability in aerial extent.	Once distributions are known, a lower limit to winter and summer aerial extents can be specified.
Samphire heath and sedgelands Community structure Aerial extent	Large areas of low samphire heath (*Sarcocornia blackiana, Halosarcia pergranulata*) at elevations of 0-1 m AHD. These are often backed by mixed sedge-lands (*Juncus kraussii*, *Lepidosperma* cf. *leptostachyum*, *Carex divisa*). Provides habitat connectivity between estuary and remnant upslope eucalypt-paperbark-peppermint woodlands. Samphire is important source of nesting material for breeding swans. No data on aerial extent. Only one-season's data on spatial distribution (Froend *et al.* 2000) and no data on temporal trends.	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability in aerial extent.	Once distributions are known, an upper and lower limit to winter and summer aerial extents can be specified.
Paperbark / flooded gum / peppermint woodlands Community structure Aerial extent Condition/health Recruitment / mortality	Some remnant paperbark (*Melaleuca rhaphiophylla*, *M. hamulosa*, *M. cuticularis*) and mixed flooded gum (*Eucalyptus rudis*) and peppermint (*Agonis flexuosa*) woodlands occur at higher elevation and along tributary rivers. Provides habitat connectivity with saltmarsh/sedgelands and remnant upslope tuart woodlands. No data on aerial extent. Only one-season's data on spatial distribution (Froend *et al.* 2000) and no data on temporal trends. No data on recruitment / mortality rates.	Data insufficient at this time.	Once distributions are known, a minimum limit to the aerial extent can be specified.
Tuart woodlands Community structure Aerial extent Condition/health Recruitment / mortality	Tuart *Eucalyptus gomphocephala* high woodland along the lower Abba and Sabina rivers at elevations > 2.5 m AHD. Provides habitat connectivity with remnant paperbark-flooded gum peppermint woodlands. No data on aerial extent. No data on spatial or temporal trends. No data on recruitment / mortality rates.	Data insufficient at this time.	Once distributions are known, a minimum limit to the aerial extent can be specified.

Table 27 continued.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Fauna			
Aquatic Invertebrates Number of zooplankton and macroinvertebrate species	No baseline data. Temporal and spatial variation is unknown. No data on contribution of various invertebrate species to waterbird and fish diets.	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability (minimum 3 years with biannual sampling). LOAC for species richness in each Ramsar wetland type to be determined following analysis of future monitoring data.	As for short-term target.
Community composition	No baseline data. Temporal and spatial variation is unknown.	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability (minimum 3 years with biannual sampling). LOAC for community composition and functional feeding groups in each Ramsar wetland type to be determined following analysis of future monitoring data (multivariate analysis should be used to derive a community 'similarity' approach).	As for short-term target.
Abundance of zooplankton and benthic invertebrate species	Temporal (intra and inter-annual) and spatial variation is unknown. Data on abundances required to maintain existing waterbird populations are unavailable. No data on the relative importance of benthic inverts in sediment bioturbation in nutrient cycling within the estuary.	There is insufficient data available. There is likely to be marked variation between years, and observed differences between years are often difficult to interpret. Need to collect data to establish spatial and temporal variability before deciding if abundance would be a useful (*i.e.* practical) indicator.	As for short-term target.
Fish & Decapod Crustacea Number of fish and crustacea species	At least 29 native fish species recorded, but generally as incidental records. Temporal and spatial variation is unknown. There is likely high inter-annual variation in fish species numbers. Many species respond to stochastic and anthropogenic influences beyond the Site (*e.g.* marine species which spawn offshore). No data on seasonal migrations into or out of the estuary. Insufficient data to quantify relationships between fish distribution and abundance and water quality. No data on contribution of individual fish species to waterbird diets.	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability (minimum 3 years with biannual sampling). LOAC for species richness to be determined following analysis of future monitoring data.	As for short-term target.
Community composition	Temporal and spatial variation in species assemblage composition is unknown.	Data insufficient at this time - need to collect baseline data that captures spatial and temporal variability (minimum 3 years with biannual sampling). LOAC for community composition to be determined following analysis of future monitoring data (multivariate analysis should be used to derive a community 'similarity' approach).	As for short-term target.

Table 27 continued.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Abundance of fish and crayfish	Temporal and spatial variation is unknown. No data on abundances required to maintain existing waterbird populations. No quantitative data on intra- and interannual variation in abundances.	There is insufficient data available. There is likely to be marked variation between years, and observed differences between years are often difficult to interpret. Need to collect data to establish spatial and temporal variability before deciding if abundance would be a useful (*i.e.* practical) indicator.	As for short-term target.
Waterbirds Number of waterbird species recorded at site annually	83 species have been recorded *in toto*, but available data suggests the number occurring in any one year is closer to 60. There is, no doubt, some interannual variation due to vagrants (particularly migrant shorebirds) and irruptions (some inland and northern breeding species).	No less than 60 species recorded for two consecutive years (assumes thorough surveys conducted each year).	No statistically significant (as determined by linear regression or an equivalent procedure) downward trend (from 60) in the number of species recorded over the selected long term period (10-20 years).
Community structure	Different areas of the Site support different waterbird communities depending on habitat availability. Communities constitute single or mixed foraging guilds and breeding guilds. Community structures also vary annually and seasonally. From a management perspective it would be useful to describe the community structures of the major management components of the Site, these being the Vasse Estuary, Wonnerup Estuary, Malbup Creek and Wonnerup Inlet. Further analysis and collection of data would be required to do this.	Community structure shows marked variation between seasons, years, major management components and habitats. Observed differences are difficult to interpret, particularly those between years. There is insufficient data available yet to define short-term LOACs for this Site.	No statistically significant change in population structure - to be determined following analysis of existing and future monitoring data - multivariate analysis should be used to derive a community 'similarity' approach.
Abundance of waterbirds recorded in annual/bi-annual surveys	Supports peak numbers of 25,000 - 35,000 in most years. Existing large numbers of birds are desirable for local tourism industry, education and for the area's 'sense of place'.	No less than 25,000 birds recorded for two consecutive years.	No statistically significant (as determined by linear regression or an equivalent procedure) downward trend (from 30,000) in the number of birds recorded over the selected long-term period (10-20 years).
Species regularly present in numbers > 1% of relevant Ramsar population: - Black-winged Stilt	This resident shorebird species regularly occurs, with annual peak numbers generally in the vicinity of 3,000 - 4,000 birds. The current 1% of (Ramsar) population level is 3,000 birds.	No less than 3,000 birds recorded for two consecutive years.	No statistically significant (as determined by linear regression or an equivalent procedure) downward trend (from 3,500) in the number of birds recorded over the selected long-term period (10-20 years).
Species regularly present in numbers > 1% of relevant Ramsar population: - Red-necked Avocet	This resident shorebird species regularly occurs, with annual peak numbers generally in the vicinity of 1,000 - 2,000 birds. The current 1% of (Ramsar) population level is 1,100 birds.	No less than 1,100 birds recorded for two consecutive years.	No statistically significant (as determined by linear regression or an equivalent procedure) downward trend (from 1,500) in the number of birds recorded over the selected long-term period (10-20 years).

Table 27 continued.

'*Ecological character*' key ecological features / potential indicators	Existing[A] condition and range of natural variation (where known)	Interim limits of acceptable change[B] Short-term Target (1-5 years)	Long-term Target (10 - 20 years)
Species regularly present in numbers > 1% of relevant Ramsar population: - Australian Shelduck	This resident duck species regularly occurs, with annual peak numbers generally in the vicinity of 2,500 - 3,500. The current 1% of (Ramsar) population level is 2,400 birds.	No less than 2,400 birds recorded for two consecutive years.	No statistically significant (as determined by linear regression or an equivalent procedure) downward trend (from 3,000) in the number of birds recorded over the selected long-term period (10-20 years).
Species regularly present in numbers > 1% of relevant Ramsar population: - Australasian Shoveler	This resident duck species regularly occurs, with annual peak numbers generally in the vicinity of 300 - 700. The current 1% of (Ramsar) population level is 120 birds.	No less than 250 birds recorded for two consecutive years.	No statistically significant (as determined by linear regression or an equivalent procedure) downward trend (from 500) in the number of birds recorded over the selected long-term period (10-20 years).
Species NOT regularly present in numbers > 1% of relevant Ramsar population (*i.e*. all species recorded on Vasse-Wonnerup apart from the five species listed above and the threatened species listed below)	The ca. 80 species of this group are known to range in annual peak numbers from 1 to 14,000. Some are present every year whereas others have only been recorded once in the past ca. 25 years. Further analysis of existing data is required before the usual range in annual peak numbers of each species can defined.	Further analysis of existing data is required before LOACs can be set for each species. Given the low numbers and/or high variability in numbers of many of these species and the broad coverage provided by the "Abundance of waterbirds" LOAC above (*i.e*. 25,000 birds), it is suggested that the interim short-term LOAC for each species should be: "No less than 50% of the lower limit of the usual range in annual peak numbers, recorded for two consecutive years". 50% is a somewhat arbitrary figure that could be refined upwards in the future when more counts have been conducted.	For each species, no statistically significant (as determined by linear regression or an equivalent procedure) downward trend (from the mid-point of the usual range in annual peak numbers) in the number of birds recorded over the selected long-term period (10-20 years). Note: determination of the "usual range" for each species currently requires the exercise of some 'site-familiar', expert judgement. In the future, when more counts have been conducted, it should be possible to more-rigorously define these ranges.
Breeding success: - Black Swan Insufficient data exists for the setting of LOACs for other breeding species on Vasse-Wonnerup.	'Swan Lake' supports in the vicinity of 50-150 pairs of nesting swans in most years.	Not less than 50 successfully nesting pairs of swans on 'Swan Lake' for two consecutive years.	No statistically significant (as determined by linear regression or an equivalent procedure) downward trend (from 100) in the number of successfully nesting pairs on 'Swan Lake'.
Threatened species: - Australasian Bittern - Painted Snipe	Each species has only been recorded on one occasion and each record was of only one individual. On current knowledge these species must be categorised as rare vagrants (*i.e.* highly infrequent - once in 30 years) to the Site.	On current knowledge, the setting of limits is not warranted.	On current knowledge, the setting of limits is not warranted.

[A]Unless otherwise indicated, 'existing' condition is the same as that at time of Ramsar listing.

[B]Limit of acceptable change = human-induced alteration of any ecosystem component, process, and/or ecosystem benefit/service considered acceptable without causing a fundamental change in the ecological character of the Site. The change may be adverse or positive. For example, some reduction in nutrient load is desirable in order to prevent frequent, severe algal blooms, fish deaths and possible ecosystem collapse. However, nutrient reduction that leads to a decline in bird food sources resulting in (for example) less than 60 waterbird species being recorded for two consecutive years or a statistically significant downward trend (from 60) in the number of species recorded over 10-20 years, would be considered an unacceptable change.

[C]ANZECC = ANZECC/ARMCANZ (2000) recommend that site-specific guideline limits or targets be set. Seasonal minima and maxima should be calculated as the 20th and 80th percentiles from baseline data. Median (rather than mean) seasonal values from monitoring data should then be compared to these site-specific guidelines. In the absence of baseline data, data from suitable reference sites may be used.

9. CHANGES TO ECOLOGICAL CHARACTER SINCE TIME OF LISTING

The *National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands* (DEW 2007) states that, as the description of ecological character is the baseline reference for assessing change, it is not appropriate to update that reference in a way that describes the wetland in a more recent state if there is evidence that the wetland has undergone adverse change since listing. An update to the description should only be considered in the following circumstances:

1. If the wetland undergoes favourable human-induced changes as a result of a rehabilitation and/or restoration project or if the wetland undergoes natural evolutionary change. In such cases the ecological character of the wetland may change to the extent that a new baseline is required for assessing impacts of proposed actions and for monitoring and evaluating future change;
2. If further substantial data, knowledge or resources are available to improve the original description. In such cases the aim would be to expand on, clarify and refine the original baseline, not to establish a new baseline by describing a more recent, changed ecological state;
3. If the boundaries of the site are extended, reduced or modified, in which case the Ramsar Information Sheet and the ecological character description should be re-examined and updated where required.

In all cases, the original description is to be retained and an updated version prepared.

9.1 Changes since Last (2000) Update to Ramsar Listing

For the Vasse-Wonnerup, there is insufficient baseline and monitoring data to identify changes since the last update in 2000 and there have been no modifications to the boundary of the Site since that time. However (largely) anecdotal evidence, as outlined in the preceding chapters, does suggest both detrimental and beneficial changes have occurred since 2000:

Detrimental Changes

- Frequency of severe phytoplankton blooms during spring, summer and autumn has increased.
- Increase in toxic algal blooms is suggested by a recent, new report of local commercial fishermen suffering skin lesions following contact with estuary water.
- Trend of increasing macroalgal blooms in both estuaries and of blue-green blooms in the Wonnerup Estuary. This is of particular concern as it may signal a shift in stable state from a seagrass-macrophyte dominated ecosystem to a phytoplankton-macroalgal dominated one. Blooms of blue-green *Nodularia* were first reported in the mid and upper reaches of Wonnerup Estuary in January 2000 (Paice 2001). Large amounts of filamentous green algae (possibly *Ulva*, *Cladophora* & *Rhizoclonium*) are also often observed in upper reaches of the Wonnerup Estuary (Paice 2001). Local residents reported increased blooms of sea lettuce (*Ulva lactuca*) and filamentous *Ulva clathrata* and *Cladophora* in the lower Vasse Estuary over summer 2003/04 (Geographe Network News, Issue 9, November 2004). If blooms are indeed increasing in frequency and occurrence it may indicate a shift in ecosystem stable state is underway (refer Section 5.4.1).
- During 2005/06 and 2006/07, local residents experienced an increase in the severity of noxious odours emitted from drying sediments of the lower Vasse Estuary as water levels declined over summer and autumn (Ron Assan, Wonnerup, pers. comm.). This was most problematic in reaches along Estuary View Drive (off Layman Road) and down to the Vasse Estuary floodgates.
- Trend toward increasing TN concentration in waters of the tributary Sabina River.
- Tributary rivers show no decline in nutrient concentration. Analyses of available nutrient and flow data indicate nutrient loads to the system have not decreased. Reduced river in-flow associated with climate change, may lead to higher nutrient levels in the water column due to concentration effects of reduced water levels. If this occurs, eutrophication of the Ramsar Site will continue to worsen (Hall *et al.* 2006).

Beneficial changes

- Reduced incidence of sudden mass fish deaths due to monitoring refinements to operation of the estuary floodgates and summer openings of the sandbar at the mouth of Wonnerup Inlet.
- Trend of decreasing TP and TN concentration for at least some lower reaches of the tributary Vasse River. The decline in water column TP levels is believed associated with Phoslock™ application as part of remedial plans for water quality under the Vasse River Cleanup Program.

9.2 Changes between 1990 Ramsar Listing and 2000 Update

Between February 1998 and May 2000, Lane *et al.* (2007) undertook detailed monthly (November - May) surveys of waterbird numbers at the Site. Data collected was compared against that recorded from similar surveys between 1981 and 1990 (refer Section 4.14.4) in order to determine if the Site continued to meet Ramsar criteria for which it was listed in 1990. Lane *et al.* (2007) concluded:

1. The Site continues to meet Ramsar Criterion 5 – regularly supports more than 20,000 waterbird species.

   Annual counts were in excess of 20,000 waterbirds for each of the three years surveyed 1998, 1998/1999 and 1999/2000. Maximum counts were ca. 35,000 waterbirds in December 1998 and ca. 20,300 in January 1999. The maximum of ca. 35,000 recorded in 1998 exceeded all previous counts 1981 – 1990, the five highest of which were ca. 29,900 (Jan. 1988), 28,900 (Dec. 1987), 28, 300 (Dec. 1986), 26,500 (Jan. 1989) and 17, 500 (Dec. 1987).

2. The Site continues to meet Ramsar Criterion 6 – regularly supports 1% of individuals in a population of one species or subspecies of waterbird.

   Five species had maximum counts in excess of relevant Ramsar (south-west regional, national or international populations, as appropriate) in 1998 - 2000:

Species	Maximum Count at Vasse Wonnerup Site 1998-2000	Population / Sub-population (Wetland International 2006)
Australian Shelduck	3378 (Jan. '99)	South-western Australia
Australian Shoveler	355 (Apr. '98)	South-western Australia
Black-winged Stilt	3494 (Jan. '00)	SE Asia – Australasia
Red-necked Avocet	2000 (Dec. '98)	Australia
Red-capped Plover	998 (Feb. '99)	Australia

   These counts were mostly within the range previously recorded (1981 - 1990) for each species. Only the red-capped plover occurred in greater abundance in 1998 - 2000; prior to this, annual occurrences have been fewer than the estimated 1% level for the Australian population. Therefore, with the exception of the red-capped plover, the Site was considered to regularly support 4 species in excess of the 1% of regional, national or international population.

3. Abundances of a number of waterbird species recorded in the 1998 - 2000 surveys were less than previous estimates. For a few of these species, this was attributed to the fact that most, but not all habitats were included in all surveys post-1998. For others, closer investigation of historic data is warranted to determine if apparent declines are indeed actual and not just artefacts of differences in survey methods. Species of concern include:
   - Blue-billed Duck,
   - Great Cormorant,
   - Great Egret,
   - Curlew Sandpiper,
   - Long-toed Stint,
   - Wood sandpiper.

   A few of these species are reported to be in regional and/or national decline (*e.g.* Blue-billed Duck, Great Egret, Curlew Sandpiper) and apparent reduced abundances at the Vasse-Wonnerup Site may reflect this.

There is insufficient baseline and monitoring data to identify changes in other components or processes between the time of Ramsar listing in 1990 and the 2000 extensions.

10. ACTUAL AND LIKELY THREATS / RISK TO THE SITE

A list of actual and likely threats to the Vasse-Wonnerup Wetlands is given in Table 28 together with the risk to the ecological integrity of the Site as a whole, and recommended management and monitoring actions. Major threats to the ecological integrity of the site are considered to be:

- Hyper-eutrophication
  - switch in stable state from macrophyte to plankton dominated,
  - botulism and resultant mass bird mortalities (though the actual risk under brackish and saltwater conditions has not been investigated),
  - increased frequency and severity of toxic algal blooms,
  - increased frequency of sudden mass fish death events,
  - loss of amenity,
  - possible ecosystem collapse.
- Urban and industrial development
  - increased use of pesticides, herbicides, heavy metals and oils,
  - physical and noise disturbance of waterbirds.
- Changes to the hydrology
  - climate change and rising seawater levels, reduced rainfall and reduced surface/groundwater flows,
  - abstraction from aquifers.
- Acid sulphate soils.

A brief discussion of actual and likely threats is presented in the following sub-sections.

10.1 Hyper-eutrophication

The Vasse-Wonnerup Site is highly nutrient-enriched (eutrophic) due to catchment input from several diffuse and point sources, including agricultural fertilisers, stock wastes, urban and industrial drains and unsewered areas of Busselton township (McAlpine *et al.* 1989, Paice 2001, DoE 2004a). Residential sub-divisions, industrial developments and agricultural intensification all have the potential to increase nutrient export to the Site if not carefully managed. Eutrophication has already lead to anoxia, fish kills, turbid and foul smelling (mephitic) water, likely reduced biodiversity of habitats and reduced aesthetic quality of the estuary. Severe eutrophication, or hyper-eutrophication, can have numerable direct and indirect adverse consequences (refer also Section 5.4 & 5.6), including:

- Change in ecosystem stable state with dominance of certain phytoplankton and macroalgal taxa;
- Change in algal and seagrass communities may ultimately affect herbivorous fish and waterbirds;
- Loss of habitat integrity;
- Increased oxygen consumption and increased incidence of hypoxia and anoxia;
- Increased severity of noxious sulphur gases (H_2S, SO_2, VOSC) emitted from drying sediments;
- Smothering of fish and waterbird feeding, shelter and breeding habitats by algal mats;
- Change in palatability of prey through anoxia;
- Increased direct toxicity effects on fish and waterbirds;
- Increased export of nutrients to Geographe Bay resulting in eutrophication of the Bay and associated water quality problems.

10.2 Urbanisation

The Busselton area is one of Australia's fastest growing centres for residential and tourism development (WAPC 2005). The population is expected to nearly double over the next 20 years (Shire of Busselton 2006). Much of the land bordering the Vasse Estuary is currently zoned rural residential and is under proposal for urban development (*e.g.* rural land sub-divisions for residential housing). Development in the vicinity of the Ramsar Site may cause a reduction in feeding and roosting habitat for waterbirds and shorebirds. Drainage and landfill of floodplain waterbodies for residential subdivision and roadways has implications for both groundwater drawdown and altered surface flows. Houses and roads built adjacent to Vasse Estuary and associated increased urban activity, traffic and lighting may disturb nesting, roosting and feeding waterbirds. Higher traffic volume alone, will increase the risk of wetland pollution from oils and vehicle emission. Concerns about such threats have previously been raised by both DEC and the local community in relation to Shire of Busselton's proposal to construct (new) Ford Road across the Vasse Estuary to cater for increased traffic (refer EPA 1999, 2000). One of the primary concerns was that the new road would pass through an area of high conservation status; upstream of Ford Road is an important area for waterbird feeding, foraging and nesting, with many birds and broods travelling both upstream and downstream of the proposed alignment (EPA 2000). Under the EPBC Act, any such proposal must be referred for ministerial approval.

Airport noise and aircraft movement over the wetlands may also scare birds; *e.g.* for recreation (powered gliders) and mosquito larvacide application (helicopter). Increased numbers of dogs, cats, foxes and rats may prey on nesting waterbirds. Soil disturbance and any further clearing of remnant vegetation clearing has the potential to increase sediment loads and turbidity levels in tributary rivers and the estuary and increase the risk of acid sulphate soil drainage.

Pollution by heavy metals, TBTs, hydrocarbons and other toxicants from road run-off and urban drains can affect birds directly through ingestion and indirectly through lethal and sub-lethal effects on macrophytes, plankton, invertebrates and fish. Sub-lethal effects of contamination by polyaromatic hydrocarbons for example, may take two or more years to become apparent. Current ANZECC/ARMCANZ (2000) water quality guidelines for the protection of aquatic ecosystems provide trigger levels for numerous chemical toxicants and are available on-line http://eied.deh.gov.au/water/quality/nwqms/volume1.html.

Increased pesticide/larvacide use (*e.g.* spraying for mosquitoes and midges) associated with growth in commercial and residential developments may have detrimental effects on non-target species either through water-borne or air-borne contamination of wetlands. Larvacides for mosquito control may reduce non-target species that are an important food resource for birds. For example, a number of overseas studies on the larvacide S-methoprene, (currently being trialled for mosquito control by the Shire of Busselton) have found lethal and sub-lethal effects on a number of freshwater crustacea, including crabs, shrimps and crayfish (see Wild & Davis 2005). Northern hemisphere studies have also shown S-methoprene to be moderately toxic to freshwater fish. Despite claims that S-methoprene is relatively non-toxic to non-target organisms, the effect on south-west estuarine and freshwater species is unknown and needs to be monitored. Current ANZECC/ARMCANZ (2000) water quality guidelines for the protection of aquatic ecosystems do not provide trigger levels for S-methoprene due to insufficient data on its effects. Similarly, the organophosphate pesticide Abate (Temephos), commonly used throughout the State to control larval midges, is believed to have deleterious effects on non-target species with some suggestion that Abate may also contribute to growth of cyanobacteria in waterbodies with otherwise low phosphate levels (Wild & Davis 2005).

Herbicides such as glyphosate (*e.g.* Roundup) are widely used by councils throughout the State for weed control. It is important that potential contamination of wetlands by these herbicides be monitored in order to determine possible effects on stream biota. Analyses of water quality should be conducted by registered laboratories that provide detection limits which meet ANZECC/ARMCANZ (2000) trigger values for the protection of slightly to moderately disturbed aquatic ecosystems; *i.e.* 0.37 mg glyphosate/L.

10.2.1 Port Geographe

Port Geographe is a major (300 ha) residential and canal project, bordering the Ramsar Site between Vasse Estuary and Geographe Bay (refer aerial image below). It is expected that the project will take ten years to complete and will include the development of 1,000 residential lots, a marina, shopping complex and tourist facilities.

Port Geographe canal and residential development on the Vasse Estuary (Google Earth, downloaded Nov. 2007)

The Port Geographe development was approved by the EPA in 1995, subject to a number of proponent commitments to be audited by DEC:

1) monitoring estuary water at a number of selected sites to detect any increase in the salinity of the Vasse-Wonnerup wetlands;
2) installation of an impervious barrier at the perimeter of the canal development in the event of detection of increased salinity in estuary;
3) recognising conservation and education values by ceding an area for reservation as a Waterfowl Conservation Area, provision of additional drought refuge areas and source of fresh water, construction of a channel to form a conservation island, construction and donation to the State of a waterbird study centre in consultation with DEC; and
4) various commitments to minimise waterbird disturbance such as:
   a) removal of stock animals and horses from reserve land;
   b) provision of a 50 metre separation between development and the landward edge of the wetlands fringing the edge of the estuary;
   c) construction of a dog-proof fence around the border to the Waterfowl Conservation Area;
   d) provision of appropriate landscaping and revegetation of the estuary edge of the development;
   e) control public access to the Waterfowl Conservation Area; and
   f) appropriate interface treatment between the development area and the conservation reserve area.

It is critical that DEC ensures proponent commitments are met and that adequate and timely monitoring be carried out to ascertain both short and long-term impacts to the Ramsar Site. Any monitoring programs must be statistically rigorous in design and results evaluated by suitably qualified DEC staff.

Given the proximity of the development to the Ramsar Site, it is recommended that potential contamination by pollutants in runoff from the development also be investigated, *e.g.* oils, hydrocarbons, heavy metals, sediment and turbidity loads, acid sulphate soil drainage (see Section 10.4). As noted in Section 5.4.1, the fact that Wilson *et al.* (2007) found large blooms of cyanobacterial *Lyngbya* in the vicinity of the Port Geographe development warrants further investigation to determine if the development is contributing to bloom formation of *Lyngbya* in the estuary. Two local commercial fishermen have recently complained of skin lesions following contact with the water whilst fishing (Jim Lane, pers. comm.). This may be associated with blooms of toxic cyanobacteria such as *Lyngbya*. In Moreton Bay, Qld, *Lyngbya majuscula* is known to cause human health problems such as acute skin lesions, dermatitis, asthma, eye irritation and putrid odours. Though it occurs naturally, blooms are most often ascribed to anthropogenic causes. In Moreton Bay, blooms of this particular *Lyngbya* species appear initiated by iron in acid sulphate soil run-off from disturbed areas (Healthy Waterways 2007). The presence of toxic *Lyngbya* species and their distribution within the Vasse-Wonnerup estuary requires further examination to determine the link (if any) with reported skin lesions and/or the Port Geographe development.

Port Geographe developers are also proposing to translocate ('borrow') 50,000 cubic metres of sand from an area west of, and immediately adjacent to, the mouth of Wonnerup Inlet (Mark Close, Shire of Busselton, pers. comm.) (refer Section 5.1). This translocation is to replace that lost to erosion further down the coast as a result of groyne construction for the marina. If this were to result in permanent opening of the sand bar on Wonnerup Inlet, it would have uncertain and possibly adverse consequences for waterbird and fringing vegetation communities adapted to existing hydrological regimes.

10.3 Changes to Hydrology

10.3.1 Changing Sea Levels / Seawater Intrusion

Sea level rise as currently predicted by climate change models (refer Section 2.1.2) may change the composition of the ecosystem of the Site. Some species will benefit where others will not. The rate of change and species' ability to respond will also affect survival. Land, housing and infrastructure already exposed to river flooding and storm surges will be particularly vulnerable to rising sea levels.

Changes in hydraulic connectivity of aquifers may also lead to seawater intrusion resulting from groundwater drawdown, as has occurred near Bunbury (DoW workshop, May 2006). This may result in landward shift in the seawater interface throughout coastal areas adjacent to Geographe Bay. The accuracy and interpretation of groundwater models used to predict groundwater drawdown needs further investigation. The potential of soil and groundwater salinisation and its likely effect on wetland ecosystems, agriculture and urban infrastructure is not known.

10.3.2 Reduction in Surface Water Flows

Climate Change

The relationship between declining rainfall and reduced river discharge and groundwater recharge is complex. CSIRO models are predicting mean flow reductions for southwest rivers of between 5% and 60% by 2030 (EPA 2006) (refer also Section 2.1.2). While reduced freshwater inflows to the Vasse-Wonnerup Estuary may reduce catchment nutrient input, lower water levels in spring and early summer are likely to exacerbate poor water quality. Increased salinity levels will ultimately alter the estuarine ecosystem with more salt tolerant species and fewer salt-sensitive species. Increased soil salinity levels may also limit agriculture around the estuary.

In regard to climate change, the EPA has previously noted that "the (Vasse-Wonnerup) estuary has…significance…(as) the only substantial coastal plain wetland that, owing to a significant degree of diversion of waters from its original surface catchment to other direct ocean outlets together with direct outflow of (then) 92 million cubic metres flow through the floodgates, has the potential to retain its current water regime should the onset of drier climatic conditions be experienced in the south wets of Australia. This could possible be achieved by the controlled, progressive re-diversion of those waters back into the estuary, and use of the current surplus water that passes directly through the estuary system" (EPA 1989b).

Busselton Flood Management

The construction of a detention basin network in the upper catchment of the Vasse River to enable the Vasse Diversion Drain to cope with estimated 1:100 year flood flows has the potential to further reduce annual discharge from the Vasse River into the Vasse Estuary (refer Section 4.4.1). The relative contribution of Vasse River flows to the water balance of the Ramsar Site needs to be modelled to determine the implications to the Ramsar Site.

10.3.3 Reduction in Groundwater

Climate Change

As noted in Section 2.1.2, the extent to which declining rainfall will be reflected in groundwater recharge is not known. There is a lack of understanding as to how the groundwater systems are responding to existing changes and the exact nature of the interconnection between aquifers. Groundwater level monitoring has shown that shallow water levels on the Swan Coastal Plain over the last 20 years have shown little change, likely because of "the flatness (topography), clay soils, shallow 'water table', winter water logging and control by drains in the Bunbury-Busselton area" (EPA 2006).

Abstraction

In a drying climate, there is mounting pressure to increase abstraction from aquifers for potable supply. DoW has recently conducted risk assessments related to abstraction for potable water supply. In particular, the threat posed by abstraction from the Yarragadee aquifer to vegetation of the Vasse-Wonnerup Wetlands under differing scenarios of abstraction and regional growth (EPA 2006). DoW identified low risk under current (as at 2005) usage, as groundwater levels in the superficial aquifer were believed generally stable and influenced by rainfall, rather than re-charge from the underlying Yarragadee aquifer. They found water levels varied by less than a metre between the summer minimum and the winter maximum. The (then) proposed 45 GL abstraction by the Water Corporation was considered to pose low-moderate risk, however when coupled with regional growth, this risk became severe for some areas of vegetation on the eastern side of the Wetlands. Even 25 GL abstraction was deemed to pose a low-high risk when coupled with regional growth. Climate change scenarios generally did not alter the 'risk' situation. However, the accuracy and interpretation of groundwater models used to predict groundwater drawdown need further investigation (Richard Pickett, DoW, pers. comm.). The Vasse-Wonnerup Wetlands would be at high risk from a 160 GL/yr abstraction from the Superficial, Leederville and Yarragadee aquifers combined, and at severe risk from a 205 GL/yr abstraction, as is projected for future regional growth in groundwater use by the year 2034 (DoW workshop May 2006, EPA 2006). Reduced summer water tables may also reduce the value of summer pastures on some agricultural lands.

Pumping of groundwater for mining developments may also pose a risk to the Site and needs to be monitored. For example, Cable Sands Ludlow Titanium Mine lies approximately 1.8 km east of the northern end of Wonnerup Estuary and approximately 100 m north of the Ludlow River. Operations commenced in late 2004. The site is directly underlain by an unconfined superficial aquifer to a maximum depth of around 8 m and with winter groundwater tables rising to 3 m below the surface in some areas of the lease (Cable Sands ERMP 2002). This aquifer supports groundwater-dependent remnant vegetation including tuart trees. Process water for the mine is pumped from the deep Yarragadee aquifer under DoW groundwater abstraction licence which has a maximum extraction limit of 4,400 kL/day (equivalent to 0.0044 GL/day). Mine approval conditions included an $80,000 contribution to DEC to assist in development of the Tuart Forest National Park Management Plan. A further $50,000/annum is used for weed control programs conducted jointly with DEC. It was also expected that $750,000 in royalty payment for lease of the land during mining would be made available to DEC for further Tuart conservation initiatives (Cable Sands ERMP 2002).

While the Environmental Review and Management Plan for the mine (Cable Sands ERMP 2002) did not consider mining operations would affect the Ramsar Site, it did identify potential impacts to surrounding wetlands as a result of disturbance of ground and surface water levels and flows. This could potentially restrict or reduce water availability to the wetlands, increase risk of contamination of surface and groundwater and cause temporary loss of habitat for waterbirds and fauna species that breed or forage in forested areas. Under licence conditions, Cable Sands is committed to "monitoring and performance assessment for groundwater, surface water, and fauna…to ensure the environmental values of wetlands surrounding the mining lease are maintained (Cable Sands ERMP 2002). Regulatory bodies such as DEC and DoW need to be appropriately funded, resourced and staffed such that they can adequately critique the design of Cable Sands' monitoring programmes, evaluate monitoring results in a timely manner and have the capacity to enforce compliance where necessary.

10.4 Acid Sulphate Soils

Most of the Ramsar Site is of high acid sulphate soil risk (see Figure 6, Section 4.2). Factors that exacerbate this risk include reduced rainfall and lowered water tables, disturbance of soils during urban development, groundwater abstraction, mining (*e.g.* mineral sands mining), drain construction, tree plantations (*e.g.* blue gums) and climate change. Acidic drainage from acid sulphate soils has the potential to detrimentally affect both the site and surrounding agricultural lands (refer Section 4.2). WAPC and DEC provide guidelines and advice for development planning on acid sulphate soils. DEC also provides criteria for the assessment of acidity in sediments and surface and groundwater:

	Surface or Groundwater	Soils or Sediments
Contamination	"Net" acidity	Titratable actual acidity (TAA)
Method of derivation	Total acidity minus total alkalinity	SPOCAS[1] or CRS[2]
Trigger level[3]	60 mg/L	0.20% S
Units	Mg/L CaCO3 equivalent	%Sulphur w/w equivalent

[1] SPOCAS Suite - Suspension Peroxide Oxidation Combined Acidity and Sulphate (SPOCAS) method.

[2] CRS - Chromium Reducible Sulphur Suite - The chromium reducible sulphur suite method.

[3] Trigger level – level at or above which further investigation is required to assess potential risks to human health, the environment or any environmental value.

Further information and technical advice can be obtained from DEC or from the DEC website at www.dec.wa.gov.au/contaminatedsites.

10.5 Tourism and Recreation

Where development occurs, there is a need for sensitive development and restriction of access to feeding, roosting, loafing and nesting sites. Consideration needs to be given to the effects of lighting, noise and other disturbance (including that during infrastructure construction) on feeding, breeding and roosting waterbirds. Tourism and recreation may disturb waterbird roosts and nesting sites, *e.g.* noise, intrusion and trampling of nests (both by people and dogs). Discarded fishing gear and other rubbish (*e.g.* plastic rings, cigarette butts & other debris) can be ingested by birds or otherwise interfere with feeding and roosting behaviours (OzEstuaries 2007). The Shire of Busselton is currently proposing to construct a Bird Observatory and Wetlands Centre on the nearby New River, together with a Busselton Wetlands (including the Ramsar Site) public awareness campaign and network of appropriately located walk trails (see Section 14.1).

10.6 Vegetation Clearing

Clearing for agriculture (past) and urbanisation (present) has already lead to native vegetation loss and spread of exotics. In many parts of the Ramsar Site, what would historically have been the upper extent of native wetland vegetation is now cleared. The lower extent is now lower than historic as flood control has allowed both wetland and dryland plants to colonise lower elevations. In the absence of clearing, it is likely increased seawater inundation or freshwater flooding would result in a successional change with the 'retreat' of most wetland plants to higher elevation and the spread of samphire Froend *et al.* (2000). Dryland plants would similarly re-establish on higher ground in response to rising groundwater and salinisation. Clearing, however, has imposed an artificial upper limit on plant distributions. Froend *et al.* (2000) state that this artificial limit "is absolute…and represents a significant constraint to wetland plant dynamics and conservation". Froend *et al.* (2000) found fringing wetland vegetation of the Vasse Estuary to already be adversely affected by influx of seawater caused by prolonged summer-autumn openings of the floodgates post-1988 (refer Section 5.4.3). Effects of seawater were most obvious in paperbarks and eucalypts where significant proportions of the local population had died or showed reduced crown vigour. Samphire also appeared to be spreading to higher elevations.

Continued vegetation clearing for either agriculture or urban expansion will further reduce biodiversity along with bird nesting, roosting and foraging habitat. It will also enhance the risk of increased sediment and nutrient loads to the Site and of acid sulphate soils and associated contamination from heavy metals. In some areas, the presence of stock has resulted in the trampling of native vegetation (Froend *et al.* 2000) and (likely) waterbird nesting materials. However, there is also anecdotal evidence that the long history of cattle grazing around the shoreline of the estuary has helped to maintain a diversity of habitats for waterbirds (McAlpine *et al.* 1989) (refer Section 5.6.2). Grazing prevents encroachment of tall dense pasture grasses that are not suitable as waterbird habitat. Pugging and trampling also creates holes and divots across exposed sands and mudflats, within and behind which shorebirds can shelter and roost.

10.7 Weeds and Feral Animals

Typha is a disturbance opportunist spread by fire. The spread of *Typha* may choke some wetland areas, reducing foraging and roosting habitat for waterbirds. However, management plans for *Typha* eradication need to be mindful of the fact that a small number of waterbird species utilise stands of *Typha* as breeding habitat.

Pasture grasses (Kikuyu & Couch), Arum Lily (*Zantedeschia aethiopica*) and Bridal Creeper (*Asparagus asparagoides*) occur in dense thickets over a wide distribution around the wetlands. There are extensive areas where cover of these plants is particularly dense and as such there is the threat that structure, composition and function of remnant riparian ecosystems will be altered (DEC 2006a). Both Arum Lily and Bridal Creeper are currently listed by the Agricultural Protection Board as 'declared plants' under the *Agriculture and Related Resources Protection Act 1976* and Bridal Creeper is considered a Weed of National Significance. Trials in the Cable Sands mining lease have been effective in controlling Arum Lily with herbicide. However, the effect of herbicide use on non-target species is not well understood. The high groundwater table makes the Site and surrounding wetlands particularly vulnerable to herbicide and pesticide contamination of groundwaters (see also Section 10.2).

Control of foxes *Vulpes vulpes* and rabbits *Oryctolagus cuniculus* is undertaken regularly within the Site, notably monthly fox baiting in Tuart Forest National Park and Reserve 31188 to reduce fox predation on ducks that nest in the tuart forest and walk their young to the wetlands.

The extent of distribution of introduced fish and crayfish species within the Site requires further investigation. Three introduced freshwater fishes - Mosquitofish, Goldfish and Redfin Perch – and the introduced freshwater crayfish, the Yabby, have all been recorded from the catchment. Of these, only the Mosquitofish has been recorded from within the boundaries of the Ramsar Site. The presence of Goldfish and Redfin Perch could only be confirmed for the Vasse River and Diversion Drain, but both species reportedly (DEC 2006a) occur within the Tuart National Park which also encompasses lower reaches of the Abba, Sabina and Ludlow. The presence of all these species is considered detrimental to the ecology of native freshwater fishes and is discussed further in Section 5.6.4.

Arum Lily in sedgeland bordering the estuary (courtesy Katie Biggs, GeoCatch)

10.8 Opening the Sand Bar

Since 1908 when the floodgates were installed on the exit channels of the Vasse and Wonnerup estuaries, any direct hydrological effects of summer openings of the sand bar have been confined to Wonnerup Inlet and The Deadwater. Openings of the bar occurred naturally pre-European settlement, and therefore risk to the ecological character of the Inlet and Deadwater is considered negligible.

Permanent openings using rock groynes or sand by-pass pumping have been previously suggested by MacAlpine *et al.* (1989) and more recently under early development plans for Port Geographe. This however, would require careful consideration of potential ecological and social impacts including floodgate operation / flood control, likely build-up of seaweed wrack in the inlet with associated water quality problems and coastal erosion. Any such development would need approval under the EPBC Act.

Table 28. Summary table of actual and likely threats to the Vasse-Wonnerup Ramsar Site, together with the risk to the ecological integrity of the Site as a whole.

Codes for 'Timing': Short-term = immediate; Median-term = 1 to 5 years; Long-term = 10 or more years.

Actual or Likely Threat	Consequence / Potential effect(s) on Components or Processes	Likelihood	Risk to Ecological Integrity	Timing	Management or Monitoring actions
Hyper-eutrophication	Increased frequency & duration of phytoplankton blooms, including toxic cyanobacterial blooms. Increased frequency and duration of macroalgal blooms - *Ulva*, *Chaetomorpha*, *Rhizoclonium*, *Cladophora*. Increased incidence of anoxia. Increase in noxious sulphur gas emissions (H_2S, SO_2, VOSC). Loss of habitat for waterbirds and fish. Loss of food sources for waterbirds and fish. Switch in ecological state - macrophyte to phytoplankton dominated. Increased risk of botulism & associated bird mortality. Increased risk of algal toxicity to birds and fish. Increased export of nutrients to Geographe Bay. Loss of amenity and reduced tourism. Possible ecosystem collapse.	**VERY HIGH**	**HIGH**	Immediate / Short-term	Currently being investigated by DoW under Vasse-Geographe CCI Water Quality Improvement Plan. Develop nutrient budget for the site, including estuary sediment storages. Revegetation of target floodplain areas - dependent on outcome of nutrient modelling and with consideration of waterbird habitat needs. Continued support for DAF projects aimed at reducing nutrient loads from rural sources *e.g.* Nutrient Smart and Greener Pastures. Continued support for DEC/GeoCatch macrophyte mapping surveys to establish benchmark. Collection of baseline data on fish and macro-invertebrate populations. Investigate risk of botulism in brackish-saline environments. Investigate potential of removing nutrient-rich sediments at strategic locations and harvesting nuisance macrophytes and algae (wetland access may prove too difficult).
Urbanisation and industrialisation	Increased urban runoff resulting in increased sedimentation and pollutants (heavy metals, oils, PAH (polyaromatic hydrocarbons), petroleum hydrocarbons, pesticides, herbicides. Drainage and road construction diverting surface flows away from wetlands and or causing habitat fragmentation. Increased risk of drainage from acid sulphate soils. Canal development leading to increased salinisation and ASS drainage in estuary. Loss of habitat connectivity; habitat fragmentation. Increased turbidity and sedimentation leading to habitat loss, changes in fauna and flora. Aircraft movements (e.g. powered gliders, mosquito larvae – spraying helicopters) over wetlands scaring waterbirds. Increased feral and pet animals preying on and disturbing waterbirds. Detrimental effects of increased pesticide / larvacide / herbicide use on non-target species (*e.g*. spraying for mosquitoes and midges). Translocation ('borrowing') of sand from estuary mouth, to replace that lost to erosion further down the coast, would have uncertain and possibly adverse consequences for waterbird and fringing vegetation communities adapted to existing hydrological regimes.	**HIGH**	**HIGH**	Immediate / Short-term	The Shire of Busselton has a current program aimed at installing pollution control devices at all stormwater drains leading from developments and other sources to the Site (Clean Drains Program). Monthly monitoring of heavy metals, petroleum hydrocarbons and pesticides at target sites. Refer ANZECC/ARMCANC (2000) guidelines: http://eied.deh.gov.au/water/quality/nwqms/volume1.html. Ensure adequate set backs and vegetated buffer zones. Determination of specific setbacks should be done in consultation with DEC and DoW and with consideration of water and nutrient balance models as well as soil and vegetation type. DEC and DoW to ensure development approval conditions are met (*e.g*. Port Geographe). Any proposed development will need to be referred for approval under the EPBC Act. The Port Geographe Action Group is currently monitoring effects in Geographe Bay. Limit urban and industrial development near wetlands and on wetland floodplains. Need for adequate floodplain mapping. The Shire of Busselton has a current project investigating the effects of pesticide / larvacide use on non-target species. Investigate the effects of increased herbicide use on non-target species.

Table 28 continued.

Actual or Likely Threat	Consequence / Potential Effect(s) on Components or Processes	Likelihood	Risk to Ecological Integrity	Timing	Management or Monitoring actions
Rise in sea-level due to climate change	Increased storm surge and coastal erosion. Changes to sandbar and weed bar formation in Wonnerup Inlet. Seawater inundation of low lying lands. Change in winter salinity regime.	HIGH subject to calibration of climate-change models	HIGH	Median / Long term	Mapping of areas likely to be affected by rise in sea-level.
Altered hydrological regimes from climate change (reduced rainfall effects on freshwater runoff and groundwater input)	Reduced duration, magnitude and frequency of estuary inundation. Reduced water depths. Changes to salinity regimes (more saline in winter - less flushing??). Loss of grazing pasture. Changes in breeding / migration cues for waterbirds and fish. Changes in floristic composition and distribution. Changes in timing and species composition of algal blooms. Increased risk of acid sulphate soil (ASS) drainage due to exposed soils. Increase in noxious sulphur gas emissions (H_2S, SO_2, VOSC) due to exposed soils. Increased release of sediment phosphorus with alteration to cycles of wetting and drying.	HIGH subject to calibration of climate-change models	HIGH	Long-term	Partly addressed under the recommendations of Phase I of Vasse-Geographe CCI Water Quality Improvement Plan for surface and groundwater monitoring. Bathymetry mapping to provide benchmark. Seasonal (biannual) transect monitoring of fringing vegetation. DEC Bunbury currently investigating vegetation mapping funded by NHT through SWCC. Monitoring of target / key bird species (DEC to advise frequency). Investigate fish migration behaviour. Monthly monitoring for potential ASS drainage at target sites.
Loss of 1:100 year flood flows due to flood control.	No inundation of the estuary floodplain. Reduced floodplain productivity.	CERTAIN	LOW	Long-term	Need for adequate floodplain mapping.
Altered hydrological regimes from increased groundwater abstraction from superficial and Leederville aquifers	Reduced timing, magnitude and frequency of flooding. Reduced water depths. Loss of grazing pasture. Changes to salinity regimes and / or seawater intrusion. Impacts on flora and fauna e.g. breeding events, vegetation distribution. Increased risk of ASS drainage.	MEDIUM	HIGH	Median-term	Monthly monitoring of groundwater levels at targeted sites to establish benchmark. Develop water budget for the wetland Investigate hydraulic gradients.
Altered hydrological regimes from increased groundwater abstraction from Yarragadee aquifer	Reduced timing, magnitude and frequency of flooding. Reduced water depth. Seawater Intrusion. Impacts on flora and fauna *e.g.* breeding events, vegetation distribution. Increased risk of ASS drainage.	LOW subject to verification of groundwater models	HIGH	Long-term	Monthly monitoring of water levels at targeted sites to establish benchmark. Develop water budget for the wetland. Investigate hydraulic gradients. Verify groundwater model with respect to Yarragadee influence. DEC and DoW to ensure all mine commitments to groundwater level and water quality monitoring and management are being met. Investigate the effects of increased herbicide use on non-target species.

Table 28 continued.

Actual or Likely Threat	Consequence / Potential effect(s) on Components or Processes	Likelihood	Risk to Ecological Integrity	Timing	Management or Monitoring Actions
Acid Sulphate Soils	Acidification of waterways with direct and indirect (sub-lethal) effects on biota. Loss of biodiversity. Contamination of groundwater used for irrigation. Soil contamination and loss of grazing lands. Corrosion of infrastructure. Increase in toxic *Lyngbya* blooms. Increased incidence of anoxia and changes to phosphorus cycling. Release of heavy metals from sediments and associated toxic effects on biota. Increased levels of heavy metals (particularly arsenic and aluminium) in sediments and surface water.	HIGH	HIGH	Immediate / Short-term	Monthly monitoring of net acidity ($CaCO_3$ equivalent) pH, SO_4 and Fe in ground and surface waters at target sites. Limit development that results in disturbance of acid sulphate soils. Guidelines for development exist within current WAPC and DEC bulletins: www.dec.wa.gov.au/contaminatedsites.
Tourism and recreation	Disturbance of roosting and nesting waterbirds, *e.g.* noise, trampling nests – both people and dogs. Discarded fishing gear and other rubbish ingested by or tangling birds.	LOW	MEDIUM	Median / Long term	Shire of Busselton has already developed plans to limit public access to specific sites *e.g.* bird hide and visitors centre. Additional project to develop a master plan for walk trails in the Busselton Wetlands. Restrict access to bird nesting and roosting sites. Permanent fencing of sensitive sites. Protect sensitive shoreline areas from trampling. Seasonal monitoring of target fish and bird species *e.g.* wetland usage, breeding and breeding success.
Native vegetation clearing associated with urban, industrial and/or agricultural expansion.	Loss of bird roosting and nesting sites. Loss of habitat connectivity. Loss of shade-cover and associated increases in water temperature and algal productivity in lower tributary rivers. Increased erosion, turbidity and sedimentation rates. Increased weed infestations.	LOW	MEDIUM	Median / Long term	Currently being addressed under GeoCatch River Action Plans and long-established State and Local government practice whereby landholders cede foreshore areas in exchange for permission to sub-divide rural holdings. Seasonal monitoring of target bird species *e.g.* wetland usage, breeding and breeding success. Weed infestation addressed under current Weed Control programs.
Weeds species	Spread of introduced plants and subsequent loss of fringing habitats.	LOW	LOW	Long-term	Weed infestation addressed under current Weed Control programs.
Feral animals	Fox and cat predation on waterbirds and chicks. Increased competition and predation by introduced fish and crayfish species, mainly in freshwater river reaches.	HIGH for fox and cat predation	MEDIUM	Median / Long term	Control of foxes *Vulpes vulpes* and rabbits *Oryctolagus cuniculus* is undertaken regularly within the Site, notably monthly fox baiting in Tuart Forest National Park and Reserve 31188. The extent of distribution of introduced fish and crayfish species within the Site requires further investigation.

11. SUMMARY OF KNOWLEDGE GAPS

It is clear from the preceding chapters that there is much that is still unknown about the functioning of the Vasse-Wonnerup wetland ecosystem. For future management to be successful in ensuring retention of current Ramsar values, a greatly enhanced and more systematic approach to monitoring is required. Adequate baseline data must first be gathered to establish benchmark levels, help select appropriate indicators of change, set targets for those indicators and focus monitoring programs. Table 29 provides a summary list of identified knowledge gaps, some of which have already been noted in Table 27 'Limits of Acceptable Change' (Section 8). Details of recommended research and monitoring programs needed to formulate management plans for the Site are summarised in Table 32 at the end of Section 12.

Table 29. Summary of identified knowledge gaps for the Vasse-Wonnerup Ramsar Site.

Subject	Identified Knowledge Gaps
Geomorphology and Soils	Effect on the wetlands of changes in sea level due to climate change.
	Inter- and intra-annual data on areal extent of the waterbody/area of Inundation for each wetland not sufficient.
	No data on sedimentation and erosion processes in either the tributary creeks or the estuary.
	No data on sediment characteristics, salinity and nutrient stores in the catchment.
	No data on sediment/water inter-relationships and biogeochemical processes (N, P, C, Si, Fe cycling/dynamics).
	Insufficient data on fine-scale distribution of acid sulphate soils within the catchment.
Hydrology / Hydrogeology	Relative contributions of groundwater, river inflow and overland runoff are not yet quantified.
	No data on surface-groundwater interactions (water balance).
	No groundwater modelling.
	No data on how existing rates of abstraction and climate change are affecting groundwater systems and how future abstraction may affect groundwater systems.
Water Quality	Baseline water quality data insufficient – need spatial data on inter- and intra-annual variation in basic water quality parameters.
	No data on nutrient dynamics (*e.g.* bioavailability, adsorption/desorption, denitrification).
	Mass-balance equations for C, N and P and the chemical and biological carrying capacity (*i.e.* the ability of the system to cope with high loads).
Phytoplankton and Aquatic Macrophytes	Successional dynamics of algal bloom formations and influence of various water quality parameters (nutrient, salinity, turbidity & flow interactions) on growth rates are not yet quantified or understood.
	Submerged aquatic vegetation distribution has only been mapped once, in November 2006.
	No data on the contribution of algal carbon to food webs.
Fringing Vegetation	Vegetation distribution has not been mapped.
	Effect of altered salinity regimes and summer-autumn openings of floodgates on riparian vegetation has not been quantified.
Aquatic Invertebrates	Zooplankton and benthic macroinvertebrate composition, diversity and abundance, and spatial variation with each wetland, and inter- and intra-annual variability are all unknown.
	Relationship between invertebrate communities and water depth, salinity and nutrient concentration has not been quantified.
Fish and Crustacea	No baseline data on fish, crab, prawn or crayfish composition, diversity and abundance.
	Seasonal movement of fish into and out of estuary has not been quantified. Migrations in response to tidal and/or freshwater flows are unknown.
	Habitat preferences of adult and juvenile fish unknown.
	Relationship between fish communities and water depth, salinity and nutrient concentration has not been quantified.

Table 29 continued.

Subject	Identified Knowledge Gaps
Waterbirds	Inter- and intra-annual relationship between waterbird communities and water depth, salinity and nutrient concentration has not been quantified and is fully not understood.
	Variation in presence and abundance, including year-by-year, of most bird species is not well quantified and not fully understood.
	There is insufficient data on the effect of off-Site variables (*e.g.* rainfall) on regional abundances and distributions of waterbird populations.
	Specific diet of adults, breeding adults and juveniles largely unknown in relation to food items present and accessible in the wetlands.
	Current use of Site for breeding is inadequately known.
	Level of threat posed by increasing human disturbance, including on (watercraft) and over (aircraft) the main waterbodies, is inadequately understood.

PART III. MONITORING AND MANAGEMENT

12. MONITORING / RESEARCH NEEDS

12.1 Past Recommendations

At present there is no comprehensive management or monitoring program for the Vasse-Wonnerup Ramsar Site. Part of the Ramsar Site is included in Nature Reserves 31188 and 41568, management of which is vested with DEC. Additional reserves are in the process of being gazetted. However, no management plan or interim management guidelines currently exist for Reserves 31188 and 41568. A conservation strategy has been prepared for the Busselton wetlands, which includes the Site (WAPC 2006), however this does not detail baseline research and monitoring requirements. There are plans to reserve further areas adjacent to the Site. A management plan for Tuart Forest National Park is being prepared by DEC subsequent to approval of the Cable Sands Ludlow Titanium Minerals Mine by the EPA in 2003 (refer DEC 2006a).

In 1997, the Vasse Estuary Technical Working Group recommended that a number of management and monitoring measures be commenced in 1997-99 (refer Lane *et al.*, 1997). These measures were based on a detailed review of the history of management of the sand bar at the mouth of the estuary, operation of the floodgates, water level / water quality problems, algal blooms, incidence of fish deaths, decline in fringing native vegetation and pasture, and importance of the wetlands as waterbird habitat. The Group believed "the most promising, practicable and affordable measures…" to be:

1) Artificial openings of the Wonnerup Inlet sand bar in response to daily fish monitoring (during and immediately following hot weather) and continuous water quality monitoring over summer-autumn (December-April);
2) A water quality monitoring program that includes continuous summer-autumn monitoring of water levels, DO, temp and salinity and periodic measurement of nutrients and algal abundance;
3) Adherence to the Water Authority's 1990 operational guidelines for the floodgates and refinement for the opening of the floodgates to take into account results from the proposed summer-autumn water quality and fish monitoring;
4) Water Corporation's scheduled 2003-04 upgrade of the floodgates to include installation of remote and/or automatic water level control and monitoring equipment;
5) Implementation of monitoring programs for fringing vegetation to assess the effectiveness of the revised 1990 floodgate operational guidelines in halting native plant deaths;
6) Implementation of monitoring programs for waterbirds to assess the impact of changes to hydrological regimes post 1988;
7) Partial revegetation of the shoreline to shade the Vasse Estuary exit channel and lower summer-autumn water temperatures with the aim of reducing fish deaths;
8) In the event that the above measures are unsuccessful in reducing fish deaths, investigation into the possible artificial aeration of the waters of the estuary.

Most of these recommendations have been acted upon, together with a number of other initiatives. Since 1997, daily visual monitoring of fish behaviour and water quality in the lower reaches of the system has occurred during the spring and summer period to anticipate and prevent mass fish deaths (White 1999, Elscot 2000). These actions continue (Jim Lane, pers. comm.). A monitoring program that aims to detect changes in the distribution and health of fringing vegetation of the Vasse Estuary, relative to the water regime and salinity (which is affected by floodgate openings), has been developed and permanent transect areas have been established (Froend 1999, Froend *et al.* 2000). The northern shoreline of the Vasse estuary exit channel has been revegetated with native trees and shrubs by St Joseph Primary School students in 1998 and Busselton Rotary in 1999 (Jim Lane, pers. comm.). Guidelines for the management of farmland adjacent to the wetlands have been developed (Oldfield 2002) and DAF, in partnership with LCDCs and individual landowners, is taking action to reduce nutrient discharge from farmland in the catchment. Action Plans have been prepared to guide landowners undertaking revegetation and rehabilitation along the upper Vasse River and the Sabina and Ludlow Rivers (GeoCatch Network Centre, 2000; GeoCatch, 2002). There is also broad-scale collaborative research being conducted under the Vasse-Geographe CCI Water Quality Improvement Plan, aimed at a general reduction in nutrient loads to waterbodies in the downstream receiving environments, including the Site (refer Hall *et al.* 2006, DoW 2006).

GeoCatch, DEC and the Shire of Busselton are working cooperatively, with community support, to implement the Lower Vasse River Cleanup Program. The program, which aims to improve the ecological health of the Lower Vasse River (located immediately upstream of the Site), involves a number of key components including: rehabilitation and revegetation to restore river ecology; dredging to remove nutrient-rich sediment; use of a modified clay product to reduce phosphorous availability in the system thereby limiting algal blooms; and the implementation of best management practices for stormwater. The program should assist to improve water quality within the Site.

All existing management and monitoring protocols are discussed in detail below, together with outstanding baseline research and monitoring needs and recommendations for future management. All baseline research and monitoring must be done with a view to establishing the most suitable indicators of change in ecological character of the Site and of setting appropriate management targets. As noted by Phillips and Muller (2006), monitoring is of little value if it is not linked to management actions. In recommending parameters and monitoring techniques, consideration has been given to those already endorsed under the National Wetland Indicators project (see Edgar *et al.* 2006), and to ANZECC/ARMCANZ (2000) water quality guidelines and monitoring protocols. A summary of recommendations from the current report is given in Table 32 together with priority.

12.2 Floodgate Operations

12.2.1 Existing Program

The Water Authority revised the operational guidelines for the floodgates in August 1990. The 1990 revision was aimed at preventing fish kills without causing damage to low-lying properties through seawater inundation, and was based on the previous two and half years of experience. A maximum summer-autumn water level was set at $^-$0.10 m AHD with the caveat that “under no circumstances should salt water” entry be allowed to raise water levels higher than this.

Controlled flows of seawater into the Vasse estuary during summer and autumn have beneficial results which include:

- reduced fish deaths,
- increased area of estuary possibly suitable for bird feeding in later summer, and
- no bad odours which could develop with the drying out of the estuary.

Past methods used to reduce frequency and severity of fish deaths have been discussed by Lane *et al.* (1997). They are summarised below together with current practices:

- Artificial opening of the sand bar - standard practice in summer during the early 1900s. Temporarily halted in 1904/05 and as a result, thousands of fish died so it was re-opened. Up until 1997 it was difficult to keep the bar open. In 1988, several attempts were made but the bar reformed with several hours. Since 1997, heavy machinery has been used to excavate a wider (13 m) cut than in the past and the bar has remained open for longer periods.
- Increased harvesting of fish by netting - mainly in 1960s to harvest fish throughout the system that would otherwise die over summer. Current ban on all but commercial netting in the Vasse and Wonnerup estuaries, however two fishermen have complained that odour and skin lesions caused by contact with the water prevent successful harvesting.
- Partial opening of the Vasse Estuary floodgates to allow fish to escape and raise water levels - first occurred in February 1988 under the Water Authority of Western Australia (now Water Corporation) to improve water quality and allow fish to migrate out to sea. This was the first authorised opening of the gates since their installation. In 1990, following consultation with landowners and government agencies, a summer-autumn water level of $^-$0.10 m AHD was set for the Vasse estuary, not to be exceeded in order to prevent salt damage to adjoining properties. Until 1997, the floodgates were left open for increasingly longer periods with summer-autumn water levels reaching $^+$0.3m AHD in some years.
- In 2004, fish gates were installed during floodgate upgrades. To date, the fish gates have been successful in reducing fish deaths without the risk that prolonged openings will lead to saltwater inundation of summer grazing pastures. Current spring water depths are stabilised at $^+$0.4 m, but with evaporation

decline to -0.1 m AHD in the Vasse Estuary and -0.4 m AHD in the Wonnerup estuary over summer-autumn.

12.2.2 Current Recommendations

It is recommended that current operation be maintained. Change in floodgate operation and increased flows (marine or riverine) and higher water levels may alter the availability and type of feeding habitat for waterbirds by reducing the area of exposed muds. Inundation and water-logging of riparian vegetation may cause decline in trees used for roosting and nesting, unless restoration of tree species can be achieved at higher elevation.

12.3 Water Quality

Nutrients should be maintained at sufficient concentrations to support existing waterbird populations without causing persistent water quality problems (*e.g.*, hypoxia-anoxia, toxic and nuisance algal blooms, decreased water clarity, persistent foul smells). However, there is insufficient baseline data from the Site or from analogue systems to set benchmark levels for nutrients in order to maintain waterbird populations. As far as the current study could determine, there is little in the world-wide literature that quantifies the relationships between waterbirds and nutrients. This is particularly so for systems that are already nutrient-enriched or eutrophic. It is also considered highly unlikely that achievable reductions in nutrient loadings could reduce productivity in the Vasse-Wonnerup Estuary to the extent that waterbird diversity or abundance would be adversely affected.

While there are no nutrient management projects specific to the Ramsar Site, there are a number of existing projects and initiatives that, if successful, will help to reduce nutrient inputs to the Site from the surrounding catchment. Most of these target agricultural sources and include the development of a detailed, catchment-scale predictive model for nutrients (and water quality in general) in the Vasse and Wonnerup estuaries and the rivers of the Vasse-Geographe catchment. While it may be unrealistic to expect substantial reductions in nutrient loads (particularly internal loads), the goal should be to prevent hyper-eutrophication and possible ecosystem collapse.

12.3.1 Existing Programs

DairyCatch

DairyCatch is a collaborative project lead by GeoCatch, Western Dairy, Dairy Australia and the Department of Agriculture to provide funding and support for dairy farmers to develop and implement best practice for natural resource management throughout Western Australia's dairy regions. DairyCatch is one of a number of farm-catchment research projects sponsored by Dairy Australia under the Sustainable Dairy Catchment Program (Edgar *et al.* 2005). The aim of the project is to assist dairy farmers to significantly reduce nutrient and bacteria loads to receiving water bodies (including those within the Vasse-Wonnerup Estuary catchment), and to improve water use efficiency. Cash and in-kind support have totalled over one million dollars with primary financing from the Natural Heritage Trust and National Landcare Program. The project was to run for three years from 2003 to 2006. The initial stage established four 'Monitor Farms' to measure the costs and benefits of effluent management plans developed by the project engineer. One of these farms is located immediately south of the Vasse-Wonnerup estuary catchment - McDonald's dairy at Jindong, near Vasse. Automatic data loggers and surface water sampling structures have been installed at all monitor farms. RBC flumes have been installed where appropriate channels were not already available, and automatic water samplers triggered by bubbler flow meters then used for flow monitoring and water collection. To date, more than 72 farmers have been involved in the project and another 42 plans have been prepared, 11 of which are underway; 30 plans are yet to be developed (Edgar *et al.* 2005). Farmers involved were eligible for matching funding up to a maximum of $5000. Farmers contributed at least $300 in cash towards development of their effluent plan and up to $5000 matching funds to implement their plan. Sophisticated individual plans for the nutrient management (see also Nutrient Smart, below) and water efficiency components of the project are still being developed.

Initial results from monitor farms indicate plans have been successful (Table 30). Significant improvements in nutrient concentrations in receiving waters downstream of the dairies have been achieved where discharge/drainage channels are vegetated rather than cleared and through fertigation of effluent onto pasture prior to water leaving the site (Western Dairy 2005). Delaying irrigation a few days after fertilizing pastures reduced export of total phosphorous in surface runoff by 80 - 90% and centre-pivot irrigation was found to reduce water use by 30 - 40%, compared to conventional surface irrigation. While the levels of total nutrient recorded were still higher than the ANZECC/ARMCANZ (2000) trigger levels for nutrients entering broader drainage systems (TP = 0.1 mg/L; TN = 0.75 mg/L), DairyCatch believe greater reductions can be achieved through a combination of effluent, fertilizer and efficient water-use plans (Western Dairy 2005).

Table 30. Preliminary results from four DairyCatch Monitor Farms showing improved nutrient concentrations in dairy effluent following various management 'treatments'. Water savings from centre pivot irrigation trials are also reported. Results are for total phosphorus (TP), soluble phosphorus (Sol-P) and total nitrogen (TN).

'Treatment'	Total P (mg/L)			Sol-P (mg/L)			Total N (mg/L)		
	pre-	post-	% reduction	pre-	post-	% reduction	pre-	post-	% reduction
Vegetated drainage channels									
Vasse area	0.8	0.1	87	--	--	--	8	4	50
Albany area	80	1	99	10	0.5		800	8	99
Fertigation									
Northcliffe area	80	0.1	99.9	--	--	--	500	1	99.9
Delayed irrigation following fertiliser application									
Harvey area	5	0.5 - 1.0	80 - 90	--	--	--	--	--	--
Centre-pivot irrigation									
Harvey area	30 - 40% less water used and 50% more pasture produced, compared with conventional surface irrigation.								

Approximately 60 soil samples have also been collected from each property on each of two sampling occasions; totalling 120 samples per farm. These were analysed for a broad range of parameters to gain an understanding of the:

- distribution of soil types within the properties,
- distribution of soil pH, organic carbon and reactive iron levels,
- distribution of soil nutrients and soil nutrient retention capacities,
- fertiliser requirements for various parts of the properties,
- nutrient budgets within the properties when soil analyses are compared with fertiliser records,
- estimates of the "break-through" times of nutrients through the various identified soil types, and
- relationship between effluent and chemical fertiliser applications throughout the properties.

It is hoped that farm nutrient budgets could eventually be tied-in with budgets modelled under Coastal Catchments Initiative programs for the greater catchments. For example, budgets developed for dairy farms within the Vasse-Wonnerup Estuary catchment could be incorporated into nutrient budgets and predictive modelling being undertaken by the DoW as part of the Vasse-Geographe CCI Water Quality Improvement Plan (refer Hall *et al.* 2006, DoW 2006).

A comparison of the success of the various Best Management Practices (BMPs), including DairySat[14], employed by dairy farms is also part of the DairyCatch project. As well as assessing environmental performance, the dairy industry sees BMPs as important in arguing the case for greater self regulation.

To date, the total benefits and costs of the project have not been determined owing to the difficulty in valuing non market environmental benefits and to the fact that an economic analysis component was not incorporated into the project at the outset. Edgar *et al.* (2005) recommend future projects "engage economists to design and undertake the work at an early stage so that methods and data collection can be coordinated with the collection

[14] DairySat: Dairy Self Assessment Tool is a part of the Dairying for Tomorrow initiative, a partnership project of Dairy Australia, the National Land & Water Resources Audit and the Australian Dairy Farmers Federation. DairySAT is a self-assessment tool designed to assess a farm's performance in environmental areas such as effluent, soils, chemicals, biodiversity, nutrients, pests and weeds, irrigation and drainage, farm waste and energy (Edgar *et al.* 2005).

of biophysical data". Edgar *et al.* (2005) also recommended that social benefit-cost analysis be used to guide further work under the DairyCatch project.

Farm Practices / Greener Pastures Project

The DairyCatch review panel (Edgar *et al.* 2005) recommended Western Dairy continues to maintain the partnerships and impetus established under the project and ensure industry development continues after the 2006 finish date. They also recommended Dairy Australia invest in ongoing research into nutrient management and farm-to-catchment modelling such as that funded under the Greener Pastures Project of the Department of Agriculture and CSIRO. This would provide an opportunity to study nitrogen in the context of farm profitability, efficiency of use and pathways of leaching/runoff in Western Australia (Edgar *et al.* 2005). Given the importance of the Ramsar Site, the Vasse-Geographe would appear ideal for such research, coupled with the fact that predictive modelling of surface water quality in the catchment is already under way. At the DAF Vasse Research Station in the Vasse River catchment, there are already five 'Nutrient Farmlets' and 'Innovative Farms' established to set benchmarks for the profitable and sustainable use of nutrients. Greener Pastures investors include DAF, Dairy Australia, Western Dairy, Land & Water Australia, CSIRO and the Western Australian Chemistry Centre.

The Lower Vasse River Cleanup Program

The Lower Vasse River Cleanup Program is a partnership project by GeoCatch, the Shire of Busselton and the Department of Water. It is designed to improve the ecological health of the Lower Vasse River, which experiences severe toxic algal blooms and sudden mass fish deaths. The program involves:

- Sediment dredging and removal in March 2001;
- Sediment treatment - Phoslock™ - in 2001, 2001/02 and 2003/04;
- Oxygenation trials;
- River restoration (bank re-shaping, revegetation and weed control) - Vasse River Action Plan - on-going;
- Urban/stormwater management;
- Community consultation and involvement (*e.g.* Ribbons of Blue);
- Monitoring and evaluation.

Work completed to date includes reshaping and revegetation of the bed and banks along 2 km of the Lower Vasse River. Some 50,000 native seedlings have been planted to provide shade and improve habitat and 60% of the river is now fenced to exclude stock. Landholders receive matching funding for fencing at a rate of $1,000/km. Oxygenation trials in 1998/99 did improve conditions for aquatic animals, but had little effect on nutrient levels or algal blooms in the river. Dredging in 2001, removed 3,000 cubic metres of nutrient-rich organic sludge from the river. Phoslock™ trials have been undertaken to reduce dissolved phosphorus and thereby attempt to reduced blue-green algal (cyanobacteria) blooms in the river (see sub-section below). Stormwater management controls have been implemented at 24 sites using the DoW "Manual for Managing Urban Stormwater Quality in Western Australia" as a guide as part of the Clean Drains Program. This has involved: establishing vegetated detention basins and swales to slow and filter stormwater and allow sediment deposition; interceptor devices and separators on drains to remove oil and grit before it enters the river; and gross pollutant and litter traps.

Monitoring is undertaken to evaluate the effectiveness of the program and includes:

- Fortnightly monitoring of inflow, outflow and basin waters within the Light Industrial Area of Busselton stormwater system for nutrients, total suspended solids, electrical conductivity, pH, temperature and dissolved oxygen.
- Six-weekly monitoring of inflow, outflow and basin waters within the Light industrial area of Busselton Stormwater system for heavy metal and hydrocarbon analyses.

- Permanent photo-points to monitor the progress of revegetation. Revegetation appears to be a success as evidenced by vigorous growth and many waterbirds nesting in the new vegetation.
- Since 1996, DoW has monitored water quality fortnightly at two sites in the lower Vasse River between late spring and autumn (November - May). Parameters monitored include TN, TP, colour (Hazen), chlorophyll-a,b,c, phaeophytin and phytoplankton. Recent analysis of data by Hall *et al.* 2006 found a decreasing trend in TP associated with Phoslock™ trials and a small unexplained decrease in TN. This monitoring will be extended to year-round sampling and incorporated into the Vasse-Geographe CCI Water Quality Improvement Plan (see below).

Phoslock Trials in the Vasse River

Phoslock™ consists of activated clay that is extremely effective in striping phosphorus from the water column as it settles over a period of a few hours. It then forms a thin film (< 1mm is all that's required) across the benthos, binding phosphorus within the sediment. Less than a millimetre of clay is all that's required to bind the phosphorus. Phoslock was developed by the Water and Rivers Commission (now DoW) in collaboration with CSIRO. Application is by surface spraying usually from a small boat. Phoslock trials conducted in 2001/2002 in the turbid phytoplankton dominated lower Vasse River substantially reduced the release of sediment phosphorus (Robb *et al.* 2003). Lower levels of filterable reactive phosphorus (FRP) were measured in treated areas compared with untreated for up to 194 days after application and a reduction in bioavailable phosphorus by up to 96%. As a result, substantially lower chlorophyll-concentrations, shorter duration of algal blooms and lower concentrations of potentially toxic algal species were recorded in treated areas. Phoslock was applied by surface spraying from a small boat and the area treated. Continued use of Phoslock will depend on available funding.

There is a lack of knowledge on the effects of Phoslock on biota such as periphyton, zooplankton, invertebrates, fish and waterbirds. Preliminary investigations conducted suggest the substance is not toxic to fish, though some species appear to show behavioural avoidance (Storey & Rippingale 2000). Caution must be used when extrapolating results between species and bottom-dwelling fishes may be at far greater risk as they are more likely to come into direct contact with the clay. Further work on fish and other aquatic biota is warranted. Investigating effects on sediment epifauna and infauna such as burrowing polychaetes, is particularly important in light of recent research that suggests polychaetes may play a significant role in nutrient flux within estuaries (De Roach 2006). In studies of Phoslock application in the Canning River, Storey and Rippingale (2000) also observed short-term effects on waterbirds due to increased human activity and general noise associated with application. Abandonment of active nests following over-spraying was observed. In order to avoid this they recommended emergent peripheral vegetation in which birds nest and roost must not be sprayed.

In macrophyte dominated, rather than algal dominated systems, the success of Phoslock application in reducing blooms is less clear. Robb *et al.* (2003) note a good ecosystem understanding is required to guide timing and quantity of application in such systems. They suggest further studies on treatment of rural and urban drains and agricultural sources as an adjunct to integrated catchment management.

Example of Phoslock spraying, Canning River, 2000 (Andrew Storey)

Vasse-Geographe CCI Water Quality Improvement Plan – Predictive Modelling

Under the Vasse-Geographe CCI Water Quality Improvement Plan, the Aquatic Sciences Branch of DoW aim to develop an estuary-catchment predictive model for water quality that will be the first of its kind in Western Australia (Christian Zammit, DoW, pers. comm.). Modelling will begin with the hydrodynamics of the system (water depth, volume & discharge.), incorporating effects of climate change. This will then be used for the next phase modelling nutrient and salinity dynamics. Finally temperature variables and wind circulation will be added to produce a comprehensive conceptual model. Water quality parameters required for input to the model are:

	Dates	Frequency	Location (& number of sites)	Water Quality Parameters
Vasse-Geographe Catchment Water Quality Modelling	Feb. 2006 - present	fortnightly	Ludlow River (2) Lower Abba River (1) Lower Sabina River (1) Lower Vasse River (2)	TN, NO_2, NO_3, NH_3, DON, TP, PO_4, Total Suspended Sediments, pH, temp., DO, colour, conductivity
	proposed	monthly	Vasse estuary (8) Wonnerup estuary (3) The Deadwater (1)	TN, TP, pH, temp., DO, colour, conductivity, chl-a,b,c, phaeophytin, phytoplankton

Baseline data will be collected monthly in the estuary and fortnightly at target surface and groundwater sites throughout the catchment (DoW 2006). Baseline sampling is required over a minimum two consecutive years. The project commenced in August 2006 and is currently funded until 2008. The modelling will also require baseline data on surface and groundwater flows within the catchment and have recommended that:

- A rainfall analysis be undertaken to ascertain the nutrient input from rainfall;
- Re-open the DoW flow gauging station 610005 on the upper Ludlow River;
- A doppler flow meter be installed to measure the flow entering the Lower Vasse River from the Vasse Diversion drain;
- Re-open the DoW flow gauging station 610016 on the Abba River;
- High frequency groundwater monitoring at specific locations to enable the quantification of groundwater nutrient loads delivered to Geographe Bay.

As discussed in Section 8 'Limits of Acceptable Change', similar research has already been undertaken by DoW (formerly part of DoE) in the Canning River and Swan River and Estuary. The research formed part of the Swan-Canning Cleanup Program (SCCP) funded through the Swan River Trust. The SCCP aims to improve the health of the rivers and estuaries which have become degraded as a result of habitat loss and increased loads of organic carbon and nutrients (DoE 2004b). Research initiatives involved weekly sampling for:

salinity (as conductivity)	TN, TP
temperature	NO_3, NO_2, NH_3
dissolved oxygen (mg/L & %)	PO_4 (FRP)
pH	alkalinity (estuary only as indirect measure of carbon)
turbidity (NTU)	chlorophyll-a
Secchi depth	phytoplankton density (cell counts)
light penetration (PAR)	phytoplankton species richness
total suspended sediments (TSS)	

Results enabled target TN, TP, DO and chlorophyll-a levels to be set for individual reaches of the Swan-Canning system, including tributary rivers. Targets included short-term (0 - 5 years) "Management Action Targets", long-term (10 - 20years) "Resource Condition Targets" and "Aspirational Targets" (>50 years) (DoE 2004b). Methods employed to set targets were based on a statistical approach (percentiles from baseline data) together with consideration of current ANZECC/ARMCANZ (2000) guidelines for water quality. Indicators chosen (*i.e.* DO, chlorophyll-a, phytoplankton cell counts, TN, DIN, TP & DIP) were based on goals relating largely to problematic algal blooms and their impact on public health and amenity. Detailed descriptions of research and results are available from the Swan River Trust, Perth, or on-line at www.swanrivertrust.wa.gov.au.

Vasse River Diversion Drain, Jan. 2007 (Andrew Storey)

12.3.2 Current Recommendations

In order to set nutrient and other water quality indicators and targets, there must first be an understanding of the sources and temporal variability of bioavailable nutrients and the interaction between physical and chemical processes within the estuary. This is particularly important in a system that is already eutrophic with (likely) very high internal nutrient loads. An approach similar to that used by DoE for the SCCP (Section 12.3.1) is recommended. The first step is the development of water and nutrient balance models. Weekly sampling for a 3 year period is considered necessary to develop reliable predictive models of water quality and nutrient-phytoplankton dynamics within the Ramsar Site (Joel Hall & Christian Zammit, DoW, pers. comm.). Sampling over a 3 year period is the minimum needed to ensure some measure of inter- and intra-annual variation is incorporated and allow time-series analysis. Thus recommendations are:

1. DoW's development of predictive models should be continued with the addition of weekly monitoring at specific estuary sites to ascertain nutrient-phytoplankton relationships and factors important for algal bloom initiation;
2. Conceptual modelling of algal bloom initiation will require NO_3, NO_2, NH_3, PO_4 (FRP), light penetration, alkalinity and total suspended sediments (TSS) to be included in the weekly estuary sampling;
3. Groundwater monitoring sites be sufficient to quantify groundwater flow and nutrient loads to the Ramsar Site;
4. Additional baseline data on water column SO_4, Fe and net acidity ($CaCO_3$ equivalent) levels be collected at sites most likely at risk from ASS and/or prone to *Lyngbya* blooms (*e.g.* in the estuary adjacent to the Port Geographe development);
5. Baseline data on soil pH and titratable actual acidity (TAA; % sulphur w/w equivalent) to better elucidate fine-scale distribution of potential (PASS) and actual acid sulphate soils (ASS);
6. Baseline sampling for pesticides, herbicides, heavy metals, oils and hydrocarbons in soils, surface and groundwater be conducted six weekly intervals at likely 'hot spots' around the Site;
7. Rainfall pluviometers be installed to help manage discharge from stormwater drains and reduce nutrient and pollutant loads to the Site.
8. As recommended by Hall *et al.* (2006) any monitoring design should also allow for univariate and multivariate analyses of the data and enough survey sites should be included to provide sufficient statistical power to detect any change (Power Analysis). Time series analysis should be used to examine trends, while arithmetic averaging and classification/ordination (*e.g.* PRIMER) analyses could be used to examine patterns in data. Trend analysis (*e.g.* Mann-Kendall) should be used to separate anthropogenic change from natural seasonal/annual fluctuations.
9. Support land scheme of DEC and Shire of Busselton to acquire and/or conserve estuary foreshore lands. Investigate pros and cons of selective livestock grazing as a means to maintaining waterbird habitat along estuary foreshore. If all foreshore lands were to be acquired or 'reserved' as conservation areas, then the possibility of re-diverting freshwater flows into the Estuary and/or increased tidal flushing could then be explored. Change in flow regime would need to occur gradually to allow fringing vegetation to re-establish at higher elevation. Possible increased nutrient loads to Geographe Bay would also need to be considered.
10. Investigate the potential of dredging to help ameliorate noxious gases released from drying sediments of the lower Vasse Estuary over summer. This may only require dredging of a ca. 100 m reach along Estuary View Drive down to the Vasse floodgates (Jim Lane, DEC, pers. comm.).

12.4 Phytoplankton and Vascular Macrophytes

12.4.1 Existing Programs

Restoration of Submerged Macrophytes

There are two current research projects into the restoration of submerged macrophytes in the lower Vasse River, which if successful could be used to help develop similar trials for areas within the Ramsar Site. The research is being conducted by undergraduate Honours students from Murdoch University and is funded by GeoCatch:

- *Restoration of submerged macrophytes in the lower Vasse River.* A number of submerged aquatic plant species were replanted over the spring and summer growing season of 2006/07 to trial species for re-establishment in the lower Vasse River. The aim is to determine how growth rates and effects of excess nutrients, reduced light, and algal competition effect successful re-establishment.
- *Techniques for restoration of submerged macrophytes.* This project is designed to assess the feasibility of using matting (carpet underlay or coir) in which propagules of submerged aquatic plants have been embedded to promote successful establishment. The soft flocculent sediment that characterises eutrophic waterbodies

tends to inhibit plant attachment. This is exacerbated by high river flow in winter which can uproot juvenile plants.

Algal Blooms and Interactions between Fish, Macroinvertebrates and Aquatic Plants

The Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University is currently undertaking a study on "The importance of the interactions of fish, macroinvertebrates and aquatic plants in the occurrence of algal blooms in the lower Vasse and Canning Rivers". The work is funded by the Swan River Trust, DoW and GeoCatch. It is designed to investigate the relationship between fish and herbivorous macroinvertebrates (*Daphnia*) on vascular macrophyte and algal biomass. Macrophytes control algal blooms by competing with them for light and nutrients and by providing sheltered habitat for herbivorous macroinvertebrates. The study will investigate the relative impact of *Daphnia* and of introduced Mosquitofish on the biomass and productivity of algae (measured as chlorophyll-a) and ribbonweed *Vallisneria americana*. It will form part of a top down approach to conceptual models of nutrient dynamics in the lower Vasse River. MAFRL is concurrently investigating seagrasses and macroalgae in the estuary under the Vasse-Geographe CCI Water Quality Improvement Plan (see below). In conjunction, these projects could be used to develop conceptual models for ecosystem function within the Ramsar Site.

Macrophyte Survey of the Vasse-Wonnerup Estuary

MAFRL's snapshot survey of macrophytes and macroalgae in the Vasse-Wonnerup Estuary (Wilson *et al.* 2007) has already been discussed (see Section 4.9). The project is a companion study to research being conducted in the lower Vasse River (see above) and the predictive modelling being undertaken by DoW as part of the Vasse-Geographe CCI Water Quality Improvement Plan.

Wilson *et al.* (2007), with technical and logistical assistance from DEC (Alan Clarke) used stratified sampling at 28 sites over a two-day period in November 2006. At each site, 5 replicate sediment cores (Perspex core 9 cm diameter x 50 cm length) were used to sample benthic flora and determine mean biomass (dry weight g/m^2). Aerial photographs were also taken by DEC during the survey to verify coverage. Wilson *et al.* (2007) recommended:

- The survey be repeated on a seasonal basis to quantify intra- and inter-annual variations in abundance, biomass and species richness;
- Aerial photography be used to target sites of interest and establish transects for more frequent sampling;
- Funding be made available for specialist taxonomists to carry out species-level identifications;
- Baseline data on sediment characteristics (chemical & physical), light climate and bathymetry be collected to enable better interpretation of variation in species abundance, biomass and distribution
- Investigation of critical levels of macroalgal tissue N and P to understand successional dynamics in relation to nutrient cycling.
- Investigation of stable state nutrient thresholds for microalgae, macroalgae and vascular macrophytes in the Vasse-Wonnerup Estuary.

12.4.2 Current Recommendations

The programs and recommendations outlined above should continue to be supported. Any hope of reducing catchment nutrient loads to the Ramsar Site and to Geographe Bay will only be realised if the impetus and funding for programs such as DairyCatch and Greener Pastures is maintained. In addition, the development of specific conceptual models for nutrient-phytoplankton-macrophyte dynamics in the Vasse-Wonnerup Estuary is necessary if target nutrient levels are to be set (see also recommendations in sub-section 12.3.2). Methods and procedures used for future baseline surveys of macroalgae and macrophytes in the estuary must be standardised and preferably compatible with those of Wilson *et al.* (2007).

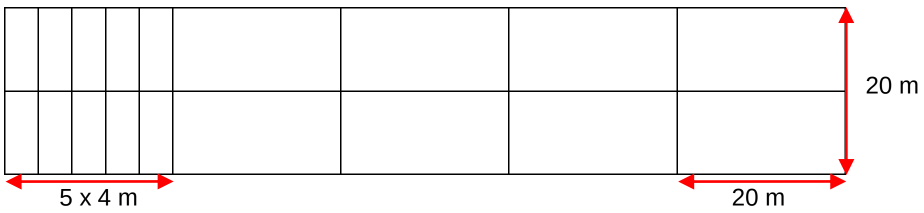
12.5 Riparian Vegetation

12.5.1 Existing Programs

Vasse Estuary Vegetation Monitoring and Mapping

Subsequent to recommendations by the Vasse Estuary Technical Working Group (Lane *et al.* 1997), CALM (now DEC) commenced a formal vegetation mapping and monitoring program in 1998 under funding from CALM GeoCatch and the Ministry for Planning. The program was devised by Froend (1999) to assess future changes in the 'health' of Vasse Estuary riparian vegetation and uses standardised and reproducible methodologies based on those outlined in the State Salinity Action Plan (SAP). Baseline monitoring for the program was undertaken by Froend *et al.* (2000) in 1999 however the scope of the project did not include a comparison of earlier survey work and mapping by Tingay and Tingay (1980). Froend *et al.* (2000) sampled a total of 10 permanently marked transects within the Vasse Estuary, from the Old Butter Factory to the floodgates and Layman Road, and included Malbup Creek and surrounding lands. The survey area was considered by the Group as that in most urgent need of protection/rehabilitation. The Wonnerup Estuary was not included due to the relative paucity of remnant fringing vegetation.

The 10 transects consisted of a number of contiguous 20 x 20 m quadrats, running perpendicular from the shore into upland vegetation to at least 2 m AHD. The 20 x 20 m quadrats were divided into five permanently marked 4 x 20 m quadrats, which in turn were divided into 4 x 4 m subplots:



Qualitative and quantitative data was collected for overstorey and understorey species (including emergent macrophytes) in each subplot including floristic composition, species richness, diversity and density, percentage foliage cover (subjective estimation), physiognomy (clinometer) and tree vigour (subjective categories for crown density, dead branches & epicormic growth). The number of recruits (tree & shrub saplings/seedlings) was also recorded together with size class structure of tree species (diameter at breast height; DBH). Vegetation mapping was done *via* ground-truthing of 1:25 000 aerial photographs for the entire estuary. Air photo overlays were then hand digitised using Arc-Info software. Surface soil salinities at each transect were measured with an electromagnetic induction meter (Geonics Ltd EM-38) and validated with limited soil sampling and direct measurement (EC of 1:5 soil:water extracts). Recent physical disturbance by humans and/or stock was also recorded. All data were lodged with DEC for future reference.

Based on percentage dead trees, tree crown vigour and tree and shrub recruitment at varying elevation, Froend *et al.* (2000) concluded the influx of seawater has had a significant impact on native fringing vegetation. Though not conclusive, the presence of salt-tolerant samphire recruits beneath tree canopies of poor vigour suggested this species may be spreading to higher elevation in response to increased soil salinisation. However, the one-off measure of soil salinity was insufficient to detect any increasing trends in soil salinity. Introduced grasses dominated the understorey at all sites. Their very dense foliage and extent of cover was taken to imply a greater tolerance than natives to rising salinities.

Froend *et al.* (2000) also compiled a list of dominant at specific elevations to assist with revegetation programs and rehabilitation of shorelines (Table 31). The list was developed from data recorded from monitoring transects and ground-truthing for the vegetation mapping. Although not specified by Froend *et al.* (2000) it is assumed that species are listed in order of dominance within each elevation category (zone).

Table 31. Dominant plant species in littoral zones of Vasse Estuary shoreline (from Froend *et al.* 2000).

Zone	Elevation	Overstorey species	Understorey species
A	0 - 0.5 m	none	*Halosarcia indica* ssp. *bidens* (Samphire) *Halosarcia pergranulata* (Samphire) *Sarcocornia quinqueflora* (Samphire) *Suaeda australis* (Seablight) *Atriplex hypoleuca* (Saltbush) *Juncus kraussii* (Sea Rush)
B	0.5 - 1.0 m	*Melaleuca cuticularis* (Saltwater Paperbark) *Melaleuca hamulosa* (Broom Bush Honey Myrtle) *Melaleuca rhaphiophylla* (Swamp Paperbark)	*Juncus kraussii* *Sarcocornia quinqueflora* *Atriplex hypoleuca* *Sporobolus virgicus* *Baumea juncea** (Bare Twigrush)
C	1.0 - 1.5 m	*Melaleuca rhaphiophylla* *Melaleuca hamulosa* *Melaleuca cuticularis* *Eucalyptus rudis* (Flooded Gum)	*Baumea juncea* *Juncus kraussii*

River Action Plans and Weed Management Plans

River Action Plans are discussed in Section 4.10.2. The Ramsar Site encompasses lower reaches of the Sabina River (Reserve 31188) and the Abba River (Tuart Forest National Park Reserve 40250). GeoCatch and the Vasse-Wonnerup LCDCs have prepared river Action Plans for the Vasse, Sabina, Abba and Ludlow rivers, including those sections contained within the Ramsar Site boundaries (see GeoCatch 2000, 2002). The plans have been prepared to guide landowners undertaking revegetation and rehabilitation along the rivers and include terrestrial weed management plans. There is also the Geographe Catchment Weed Plan which provides a general reference on weed management, while government agencies have responsibility for weed control on government owned land. Herbicides are often the most cost-effective means of weed control. However, the effect of wide-spread herbicide use on non-target species is not well understood (refer Section 10.2). The high groundwater table makes the Ramsar Site and surrounding wetlands particularly vulnerable to herbicide and pesticide contamination of groundwaters.

12.5.2 Current Recommendations

For monitoring limits of acceptable change:

1) It is recommended that fringing vegetation be monitored at least every 3 to 5 years in order to detect fine-scale shifts in vegetation communities. The monitoring program using same methodologies and sites as Froend (1999) and Froend *et al.* (2000) be conducted, in particular:
   a) ensure that the 10 monitoring transects and the 20 x 20 m quadrats within them remain permanently and visibly marked and, as far as possible, undisturbed,
   b) monitor extent, density and foliage cover of tree species where the effect of seawater influx has been most noticeable,
   c) monitor extent and spread of samphire communities as indicators of increased soil salinities at higher elevation, and
   d) monitor extent and spread of weed species.
2) Where possible, vegetation mapping of Froend (1999) and Froend *et al.* (2000) should be compared with that of Tingay and Tingay (1980), to help discern broad-scale changes pre- and post-1988. Future monitoring must use standardised methods and permanent transects if meaningful comparisons are to be made.
3) Though some of the monitoring categories used by Froend *et al.* (2000) are qualitative and subjective, they should be readily reproducible. Attempts should be made to ensure any subjective scores are as precise as possible and thus compatible with baseline data.

4) As recommended by McMahon (2006) in the ECD for the Lake Toolibin Ramsar site, 'successful' recruitment needs to be defined and should include recruitment that occurs naturally and that resultant of rehabilitation activities. Recruitment should be quantified using similar criteria as suggested by Froend and Storey (1996) for Lake Toolibin:
   a) number of recruits more than (say) 5 years old, and
   b) number of recruits reaching reproductive maturity.
5) In order to interpret changes in vegetation health, there must be concurrent monitoring of extent and frequency of surface and groundwater inundation, rainfall and soil and water salinity.
6) Monitoring design should also allow for univariate and multivariate analyses of the data and enough survey sites should be included to provide sufficient statistical power to detect any change (Power Analysis[15]). Time series analysis of vegetation composition should be used to examine trends, while arithmetic averaging and classification/ordination (*e.g.* PRIMER) analyses should be used to examine patterns in the plot and transect data. Trend analysis (*e.g.* Mann-Kendall) may be useful for separating anthropogenic change from natural seasonal/annual fluctuations.
7) Continue Geographe Catchment Weed Plan. Success of weed control programs should be assessed by investigating seasonal changes in distribution and abundance of infestations.
8) Rapid foreshore assessment methods of Pen and Scott (1995) that are currently employed for River Action Plans, provide a cost-effective approach to monitoring vegetation changes (include spread of weeds) across large areas of the catchment. These should continue to be used for lower reaches of tributary rivers encompassed within the Ramsar Site and as an adjunct to targeted transect monitoring.
9) Remote sensing (satellite or aerial photography) as recommended by Froend (1999) could be combined with ground-truthing using transect and foreshore assessment surveys to examine general 'health and response to flooding and/or salinity. Froend (1999) recommended it be used in conjunction with other environmental data (*e.g.* soil salinity, rainfall, water table, topography) and GIS, it can be used to model and predict successional changes in wetland vegetation communities.
10) Investigate potential for re-vegetation of estuary foreshore (avoiding monitoring plots of Froend *et al.* (2000)) and the likely role of selective livestock grazing in maintaining water bird habitat. This would need to be done in conjunction with surveys of water bird habitat usage and comparisons of grazed *vs* ungrazed lands; grass-dominated *vs* native vegetation/samphire *vs* exposed mudflat habitat
11) Continue river restoration and revegetation programs already begun under Lower Vasse River Cleanup Program and River Action Plans for the Vasse, Sabina, Abba and Ludlow.

[15] Following the baseline surveys, issues such as Power Analysis (*i.e.* the ability to detect a significant spatial or temporal difference, should one exist) and Type I and Type II errors should be considered, with the aim of an ensuring monitoring design maximises statistical power and therefore minimises the probability of making a Type II error. Type I errors are the mistake of concluding significant difference where none exists. Type II errors are the probability of concluding that there is no significant difference even though there is one.

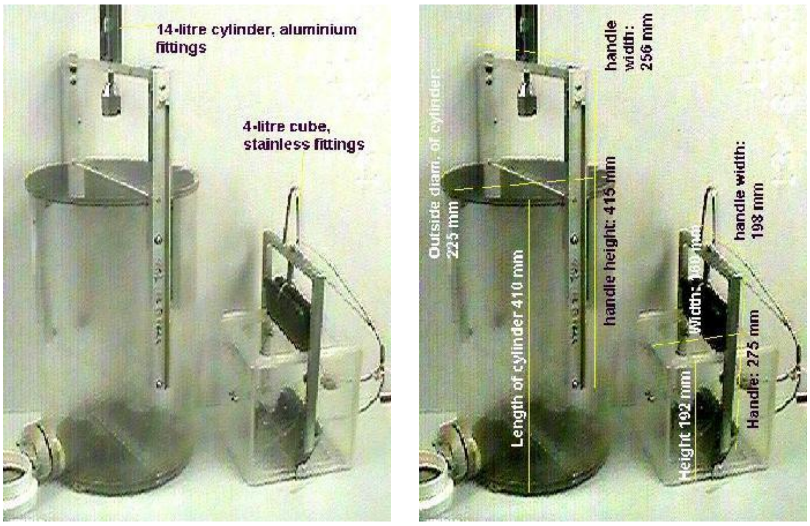
12.6 Aquatic Invertebrates

There is currently no baseline data on inter- or intra-annual variations in species numbers, richness or biomass. Nor is there data on the relative contribution of the various invertebrate species to the diet of waterbirds. Quantitative and semi-qualitative baseline surveys of zooplankton and benthic macroinvertebrates species richness and abundance are recommended. This should involve at least annual (standardised to time of year), or preferably seasonal (bi-annual) species-level sampling over a minimum of two years. For example, sampling time could coincide with maximum waterbird usage.

Quantitative zooplankton in the water column should be sampled using:

- a plankton net with a minimum 50 μm mesh size and conducted over a standard trawl distance, or
- zooplankton traps (pictured).

Plankton net



Zooplankton traps (Russ Shiel, University of Adelaide)

Quantitative sampling for benthic macroinvertebrates should be carried out using Perspex sediment cores of a least 10 cm diameter pushed into the benthos to a depth of 10cm. This should be done in conjunction with semi-qualitative standardised sweep-netting (250 μm mesh size) to enable the maximum number of taxa to be identified. Concurrent habitat mapping would need to be carried out to determine invertebrate species' habitat preferences.

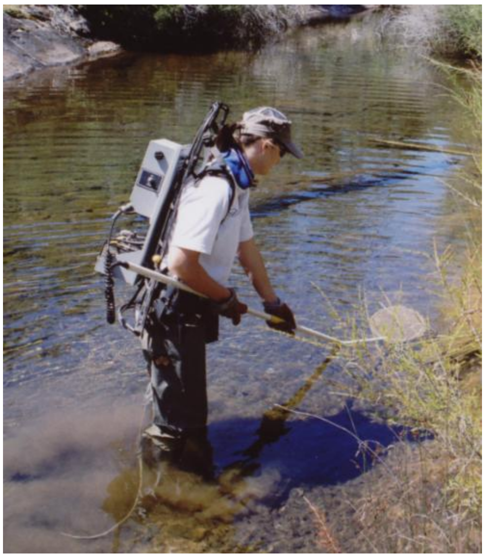
All baseline sampling should be spatially stratified (*e.g.* based on known waterbird foraging habitat), replicated and repeatable. Monitoring design should also allow for univariate and multivariate analyses of the data and enough survey sites should be included to provide sufficient statistical power to detect any change (Power Analysis, see footnote page 139). Arithmetic averaging and classification/ordination (*e.g.* PRIMER) analyses should be used to examine patterns in community composition data.

12.7 Fish

There is no current quantitative research or monitoring program for fish within the Ramsar Site, and no baseline data on intra- or inter-annual variation in fish communities or migratory behaviour. Nor are there any data on changes in commercial and recreational fish stocks, though anecdotal evidence suggests a decline in catch per unit effort (CPUE). Fish activity is qualitatively assessed at the floodgates over summer-autumn by DEC staff so that opening of the fish gates can be timed to prevent sudden mass fish deaths (refer White 1999, Elscot 2000). The relative contribution of the various fish species to the diet of waterbirds is unknown. Baseline surveys of fish species richness and abundance are recommended.

Fyke net

This should involve seasonal (bi-annual), species-level CPUE sampling over a minimum of two years. All sampling should be spatially stratified to provide good coverage of channel and littoral habitat and must be replicated and repeatable. For example fyke nets (pictured) and mesh box traps could be set overnight and cleared each morning. Fyke nets and traps are useful in that they allow collected fish to be sampled live. All fish caught should be identified to species and their length recorded. Under freshwater conditions, electrofishing, using either a backpack (pictured) or from a boat, is also an extremely effective technique for sampling both fish and crayfish.



Back-pack electrofishing (Sue Creagh)

Passive Integrated Transponder (PIT) tagging could be used to investigate fish migration in and out of the estuary. PIT tags are the same as microchips used to permanently identify pet cats and dogs. They are small, unobtrusive inert tags that are uniquely identified and are automatically stimulated by a tag reader to omit their unique electronic identifying signal as soon as they pass the tag reader/logger positioned to 'scan' across the selected estuary cross-section (*e.g.* the floodgates). As such, they allow the instantaneous logging of the upstream/downstream movement of individual fish. By combining this information with logged readings of changes in those parameters thought to stimulate migration (*i.e.* discharge, salinity, temperature and possibly dissolved oxygen), it is possible to relate changes in fish movements to changes in perceived stimuli (*i.e.* flow, salinity, temperature, DO) in real time.

PIT tags (Michigan Government website, USA)

12.8 Waterbirds

Standardised quantitative data is needed in order to determine any changes in waterbird diversity, abundance, numbers breeding and population composition in different parts of the Ramsar Site over time. Investigations of diet, food and habitat preferences and breeding success would help interpret any observed changes in the waterbird community. The authors are mindful that the spatial complexity of, and access to, the Vasse-Wonnerup Site has limited survey efforts in the past (refer Section 14). The following recommendations are based on advice from DEC (Jim Lane, pers. comm., August 2007).

1. General waterbird surveys should preferably be conducted monthly from November to May each year, with December to February (usual months of peak total numbers) as minimum;
2. Surveys for migratory shorebirds should preferably be conducted monthly from November to April each year, with January to March (usual months of peak total numbers of migratories) as a minimum;
3. Counts of black swans, active nest mounds, broods and cygnets on 'Swan Lake' should be conducted monthly from July to November each year;
4. Surveys to quantify usage of Tuart trees within the Tuart Forest National Park component of the Ramsar Site by nesting waterbirds should be conducted in winter-spring of at least two years;
5. It would be useful, though particularly time-consuming, to conduct regular searches for waterbird nests and young throughout Vasse-Wonnerup in winter-spring each year;
6. The above surveys should have regard to the following, as appropriate:
    - i). number of birds of each species and location (particularly with respect to recent and historical survey sectors reported by Lane *et al.* 2007),
    - ii). water level (m AHD at floodgates) and extent of inundation (*i.e.* location of waters edge) of relevant waterbodies,
    - iii). ideally, salinity of relevant waterbodies and parts thereof (refer to Lane *et al.* 1997 for sampling sites),
    - iv). habitat type,
    - v). behaviour (feeding, loafing, roosting, nesting),
    - vi). opportunistic evidence of breeding activity and success,
    - vii). opportunistic evidence of disturbance of waterbirds (people, dogs),
    - viii). opportunistic evidence of bird mortality and feral predators (foxes, cats);
7. Investigate diet of black swans and other species representative of different feeding guilds;
8. Consider the possible use of stable isotope (13C:12C and 15N:14N ratio) analyses to ascertain sources of carbon in food chains and ultimately waterbird diet.

12.9 Control of Pest Species (Animals)

12.9.1 Existing Programs

Control of foxes *Vulpes vulpes* is undertaken monthly within the Site within the Tuart Forest National Park to reduce fox predation on ducks that nest in the tuart forest and walk their young to the wetlands.

A goldfish eradication program as recommended by Morgan and Beatty (2004) for the lower Vasse River could be used in tributary rivers within of the Ramsar Site if goldfish are also found there. Morgan and Beatty recommend this be done through an intensive capture effort prior to the start of the breeding season in spring before this pest can become well established. They also suggest, consideration should be given to the return of a more natural flow regime *via* the removal of the stop-boards at the Old Butter Factory and opening of the valve at the Diversion Drain for longer periods. Management of introduced fish species that are established in a system, in general, is not particularly successful and can be very expensive. The best management is to prevent their introduction in the first place. Eradication is often only possible by culling the whole fish fauna and then allowing native fish species to re-invade from refuge populations. This is not to be recommended except in the most extreme situations, and can only realistically be applied in small, isolated situations (*e.g.* an isolated river reach).

12.9.2 Current Recommendations

1) As recommended by Morgan and Beatty (2004), a goldfish eradication program for the Vasse River which if successful could be extended to other tributary rivers where baseline surveys indicate the need. Consideration of a return to a more natural flow regime in the lower Vasse River by manipulating inflow from Diversion Drain and outflow through the stop-boards, with the latter being timed to avoid potential adverse impact on downstream water quality.
2) Regular review of results from monthly baiting programs should be carried out to determine inter- and intra-annual trends in indices of fox numbers and distribution. Ideally, a study of mortality of nesting waterbirds and their young would be undertaken to determine whether or not reductions in fox numbers result in improved duckling survival.

Table 32. Recommended research and monitoring programs for the Vasse-Wonnerup Site.

Parameter	Type of Monitoring / Research	Location	Frequency & Duration	Reason Required	Relevant Existing / Recent Programs	Priority
Geomorphology						
Seasonal area of inundation Aerial extent; Duration of inundation.	Establish benchmark; Satellite or aerial mapping of extent and duration of inundation in different seasons.	- throughout estuary, - lower tributary rivers, - floodplain.	Quarterly	Indicator of change in physical form of wetland; surrogate indicator of change in carrying capacity of waterbird community. Detect future change in aerial extent of each Ramsar wetland type and seasonal inundation, both of which will influence waterbird (& fish) diversity and abundance. Maintenance of freshwater in spring-early summer critical for juvenile waterfowl.	CSIRO Landsat imagery.	**HIGH**
Aerial extent of Ramsar wetland types	Establish benchmark; Satellite or aerial mapping of extent and duration of inundation.	- throughout.	Annual.	Indicator of change in physical form and hydrology of the wetland; surrogate indicator of change in waterbird community. Detect future change in aerial extent of wetland habitats which will influence waterbird (& fish) diversity and abundance.	CSIRO Landsat imagery.	**HIGH**
Water Depth (metres AHD)	Establish benchmark; Automated continuous water level recordings (m AHD).	- both estuaries and Inlet.	Continuous and on-going.	Links in with wetland bathymetry, floodgate operation and sand bar opening to assist in understanding system water balance. Indicator of change in physical form and hydrology of the wetland. Surrogate indicator of change in waterbird community. Detect future change in seasonal water depths, which in turn will influence waterbird (and fish) diversity and abundance.	Levels already monitored at the Vasse and Wonnerup floodgates as part of floodgate operational procedures, together with sand bar openings.	**HIGH**
Wetland bathymetry.	Accurate determination of wetland bathymetry.	- Vasse & Wonnerup estuaries.	Once off survey.	Needed to establish wetland volumes to assist in system hydrological modelling	DEC project.	**HIGH**
Sea-level.	Establish benchmark (m AHD).	- Geographe Bay.	Continuous and on-going.	Detect increase in sea-level.	DPI	**HIGH**
Coastal and Inlet morphology.	Establish benchmark.	- Wonnerup Inlet.	Annual.	Indicator of catchment disturbance. Detect increase in sea-level and natural changes to coast, sandbar and morphology of Wonnerup Inlet. Mapping of low-lying areas likely to be affected by rise in sea-level with interpretation of changes in area of inundation.	SWCC funded project.	**HIGH**

Table 32 continued.

Parameter	Type of Monitoring / Research	Location	Frequency & Duration	Reason Required	Relevant Existing / Recent Programs	Priority
Soil and Sediments						
Salinity TDS (mg/L), ECond (mS/cm or µS/cm).	Detect change; Repeatable longitudinal transect sampling of soils from target sites for laboratory analyses	- target sites around Vasse and Wonnerup estuaries	Annual (summer-autumn)	Indicator of change in soil properties. Detect salinisation due to floodgate operation and/or climate change. Changes in soil salinity will influence native vegetation community structure and viability of grazing lands.	DEC vegetation mapping.	HIGH
Sediment nutrient stores Concentration (µg/L or mg/L) TN, DON, NO_2, NO_3, NH_3, TP, PO_4.	Establish benchmark; Replicate soil samples for laboratory analyses	- key sites on estuary mudflats, saltmarshes, sedge-lands, seagrass beds, - river deltas.	Advice required.	Understand role of sediments as sources and sinks of nutrients. Provide information on bioavailability and rates of denitrification. Help prioritise monitoring and management intervention.	Could link in with predictive modelling of Aquatic Sciences Branch DoW under CCI Vasse-Geographe CCI WQ Improvement Plan; Implement recommendations of 2006 Snap-shot Survey of Macroalgae and Macrophytes (Wilson *et al.* 2007) to investigate estuary soil characteristics. Include lower tributary rivers.	HIGH
Acid sulphate soils Map extent of ASS based on soil pH, TAA (%sulphur w/w equivalent).	Establish benchmark; Replicate soil samples for laboratory analyses.	- target sites around Vasse and Wonnerup estuaries.	Advice required.	Early indicator of soil acidification and potential sources of acid drainage.	Water Corporation south-west groundwater developments; DEC protocols for assessing acid sulphate soils. www.dec.wa.gov.au/contaminatedsites	HIGH
Metals, Petroleum Hydrocarbons, Pesticides (various units of measure, refer ANZECC/ARMCANZ 2000)	Establish benchmark; Water samples for laboratory analyses.	- key sites (likely 'hotspots') throughout estuary, - loads from lower tributary rivers.	Advice required.	Direct lethal and sub-lethal effects on biota. Effects of some compounds (*e.g.* polyaromatic hydrocarbons) on food webs and breeding/ recruitment success may take two or more years to become apparent. Monitoring sites should be in likely receiving environment for pollutants or with known soil/sediment contamination.		LOW
Sedimentation Erosion / deposition rate.	Establish benchmark; Repeatable, transect or quadrat sampling.	- key sites on estuary mudflats, saltmarshes, sedge-lands, seagrass beds, - river deltas.	Advice required.	Indicator of change in physical form and soil properties. Identify zones of deposition and rates of sedimentation at target sites in estuary and river deltas. Help prioritise monitoring and management intervention.	DEC bathymetry mapping.	LOW

Table 32 continued.

Parameter	Type of Monitoring / Research	Location	Frequency & Duration	Reason Required	Relevant Existing / Recent Programs	Priority
Hydrology / Hydrogeology						
Groundwater inflows Discharge; Frequency; Duration; Water table level.	Establish benchmark - groundwater modelling; Gauging stations.	- key sites (*e.g.* ground-water nutrient hotspots).	Continuous and on-going.	Indicator of hydrological change. Information on groundwater inflow to the Site needed to develop water and nutrient balance models. Freshwater inflow can act as a cue for fish reproductive behaviour.	Vasse-Geographe CCI Catchment WQ project (Aquatic Sciences Branch DoW). Implement recommendations of phase I of CCI Vasse-Geographe Catchment Water Quality Monitoring project (refer DoW 2006).	HIGH
Surface water inflows Discharge; Frequency; Duration.	Establish benchmark - surface water modelling; Gauging stations.	- estuary floodgates, - key sites along tributary rivers.	Continuous and on-going.	Indicator of hydrological change. Information on surface water inflow to the Site needed to develop water and nutrient balance models. Freshwater inflow can act as a cue for fish reproductive behaviour.	DoW gauging stations; Vasse-Geographe CCI WQ Improvement Plan (Aquatic Sciences Branch DoW, predictive modelling).	HIGH
Water Quality						
Nutrients Concentration (μg/L or mg/L) TN, DON, NO_2, NO_3, NH_3, TP, PO_4. Nutrient loads (per unit area or per unit volume). Nitrogen isotopes ratios (^{15}N:^{14}N) to determine source of inputs?	Establish benchmark; Water samples for laboratory analyses.	targeted sites: - throughout estuary, - lower tributary rivers, - key groundwater sites.	Fortnightly for minimum 2 years for predictive modelling; Weekly at targeted sites to ascertain algal dynamics.	Indicator of water quality. Determine relative contribution of point and diffuse sources to nutrient loads. Understand nutrient cycling and bioavailability. Develop nutrient balance models. Indicator of change in nutrient status of the wetland.	Vasse-Geographe CCI WQ Improvement Plan (Aquatic Sciences Branch DoW, predictive modelling); Implement recommendations of Phase I of Vasse-Geographe CCI WQ Plan (refer Hall *et al.* 2006, DoW 2006) to collect baseline data on water quality to aid development of predictive models.	HIGH
Dissolved Oxygen Concentration (mg/L and % saturation).	Detect change; *In situ* measurement.	targeted sites: - throughout estuary, - lower tributary rivers,	Fortnightly for minimum 2 years for predictive modelling; Weekly at targeted sites for algal dynamics.	Indicator of water quality. Improve understanding of oxygen dynamics and effects on biota and nutrient cycling. Prevent fish deaths.	Vasse-Geographe CCI WQ Improvement Plan (Aquatic Sciences Branch DoW, predictive modelling).	HIGH
pH	Establish benchmark; *In situ* measurement.	targeted sites: - throughout estuary, - lower tributary rivers.	Fortnightly for minimum 2 years for predictive modelling; Weekly at targeted sites for algal dynamics.	Indicator of water quality; surrogate indicator of acid soil drainage and potential heavy metal pollution. Improve understanding of fluctuations in pH.	Vasse-Geographe CCI WQ Improvement Plan (Aquatic Sciences Branch DoW, predictive modelling).	HIGH

Table 32 continued.

Parameter	Type of Monitoring / Research	Location	Frequency & Duration	Reason Required	Relevant Existing / Recent Programs	Priority
Sulphate and Iron Concentration of dissolved SO_4 and Fe (mg/L) and net acidity (CaCO3 equivalent).	Establish benchmark; Water samples for laboratory analyses.	- key sites in estuary; in particular areas adjacent to developments (*e.g.* Port Geographe and Ford Rd).	Advice required.	Detect runoff from of acid sulphate soils and potential for heavy metal pollution. Determine the influence of SO_4-Fe-PO_4 interactions on cyanobacterial bloom formation.	Could link in with predictive modelling of Aquatic Sciences Branch DoW under CCI Vasse-Geographe CCI WQ Improvement Plan, or Macroalgae and Macrophyte Surveys (DEC/GeoCatch).	MEDIUM
Total Suspended Solids and Turbidity Colour (Hazen) and TSS (mg/L) and/or turbidity (NTU) and/or Secchi depth (cm).	Establish benchmark; Water samples for laboratory analyses.	targeted sites: - throughout estuary, - lower tributary rivers,	Fortnightly for minimum 2 years for predictive modelling. Weekly at targeted sites to ascertain nutrient-phytoplankton-macrophyte dynamics.	Indicator of water quality. Influences plant and animal communities, in particular seagrass and algal bloom dynamics. Light penetration through the water column affected by both suspended particulate matter (including phytoplankton) and coloured dissolved organic matter such as tannins.	Vasse-Geographe CCI WQ Improvement Plan (Aquatic Sciences Branch DoW, predictive modelling).	HIGH
Salinity TDS (mg/L) and/or EC (mS/cm)	Detect change *In situ* measurement or collection of water samples for laboratory analyses	targeted sites: - throughout estuary, - lower tributary rivers,	Fortnightly for minimum 2 years for predictive modelling. Weekly at targeted sites to ascertain nutrient-phytoplankton-macrophyte dynamics.	Indicator of water quality. Influences plant and animal community structure and distribution. Influences algal bloom dynamics. Salinity tolerance of juvenile waterfowl <15,300 mg/L TDS. Seasonal changes in salinity can act as cues for reproductive migration and spawning in fishes.	Vasse-Geographe CCI WQ Improvement Plan (Aquatic Sciences Branch DoW, predictive modelling).	HIGH
Temperature	Detect change; *In situ* measurement.	targeted sites: - throughout estuary, - lower tributary rivers,	Fortnightly for minimum 2 years for predictive modelling. Weekly at targeted sites for algal dynamics.	Indicator of change in water quality. Influence on algal bloom dynamics. Climate change and warmer water temperatures may lead to algal blooms occurring earlier in the year. Temperature varies dramatically over the day and month, dependent on ambient air temperature, water depth and degree of riparian shading. Has a major influencing role on productivity.	Vasse-Geographe CCI WQ Improvement Plan (Aquatic Sciences Branch DoW, predictive modelling).	HIGH
Metals, Petroleum Hydrocarbons, Oil, Pesticides, Herbicides (various units of measure, refer ANZECC/ARMCANZ 2000)	Establish benchmark; Water samples for laboratory analyses.	- key sites (likely 'hotspots') throughout estuary, - lower tributary rivers.	Advice required	Direct lethal and sub-lethal effects on biota. Effects of some compounds (*e.g*. polycarbonate hydrocarbons) on food webs and breeding/ recruitment success may take ≥2 years to become apparent. Monitoring sites should be chosen in likely receiving environment for pollutants or with known soil/sediment contamination. Indicates possible contaminants should ASS become a problem, and low pH mobilises metals.	Lower Vasse River Cleanup Program, Clean Drains Program.	LOW

Table 32 continued.

Parameter	Type of Monitoring / Research	Location	Frequency & Duration	Reason Required	Relevant Existing / Recent Programs	Priority
Phytoplankton and Aquatic Macrophytes						
Phytoplankton Concentration of chlorophyll-a,b,c and phaeophytin; Species richness, concentration, biomass of phytoplankton.	Establish benchmark; Repeatable replicated transect sampling for community structure, biomass (dry weight grams per unit area) and concentration of chlorophylls and phaeophytin.	- throughout estuary.	Weekly for a minimum of 2 years to ascertain nutrient-phytoplankton-macrophyte dynamics.	Help refine indicators for phytoplankton biomass; surrogate indicator of nutrient and turbidity status. Understand successional dynamics and bloom formation – improve capacity to predict and therefore limit severe blooms, help prevent fish deaths and potential loss of waterbird habitat. Confirm presence of potentially toxic cyanobacteria species.	Vasse-Geographe CCI WQ Improvement Plan (Aquatic Sciences Branch DoW, predictive modelling); Macroalgae and Macrophyte Surveys (DEC/GeoCatch) - implement recommendations of 2006 Snap-shot Survey of Macroalgae and Macrophytes (Wilson *et al*. 2007).	HIGH
Macro-algae Distribution and biomass of *Ruppia*, *Chara*, *Ulva*, *Cladophora*, *Rhizoclonium*, *Chaetomorpha* species *etc.*	Establish benchmark; Satellite or aerial extent together with ground truthing - repeatable replicated transect sampling for community structure and biomass (dry weight grams per unit area).	- throughout estuary	Bi-annual (winter-spring and summer-autumn) for a minimum 2-3 years.	Help refine indicators for macro-algal biomass; surrogate indicator of nutrient and turbidity status. Understand successional dynamics, seasonal distribution & biomass of species; improve capacity to predict and therefore limit severe macroalgal blooms; prevent seagrass loss.	Macroalgae and Macrophyte Surveys (DEC/GeoCatch); CSIRO Landsat imagery.	HIGH
Seagrass Community structure and aerial extent of *Ruppia* and *Lepilaena*.	Establish benchmark Satellite or aerial extent together with ground truthing - repeatable replicated transect sampling for community structure and biomass (dry weight grams per unit area).	- throughout estuary.	Bi-annual (winter-spring and summer-autumn) for a minimum 2-3 years.	Help refine indicators for macro-algal biomass; surrogate indicator of nutrient and turbidity status. Important food and habitat resource for waterfowl (& likely also fish & macro-invertebrates. Support biofilms which can play an important role in denitrification. Important in stabilising sediments.	Macroalgae and Macrophyte Surveys (DEC/GeoCatch); CSIRO Landsat imagery.	HIGH
Fringing vegetation (and surrounding land-use)						
Community composition; Aerial extent; Condition / health; Recruitment / mortality.	Establish benchmark Satellite or aerial extent together with ground truthing - repeatable replicated transect sampling	- samphire heath and sedgelands, - paperbark / flooded gum / peppermint woodlands, - tuart woodlands.	Once every 3 - 5 years, at same time of year.	Indicators of change in vegetation structure and extent; surrogate indicators of hydrological and salinity regimes. Fringing vegetation provides important shelter, roosting and breeding habitat for waterbirds. Important for soil stability and reducing catchment runoff of nutrients and sediment. Effects groundwater level and discharge and secondary salinisation. Provides habitat connectivity.	DEC vegetation mapping. Continue vegetation health monitoring project as established by Froend *et al*. (2000), in conjunction with monitoring of water levels and salinities. NHT funding for on-going transect monitoring currently being sought by DEC Bunbury through SWCC.	MEDIUM

Table 32 continued.

Parameter	Type of Monitoring / Research	Location	Frequency & Duration	Reason Required	Relevant Existing / Recent Programs	Priority
					Vegetation maps of Tingay & Tingay (1980) could be used as broad benchmark for Vasse Estuary. GeoCatch River Action Plans.	
Surrounding Land-use (% land in different land-use categories)	Detect change in land use/zoning etc	- throughout catchment.	Annual.	Indicator of catchment disturbance. Incorporate the effects of changes in land use, vegetation cover and infrastructure (*e.g.* roads, rail-lines) on sediments, nutrients and other contaminant loads to wetlands.	WAPC mapping; CSIRO Landsat imagery.	HIGH
Invertebrates						
Zooplankton and Benthic Macroinvertebrates Abundance, species richness and community composition.	Establish benchmark Repeatable replicated quantitative and semi-quantitative sampling (*e.g.* plankton trawls, zoo-plankton traps, benthic cores & sweep netting) Collect concurrent baseline data on water quality and water depth.	- throughout estuary, - lower tributary rivers.	Bi-annual (winter-spring and summer-autumn) for a minimum 2-3 years.	Help refine indicators for aquatic invertebrate communities; surrogate indicators of water quality. Help quantify relationships between invertebrate and waterbird abundances. Help quantify relative importance of sediment bio-turbation in nutrient cycling within the estuary. Invertebrates are important part of freshwater and estuarine foodwebs. High abundance of invertebrates supports high waterbird abundance. Important food resource for fish. Sensitive to changes in flow regime, sedimentation, water chemistry and thus changes in land-use.		LOW
Fish						
Fish and Decapod Crustacea Abundance, species richness and community composition.	Establish benchmark Catch per unit effort sampling (*e.g.* fyke nets) Fish tagging/PIT tagging at gates to understand movements Collect concurrent data on fish community, water quality and water depth.	- throughout estuary, - lower tributary rivers.	Bi-annual (winter-spring and summer-autumn) for a minimum 2-3 years.	Help refine indicators for fish communities. Provide data on seasonal migrations into or out of the estuary. Quantify relationships between fish distribution and abundance and water quality. Help quantify relationships between fish abundances and waterbird abundances.	Fish fauna of the Vasse River (GeoCatch, Vasse River Cleanup Program).	LOW

Table 32 continued.

Parameter	Type of Monitoring / Research	Location	Frequency & Duration	Reason Required	Relevant Existing / Recent Programs	Priority
Waterbirds						
Abundance, species richness & community composition.	Waterbird counts - describe community structures of the major management components of the Site. Concurrent data on water quality, water depth and aerial extent of inundation. Concurrent data on waterbird behaviour (feeding, loafing, roosting, nesting), evidence of disturbance (people, dogs), evidence of mortality / predation.	- Vasse Estuary, Wonnerup Estuary, Malbup Creek and Wonnerup Inlet.	General waterbird surveys should be conducted monthly Nov. to May each year, with Dec. to Feb. (usual months of peak total numbers) as minimum. Surveys for migratory shorebirds should be conducted monthly Nov. to Apr. each year, with Jan. to Mar. (usual months of peak total numbers of migratories) as minimum.	Community structure shows marked variation between seasons, years, major management components and habitats. Observed differences are difficult to interpret, particularly those between years. Inter- and intra-annual relationship between waterbird communities and water depth, salinity, nutrient concentration and food availability has not been quantified and is not understood.		**HIGH**
	Targeted surveys to better define habitat preferences.	- as above	As above	As above		
	Targeted surveys to search for “missing” species.	- as above	As above	Several previously recorded, non-vagrant and non-irruptive bird species were not encountered during the most recent (1998-2000) surveys. Reason(s) for apparent absence unknown.		**HIGH**
	Implement thorough, regular and systematic waterbird counts of the Site.	- throughout	As above	Year-by-year occurrence of waterbird species on Vasse-Wonnerup not fully known.		**HIGH**
	Collate information on current and prior years' off-Site variables (*e.g.* rainfall) and variations in regional abundances and distributions of waterbird populations.		One-off	There is insufficient data on the effect of off-Site variables (*e.g.* rainfall) on regional abundances and distributions of waterbird populations.		**HIGH**
Waterbird diet.	Baseline, Site-specific information on food preferences of Black Swans and other species representative of different feeding guilds. Key food items (*e.g. Ruppia*, *Chara*) to be identified, mapped and monitored.	To be conducted in conjunction with regular and systematic waterbird counts of the Site, as indicated above.	To be conducted in conjunction with regular and systematic waterbird counts of the Site, as indicated above.	Specific diet of adults, breeding adults and juveniles largely unknown in relation to food items present and accessible in the wetlands, seasonally and between years.		**HIGH**

Table 32 continued.

Parameter	Type of Monitoring / Research	Location	Frequency & Duration	Reason Required	Relevant Existing / Recent Programs	Priority
Waterbird breeding.	Counts of black swans, active nest mounds, broods and cygnets.	- 'Swan Lake'.	Monthly from July to Nov. each year.	Monitor breeding and recruitment success of the Black Swan colony.		HIGH
	Counts of waterbirds, active nests and chicks in Tuart trees in Tuart National Park component of the Site.	- Tuart Forest National Park component of the Site.	Monthly during winter-spring of at least two years.	Quantify usage of Tuart trees by nesting waterbirds. Current use of Site for breeding is inadequately understood. Need to determine breeding status and success.		HIGH
	Systematic searches for nests and/or young of other potential breeding species; Description of breeding habitat, in particular the plant species, structure, elevation (and nest height), inundation and perturbations.	- throughout.	Monthly from Aug. to Nov. each year.	Current use of Site for breeding is inadequately understood. Need to determine breeding status and success. With altered management, use could perhaps be greater than at present. The most appropriate and practicable management regimes to capitalize on breeding potential should be identified.		HIGH
Ecosystem processes						
Food web structure Stable isotope (C & N) analyses.	Describe foodweb (trophic structure) using stable isotope analysis of tissue (plant & animal) samples.	- each estuary	One-off	Establish a food web structure for both estuaries to describe major carbon sources driving the food webs and food chains within the systems to elucidate predator prey relationships and to describe trophic positions of consumers. Identify carbon sources supporting waterbirds.		LOW
Pest species Weeds and feral animals.	Systematic searches for introduced pest and weed species; Begin an ongoing and coordinated mapping process to document occurrences (and impacts) of feral species across the wetland.	- throughout	Annual	To evaluate and help determine existing threat/impacts. To gain a better understanding of the prevalence of foxes and cats, rabbits, weed infestations *etc*. Eradication unlikely for some species, however, once better population estimates are obtained, targets for control can be set for a co-ordinated local control program.	To be conducted as part of ongoing controls; Responsibility: DEC, Busselton Shire, adjoining leaseholders.	MEDIUM

13. RECOMMENDATIONS FOR MANAGEMENT

13.1 Key Management Actions

A key findings of the present study is the need for collection of systematic records on water depth, water flow (magnitude, frequency, depth, duration, velocity), water quality, aerial extents of vegetation communities/habitat types, presence of invertebrates and fish, presence of waterbirds, breeding of waterbirds, waterbird counts and possible presence of threatened painted snipe and Australasian bittern. Currently available information is not sufficient to adequately describe the ecological character of the Site nor statistically robust enough to evaluate future change or even change since time of listing. Sufficient funding, resources and personnel must be made available to ensure not only that adequate baseline data is collected, but that long-term monitoring can be undertaken and all data records are appropriately analysed in a timely manner. Recommendations of particular importance include:

- Ongoing funding and support for existing/recent catchment management initiatives:
  - Vasse-Geographe CCI Water Quality Improvement Plan, in particular the predictive modelling being undertaken by the Aquatic Sciences Branch DoW (GeoCatch/DoW);
  - DairyCatch (collaboration with DAF);
  - Nutrient Smart (GeoCatch);
  - Greener Pastures (collaboration with DAF);
  - Research into phytoplankton-macrophyte dynamics (DEC/GeoCatch);
  - Vegetation mapping (DEC);
  - River Action Plans (GeoCatch);
  - Clean Drains Program.
- Regular mapping of aerial extent of wetland types/habitats and aerial extent of inundation.
- Restore vegetation buffer zones of estuary and tributary rivers
  - support the ongoing practice of State Government acquiring and conserving estuary foreshore lands;
  - investigate pros and cons of selective livestock grazing as a means to maintaining waterbird habitat along estuary foreshore.
- Investigate the potential of dredging to help ameliorate noxious gases released from drying sediments of the lower Vasse Estuary over summer. This may only require dredging of a ca. 100 m reach along Estuary View Drive down to the Vasse floodgates (Jim Lane, DEC, pers. comm.).
- Standardised monitoring techniques must be used for all data collection:
  - all reporting should detail methodologies;
  - statistically rigorous sampling design;
  - regular calibration/maintenance of equipment (*e.g.* Water Corporation needs to ensure that automatic loggers on the estuary floodgates are properly maintained).
- Analysis of baseline/monitoring data and reporting of results must be done in a timely manner (in the order of months not years).
- Assurance of funding to maintain long-term monitoring is vital if management plans are to succeed:
  - better State funding rather than reliance on NHT and/or NRM funds;
  - funding cycles of 5-10 years, not 2-3 years to maintain continuity of monitoring programs and provide job security to attract and keep experienced personnel.
- Enforce existing statutory & subsidiary legislation.
  - ensure commitments made by urban, agricultural and industrial developers are sufficient to protect the Site and that they are actually met (*e.g.* Cable Sands; Port Geographe).

13.2 Towards a Management Plan for the Ramsar Site

13.2.1 Bayesian Belief Networks

Bayesian belief networks (BBN) are a potential tool useful to assess causality and probability to help optimise management interventions, in areas where significant uncertainty exists. They are a decision support tool that, like water/nutrient balance models, can help focus management programs (*e.g.* Dairy Catch, Greener Pastures and revegetation initiatives) and improve management outcomes. BBN's (also known as Bayesian networks, probability networks, influence networks or Bayes' belief nets) are graphical models which represent relationships among uncertain variables, in which probabilities may be estimated subjectively (Burgman 2005). They have already been applied to Lake Warden and Lake Toolibin, where they were used in conjunction with water balance models to address decision making in the face of uncertainty in mitigation of secondary salinisation, altered hydrology and loss of waterbird abundance (Ryan Vogwill, DEC, pers comm.).

BBNs are used to make the best possible prediction based on the best available data and expert opinion. They are often considered particularly useful in assessing the relative importance of ecosystem components or processes for which there are no quantitative data (Hamilton *et al.* 2005, 2007). As such they can be used to help set interim targets, but are also useful in systems too complicated to currently model. They can be used to assess the potential for harm to occur to an ecosystem as a whole (due to say an overarching threat like climate change) but more typically targeted at a particular process or outcome. For example the chance of an algal bloom as diagrammatically represented below in Figure 17. The degree of uncertainty will depend on the quality of the data or information used and will cascade through the network. For this reason, networks that focus on particular ecosystem processes will have greater accuracy. They should be used to assess the relative probability (*i.e.* option A is better than option B), rather than absolute probability of success (*i.e.* option A has a 78.3% chance of success) of a particular management activity (Ryan Vogwill, DEC, pers. comm.). The BBN will also need to be updated as new information becomes available.

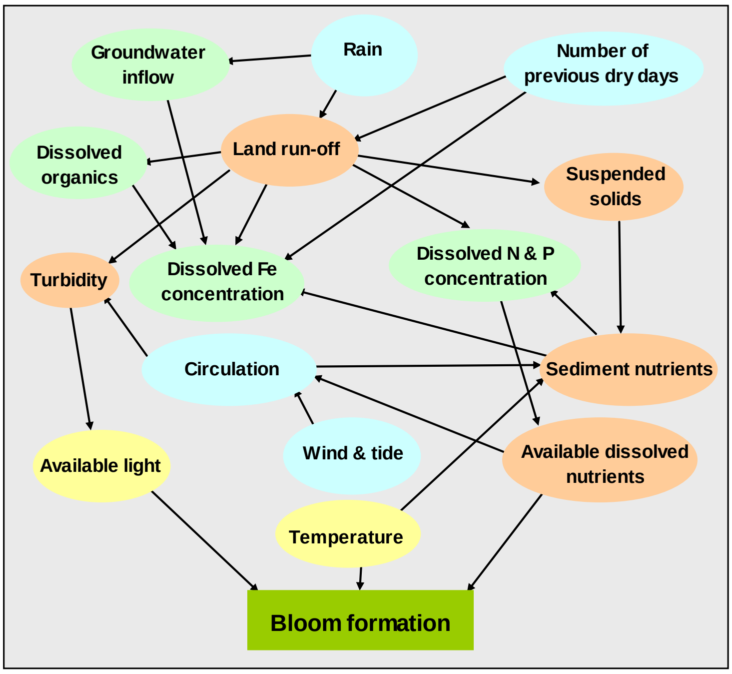


Figure 17. Example of BBN incorporating all processes likely to effect cyanobacterial bloom formation (after SEQ Healthy Waterways Newsletter *Lyngbya* Update, March 2007, http://www.healthywaterways.org/lyngbya-links.html.

If BBNs are to be used to aid water quality and algal bloom management for the Vasse-Wonnerup, then it is important to have a good understanding of complicated issues such, as but not limited too: nutrient and sediment flux, surface water/groundwater interaction, distribution of key components, tolerances and threshold conditions, decline and mortality in key biota, water quantity/quality and sediment interactions, sediment loads and movement. However, an exhaustive analysis is not necessarily required (although preferable). A starting point would be the completion of the water and nutrient balance modelling being undertaken by DoW as part of the Vasse-Geographe CCI (refer Section 12.3.2). Then a catchment-scale assessment of the feasibility (possibly using a BBN) of mitigation based on current asset condition, policies, social feasibility assessment and catchment land use, prior to deciding on a detailed monitoring and evaluation program (Ryan Vogwill, pers. comm.).

14. COMMUNICATION, EDUCATION AND PUBLIC AWARENESS

A program of Communication, Education and Public Awareness 2003-2008 was established under the Ramsar Convention. The program is designed to generate coordinated international and national campaigns that help raise public awareness of the value of wetlands and foster wise use and management. In response, Australia established the Wetland Communication, Education and Public Awareness (CEPA) National Action Plan 2001-2005. A description of key communication, education and/or public awareness activities is to be included as part of the ECD for Ramsar sites.

14.1 Busselton Bird Observatory and Wetlands Centre

The Shire, with guidance from DEC, other agencies and the community, has recently commenced planning for a major 'Wetlands Experience' tourism attraction, including a Busselton Bird Observatory and Wetlands Centre on the New River and walk trails providing guided access to the wetlands and Tuart Forest. The Shire of Busselton is currently proposing to construct a Bird Observatory and Wetlands Centre on the nearby New River together with a Busselton Wetlands (including the Ramsar Site) public awareness campaign and a network of appropriately located walk trails (see Section 14.1).

Bird hide on Malbup Creek (courtesy Martin Pritchard, GeoCatch).

The Shire of Busselton, with guidance from DEC, other agencies and the community, has recently commenced planning for establishment of a Bird Observatory and Wetlands Centre on the New River, in Busselton townsite. The aim of developing the Centre is to help conserve the Busselton Wetlands (including the Ramsar Site) through rehabilitation of degraded wetland areas and education of visitors and the community about the importance of the Ramsar Site and nearby wetlands. In concept, the Centre will include spaces for interpretive displays, merchandising, a meeting room/function area, basic research laboratory and a small theatre. A network of trails, boardwalks and bird hides within the immediate surrounds will also be constructed. The trails will link with others already established in parts of the wetlands and the nearby remnant Tuart forest and will include sites where future conservation works will rehabilitate wetlands and restore fringing native vegetation and bird habitat. The Shire would also like to foster collaborative teaching and research with the Capel Eco Discovery Centre in at Iluka Resources Limited Capel mine site, some 20 km north of Busselton. The Capel Eco Discovery Centre is already a regular destination for visiting school groups and is strongly supported by the WA Science Teachers Association. It is envisaged that the Centre will operate as a not for profit organisation. Funding for the project of up to $5.25m will be sought mostly from Government grants.

14.2 Ribbons of Blue

Ribbons of Blue is part of the Natural Heritage Trust funded Waterwatch Australia network. Ribbons of Blue programs involve school students and community groups in monitoring river and wetland environments. Monitoring is conducted for water quality and aquatic macroinvertebrate communities. Participating groups are encouraged to develop action plans to help manage any problems identified. The program has established numerous of monitoring sites throughout the State, including sites on the Abba and Sabina River, just outside the boundary of the Ramsar Site. Though the programs are not specifically aimed at the Ramsar Site, there is scope for education as to the importance of catchment health in maintaining Ramsar values.

In Western Australia, Ribbons of Blue is coordinated by the DoE and supported by GeoCatch, the Swan River Trust, Department of Education and Training, WA Plantation Resources, Friends of the River Toodyay, and Manjimup Land Conservation District Committee. Ribbons of Blue regional coordinators provide technical expertise during fieldwork, training, professional development, and help plan on-going monitoring and education programs.

14.3 GeoCatch Wild Walks

GeoCatch recently (2005/06) instigated a program of Wild Walks. Experts in various fields are invited to lead group walks aimed at educating the public about general bush, wetland and river ecology, the Ramsar Site and cultural heritage. To date, the walks have proved a great success.


Walk trails at mouth of Abba River (courtesy Martin Pritchard, GeoCatch).

14.4 The Wetlands Project

The Wetlands Project is funded through the NHT provides technical advice and financial incentives for land mangers and landholders to improve wetland values on private and public land. In 2006, the project was co-ordinated by GeoCatch. Community groups, volunteers, local shires and land managers across the two catchments co-operated to improve public priority wetlands other than Ramsar sites or sites listed in the *Directory of Important Wetlands in Australia* (DIWA, Environment Australia 2001). Wetlands included: New River, Vasse River, Broadwater System, Elmore Lagoon, Muddy Lakes, Hay Park, Cathedral Ave, Rosamel, Picton and Kemerton wetlands (Geographe Network News, Issue 20, November 2006). Wetland improvement on private land was equally successful with Twenty-two landholders also received technical advice on wetland improvement on their private lands. Another eight sites on private land received funding for on-ground works, and eight sites had baseline data collected to determine wetland health, which will be incorporated into the DoW statewide wetland database, WetlandBase (Geographe Network News, Issue 20, November 2006). Work undertaken involved:

- Opening night at the wetland-themed art exhibition, in partnership with ArtGeo and involving 25 local artists. Artworks depicted both the beauty and degradation of wetlands in the local area;
- Weed control achieved on 93 hectares of wetlands;
- Rehabilitation of 32 hectares of degraded wetlands;
- 120 hectares of wetland fenced to exclude stock and improve biodiversity values;
- Two Sedges and Rushes Identification workshops held and very well attended.

In 2007, the Wetland Project will be extended to the Ramsar sites and DIWA sites. This part of the project will be overseen by DEC, and GeoCatch will continue to provide financial incentives to landholders for on-ground works to improve wetland values on private land.

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). See "Limits of Acceptable Change".
Administrative Authority	the agency within each Contracting Party charged by the national government with implementation of the Ramsar Convention within its territory. http://www.ramsar.org/about/about_glossary.htm
Adverse conditions (Criterion 4)	ecological conditions unusually hostile to the survival of plant or animal species, such as occur during severe weather like prolonged drought, flooding, cold, *etc* (Ramsar Convention 2006).
Aeolian	erosion and deposition of sediments by wind processes (Phillips & Muller 2006).
Anoxia	no oxygen. See also "Hypoxia".
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 2002a, Resolution VIII.6).
Attributes of wetlands	attributes of a wetland include biological diversity and unique cultural and heritage features. These attributes may lead to certain uses or the derivation of particular products, but they may also have intrinsic, unquantifiable importance (Ramsar Convention 1996, Resolution VI.1). This term has been replaced by Ecosystem Components.
Baseline	condition at a starting point, usually the time of listing (Lambert & Elix 2006).
Benchmark	a standard or point of reference (ANZECC/ARMCANZ 2000). a pre-determined state (based on the values which are sought to be protected) to be achieved or maintained (Lambert & Elix 2006).
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 (Criteria 1 & 3)	a scientifically rigorous determination of regions as established using biological and physical parameters such as climate, soil type, vegetation cover, *etc*. (Ramsar Convention 2006).
Biological diversity (Criteria 3 & 7)	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 2006).
Biomass	the amount of living material in a unit area or volume, usually expressed as mass or weight (Phillips & Muller 2006).
Bioturbation	stirring or mixing of sediments by resident biota, particularly burrowing or boring animals. Bioturbation can play a major role in nutrient and carbon re-cycling through resuspension of sediments. It also enhances organic decomposition and redistribution of organic material, and enables deeper penetration of oxygenated waters into the microscopic spaces in the soil.
Brackish	water with a salinity of between 1,000 mg/L and 3, 000 mg/L (or 200 - 880 mS/m) (ANZECC/ARMCANZ 2000).
Catchment	the total area draining into a river, reservoir, or other body of water (ANZECC/ARMCANZ 2000).
Change in ecological character	is 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/ ARMCANZ 2000).
Community composition	All the types of taxa present in a community (ANZECC/ARMCANZ 2000).
Community structure	All the types of taxa present in a community and their relative abundances (ANZECC/ ARMCANZ 2000).
Conceptual model	Wetland conceptual models (or diagrams) illustrate our understanding of ecosystem components and processes and the interactions between them.
Contracting Parties	are countries that are Member States to the Ramsar Convention on Wetlands, 153 as of September 2006. 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. http://www.ramsar.org/key_cp_e.htm
Critical stage (Criterion 4)	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 2006).
Crustacean	belonging to the Crustacea, a phylum of (chiefly aquatic) arthropod animals, including the lobsters, prawns, crabs, barnacles, slaters *etc*, commonly having the body covered with a hard exoskeleton or carapace (Phillips & Muller 2006).
Cyanobacteria	aquatic bacteria that can photosynthesise (Phillips & Muller 2006) and typically appear blue-green in colour.
Decapod	belonging to the taxonomic Order (grouping) Decapoda, which includes, shrimps, prawns, crabs and crayfish.
Detritus	any disintegrated material (debris) which accumulates on the bottom of a water body.
Ecological character	is 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 (Criterion 2)	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 2006).
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).
Ecosystem components	include 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	are 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	are 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".

Ecologically sustainable development	development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends (ANZECC/ARMCANZ 2000).
Estuarine	of or belonging to an estuary. An estuary is a waterbody where river currents are met by ocean tides.
Euryhaline	species that are able to tolerate a wide range of salinities, from fresh through to saline.
Fluvial geomorphology	the study of water-shaped landforms (Gordon *et al*. 1999)
Freshwater	water with a salinity of less than 500 mg/L (or < 90 mS/m) (ANZECC/ARMCANZ 2000).
Functions of wetlands	the activities or actions which occur naturally in wetlands as a product of interactions between the ecosystem structure and processes. Functions include flood water control; nutrient, sediment and contaminant retention; food web support; shoreline stabilisation and erosion controls; storm protection; and stabilization of local climatic conditions, particularly rainfall and temperature (Ramsar Convention 1996 Resolution VI.1). This term was replaced in with "Ecosystem Services/Benefits" (Ramsar Convention 2006).
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/ARMCANZ 2000).
Hypoxia	Very low oxygen (typically less than or equal to 2 mg/L, equivalent to 2 parts per million (ppm).
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 2006).
Indigenous species (Criterion 7)	a species that originates and occurs naturally in a particular country (Ramsar Convention 2006).
Introduced (non-native) species	a species that does not originate or occur naturally in a particular country (Ramsar Convention 2006).
Limits of Acceptable Change (LOAC)	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 Contracting Parties 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. http://www.ramsar.org/about/about_glossary.htm
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.
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).
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 2002a, Resolution VIII.6). Note that the collection of time-series information that is not hypothesis-driven from wetland assessment should be termed *surveillance* rather than monitoring.
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).

Propagules	any vegetative portions of a plant, such as a bud or other offshoot, that aids in dispersal of the species and from which a new individual may develop (Phillips & Muller 2006).
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". http://www.ramsar.org/about/about_glossary.htm
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. http://www.ramsar.org/about/about_glossary.htm
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. http://www.ramsar.org/index_very_key_docs.htm
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. http://www.ramsar.org/about/about_glossary.htm Also known as the "Ramsar Information Sheet".
Ramsar List	the List of Wetlands of International Importance. http://www.ramsar.org/about/about_glossary.htm
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. http://www.ramsar.org/about/about_glossary.htm
Ramsar Sites Database	repository of ecological, biological, socio-economic, and political data and maps with boundaries on all Ramsar sites, maintained by Wetlands International in Wageningen, the Netherlands, under contract to the Convention. http://www.ramsar.org/about/about_glossary.htm
Restore	move 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/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.
Values of wetlands	the perceived benefits to society, either direct or indirect, that result from wetland functions. These values include human welfare, environmental quality, and wildlife support (Ramsar Convention 1996, Resolution VI.1). This term was replaced by "Ecosystem Services/Benefits" (Ramsar Convention 2006).
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).
Wetland Assessment	the identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities (Finlayson *et al*. 2001, Ramsar Convention 2002a).
Wetland Types (Criterion 1)	as defined by the Ramsar Convention's wetland classification system. http://www.ramsar.org/ris/key_ris.htm#type
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.
Zooplankton	Tiny, often microscopic invertebrates that float (or weakly swim) throughout estuaries, the ocean and other waterbodies.

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APPENDICES

Appendix A Maps of the Vasse-Wonnerup Wetlands Ramsar Site and Surrounding Area

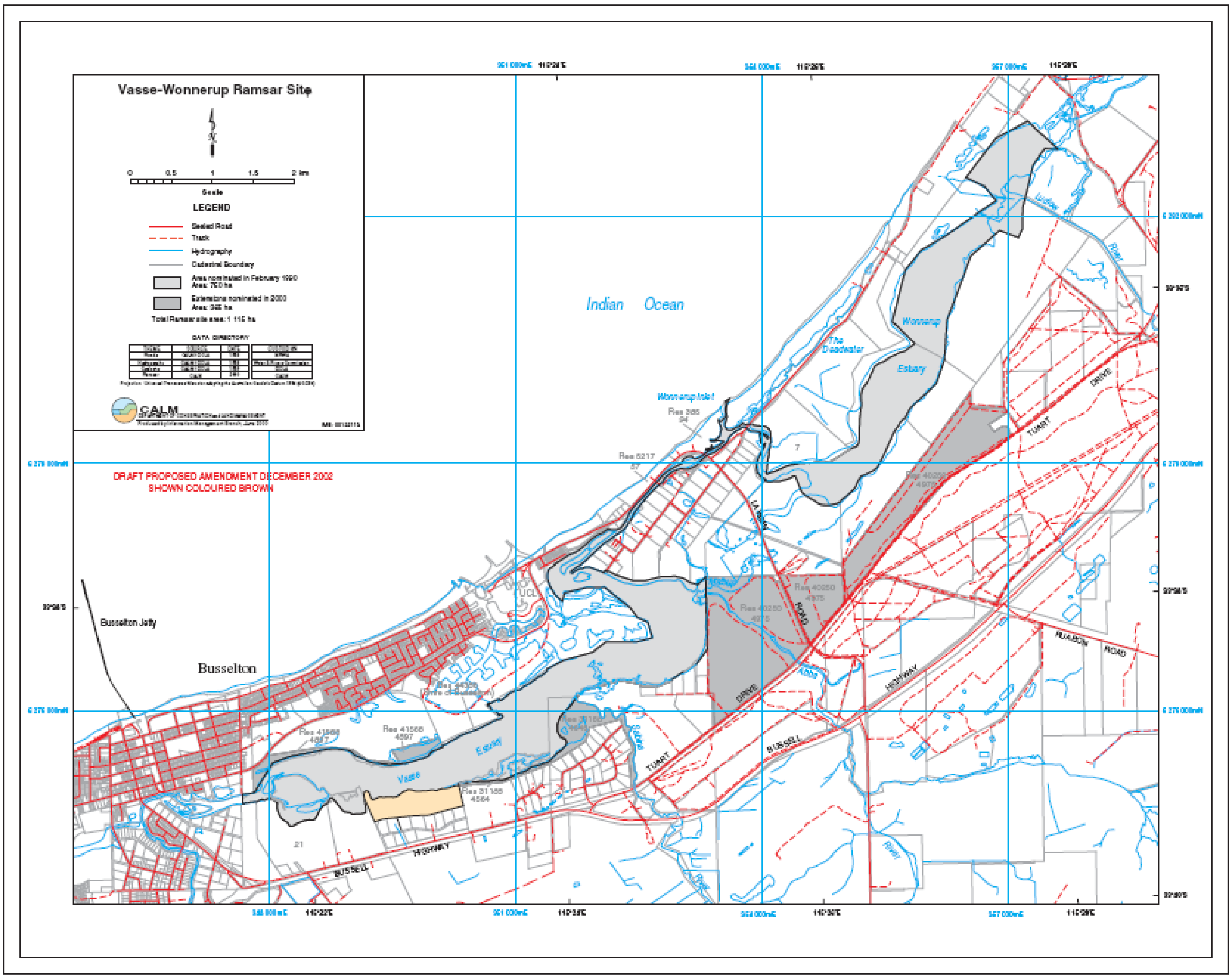

Fig. A1. Vasse-Wonnerup Ramsar Site.

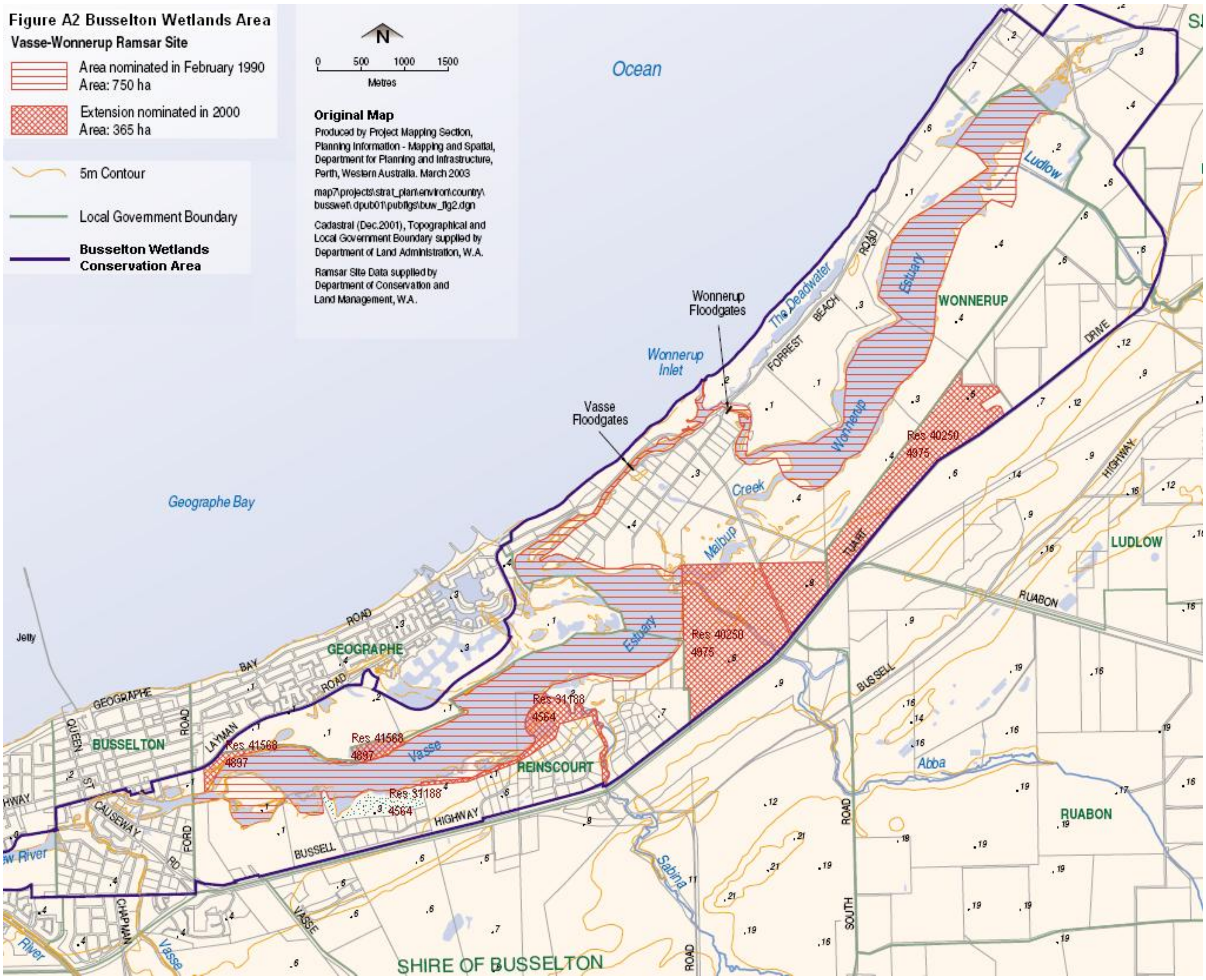

Fig. A2. Busselton Wetlands Conservation area.

Fig. A3. Ortho-rectified aerial image of Site.

Fig. A4. 1:100 Year Flood level.

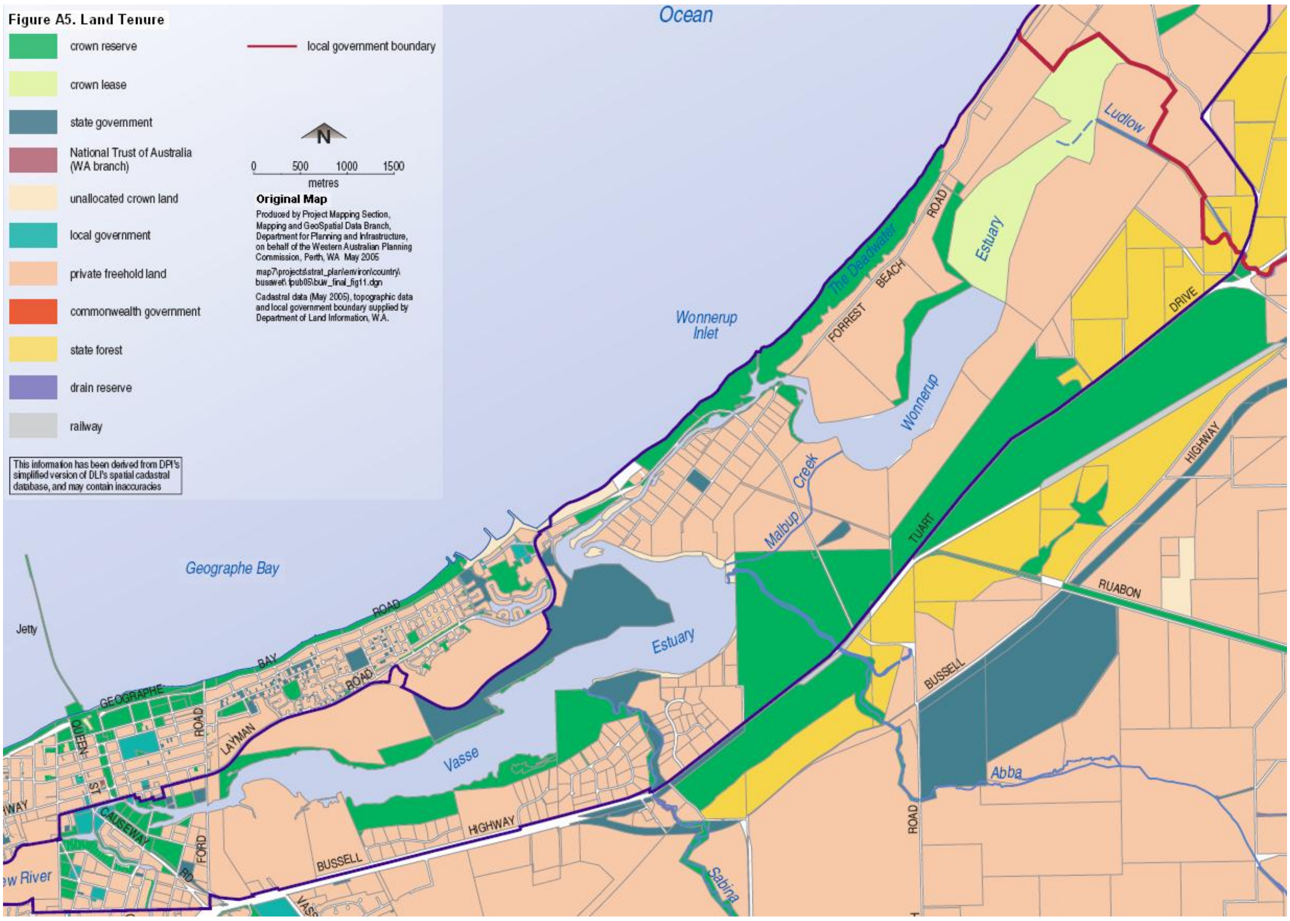

Fig. A5. Land tenure.

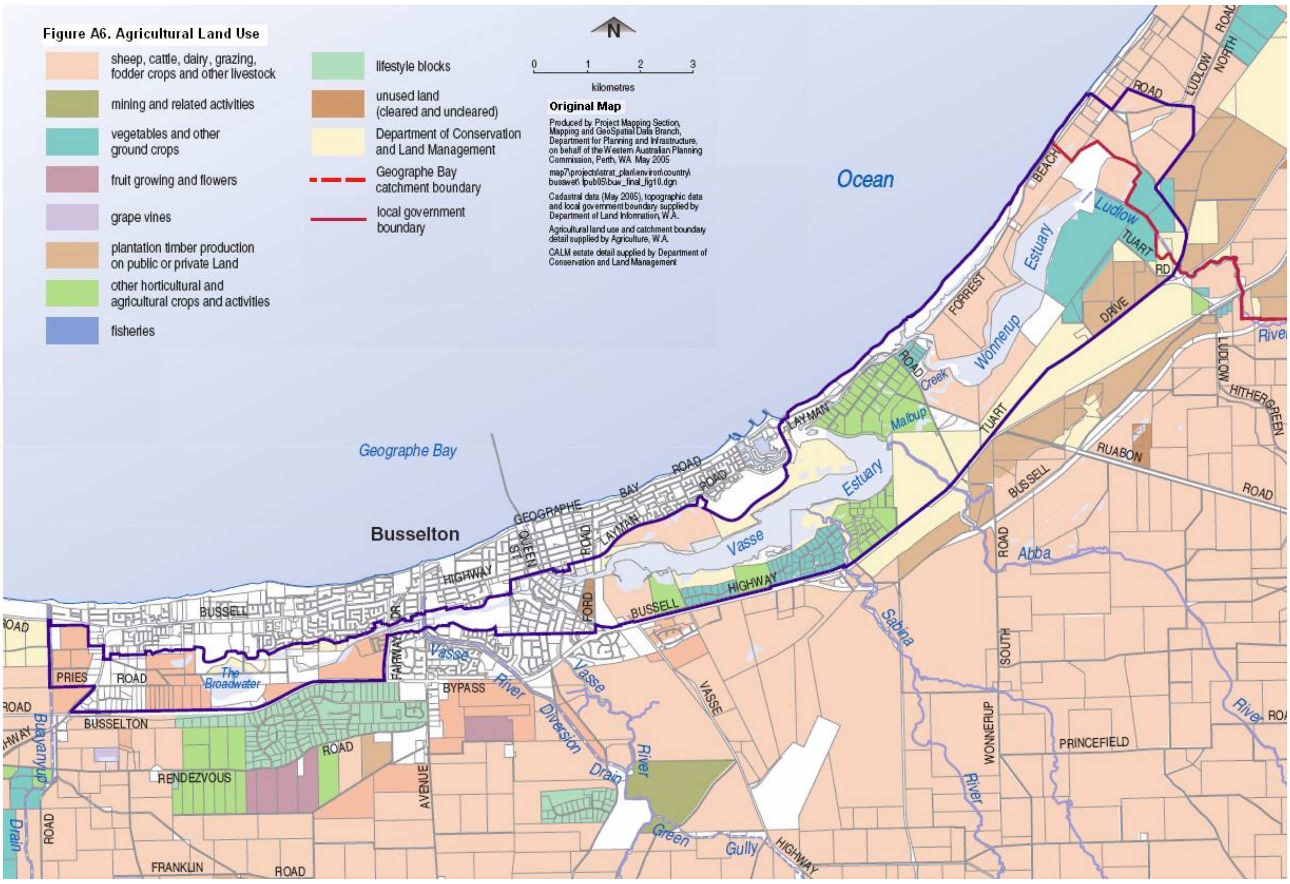

Fig. A6. Agricultural land use.

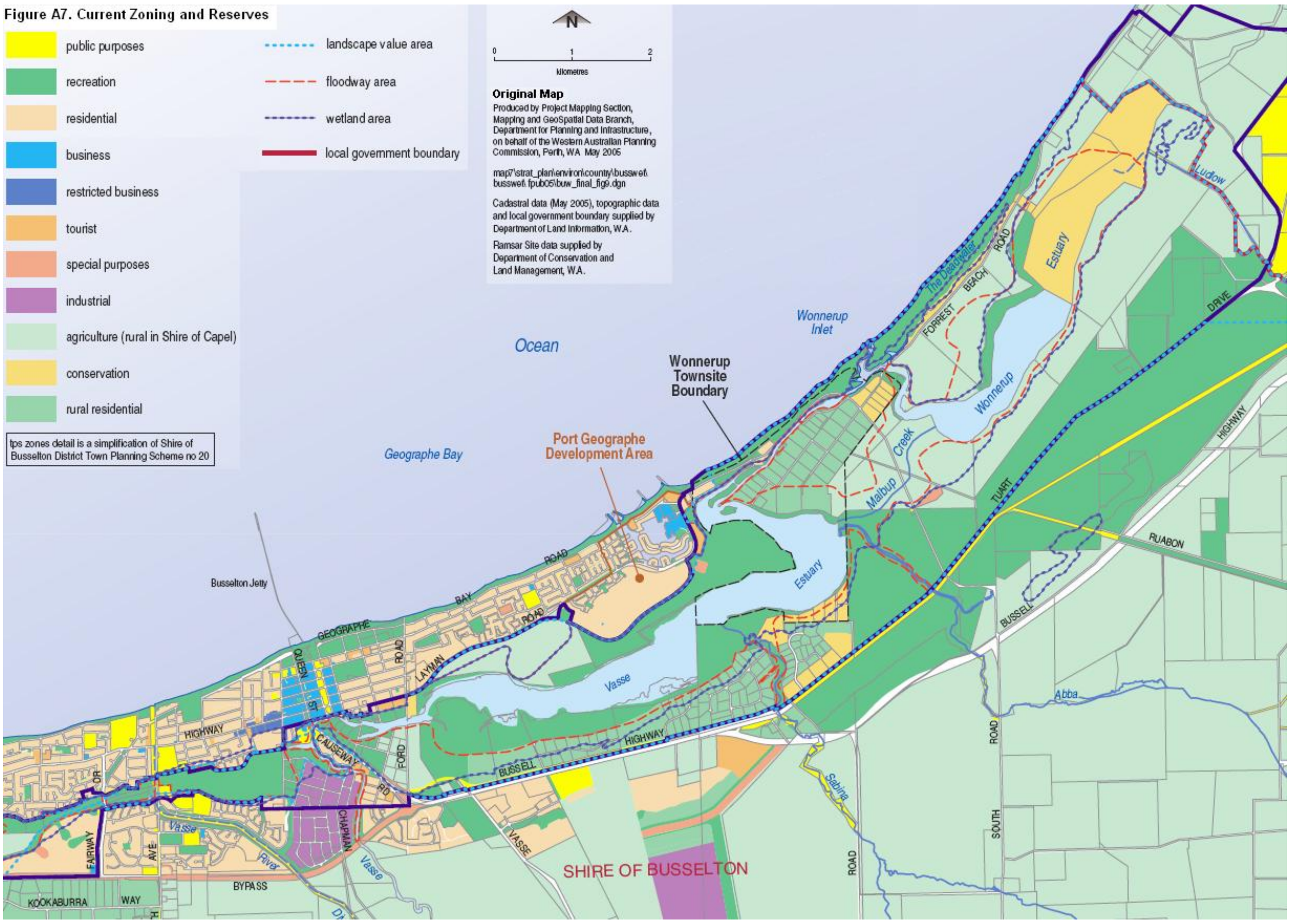

Fig. A7. Current zoning and reserves.

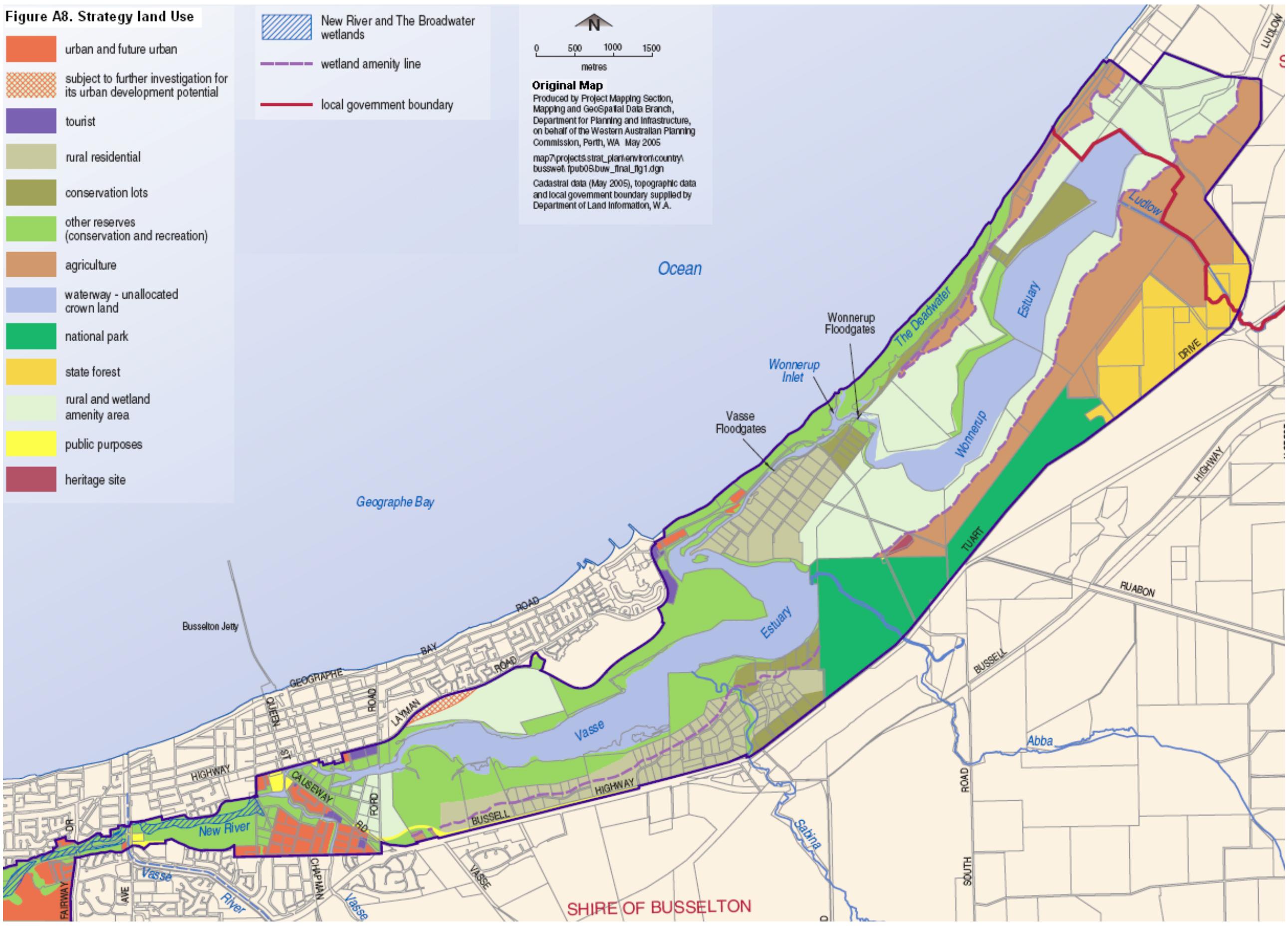

Fig. A8. "Strategy" Land Use.

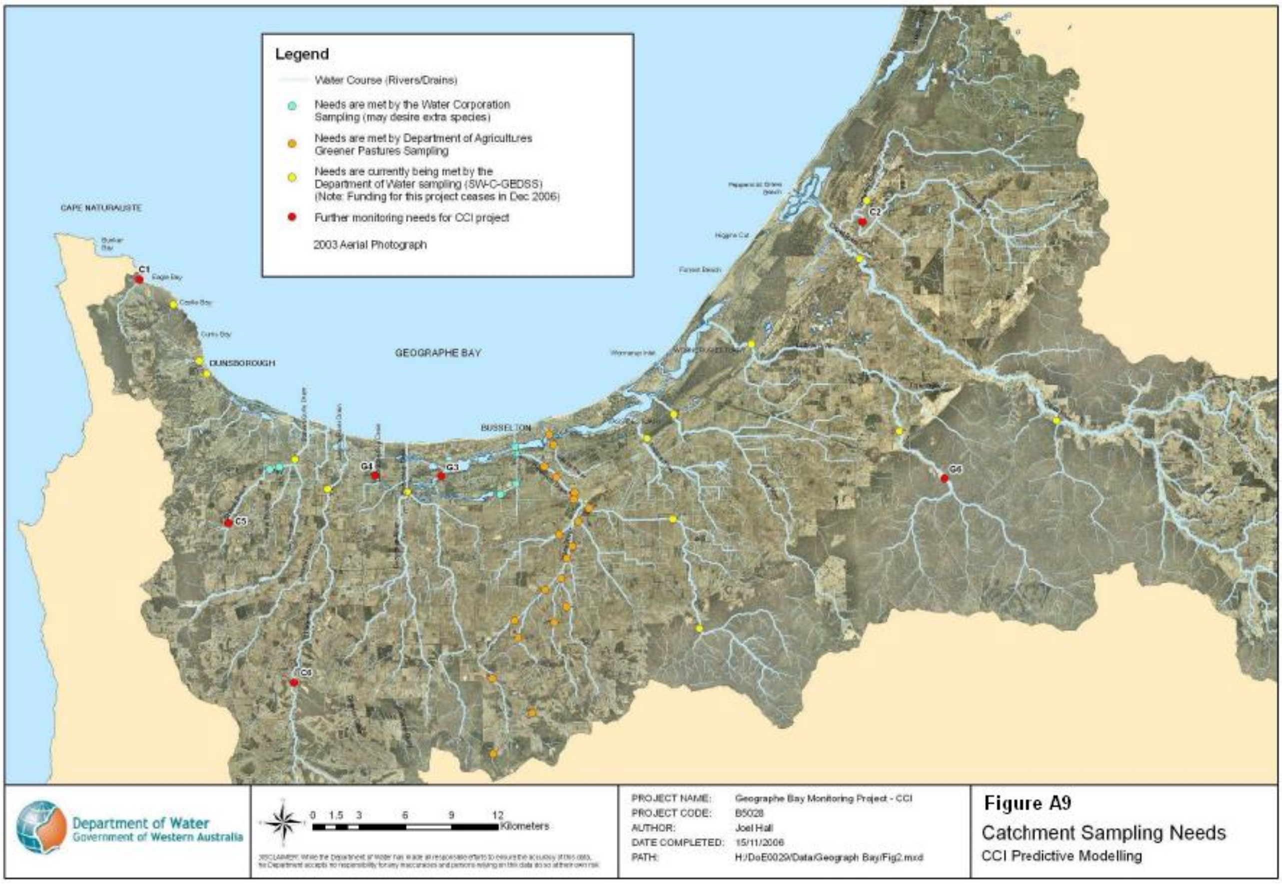

Fig. A9. CCI predictive modelling river sites.

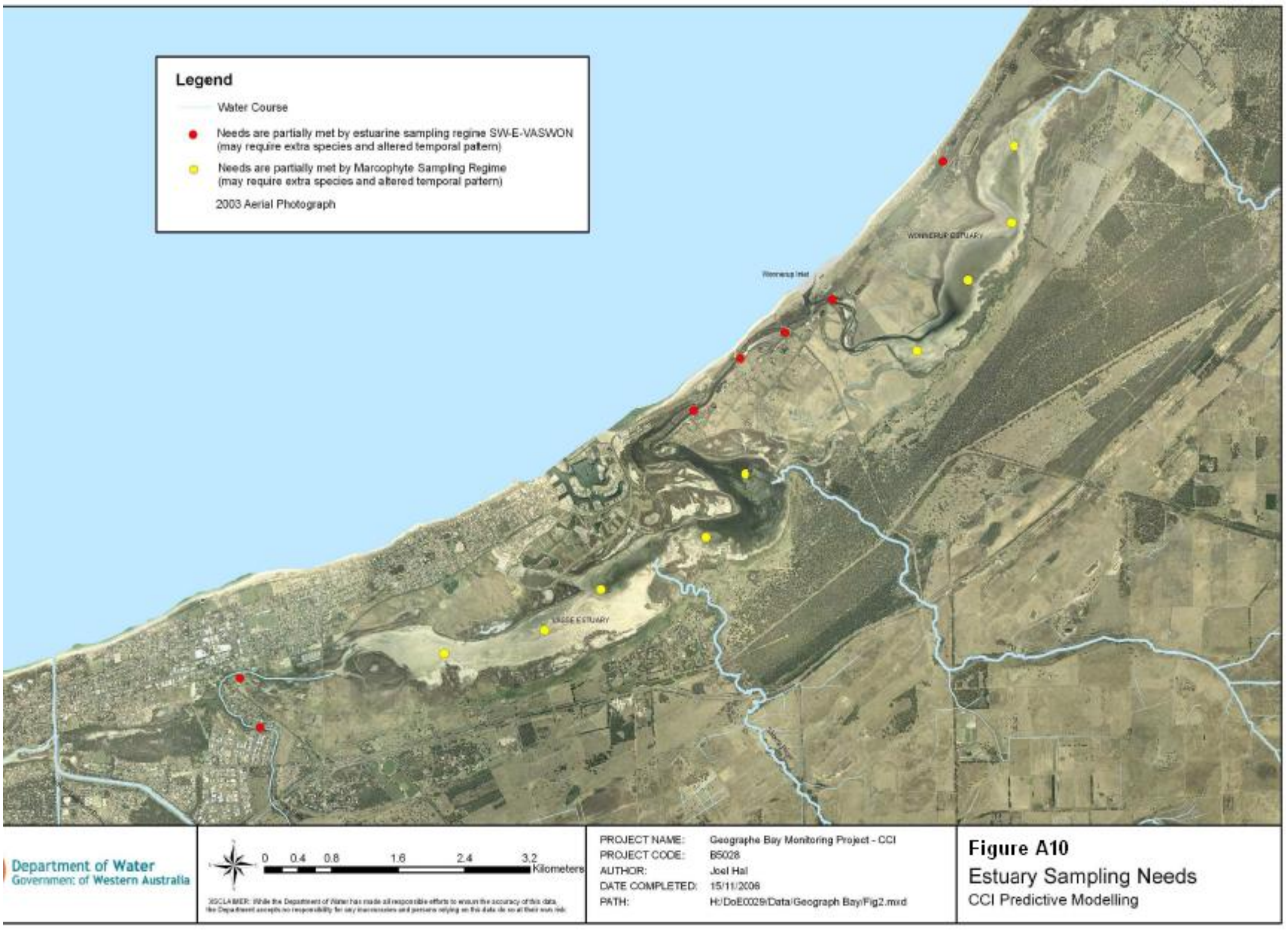

Fig. A10. CCI predictive modelling estuary sites.

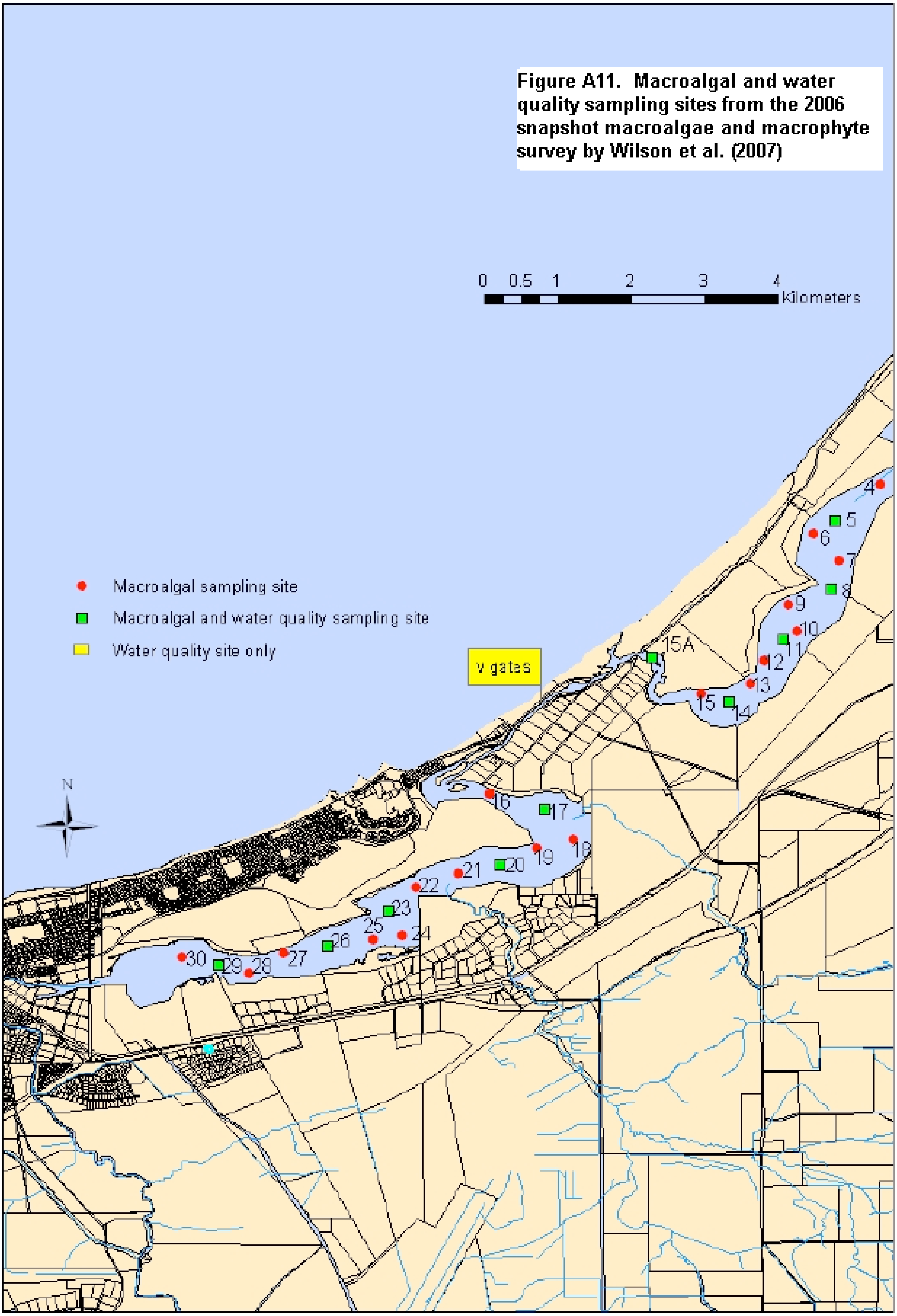

Fig. A11. Murdoch Uni macrophyte sampling sites.

Appendix B Proposed 2007 Update of Information Sheet on Ramsar Wetlands (RIS)

FOR OFFICE USE ONLY.

DD	MM	YY

Designation date

Site Reference Number

1. Name and address of the compiler of this form:
Western Australian Department of Conservation and Land Management (DCLM; now Dept. of Environment and Conservation, DEC) in 1990. Updated by Roger Jaensch, Wetlands International – Oceania, on behalf of DCLM, in 1998, and by DCLM staff in 2000 and 2003. Updated by Wetland Research & Management (environmental consultants) on behalf of DEC in August 2007.

2. Date this sheet was completed/updated:
Updated by Wetland Research & Management (environmental consultants) on behalf of DEC; August 2007.
All inquiries should be directed to Jim Lane, DEC, 14 Queen Street, Busselton WA 6280, Australia, (Tel: +61-8-9752-5556; Fax: +61-8-9752-1432; email: jim.lane@dec.wa.gov.au).

3. Country:
Australia

4. Name of the Ramsar site:
Vasse-Wonnerup System, Western Australia

5. Designation of new Ramsar site or update of existing site:

This RIS is for (tick one box only)**:**
a) Designation of a new Ramsar site ☐; or
b) Updated information on an existing Ramsar site ☑

6. For RIS updates only, changes to the site since its designation or earlier update:

a) Site boundary and area

The Ramsar site boundary and site area are unchanged: ☑

or
If the site boundary has changed:
i) the boundary has been delineated more accurately ☐; or
ii) the boundary has been extended ☐; or
iii) the boundary has been restricted** ☐

and/or

If the site area has changed:
i) the area has been measured more accurately ☐; or
ii) the area has been extended ☐; or
iii) the area has been reduced** ☐

** **Important note**: If the boundary and/or area of the designated site is being restricted/reduced, the Contracting Party should have followed the procedures established by the Conference of the Parties in the Annex to COP9 Resolution IX.6 and provided a report in line with paragraph 28 of that Annex, prior to the submission of an updated RIS.

b) Describe briefly any major changes to the ecological character of the Ramsar site, including in the application of the Criteria, since the previous RIS for the site:

Following a review of waterbird data by Lane *et al.* (2007), two waterbird species have been added as qualifying against Criterion 6, bringing the total to four (refer item 14).

7. Map of site:
Refer to Annex III of the *Explanatory Note and Guidelines*, for detailed guidance on provision of suitable maps, including digital maps.

a) A map of the site, with clearly delineated boundaries, is included as:

i**) a hard copy** (required for inclusion of site in the Ramsar List): ☑;

ii**) an electronic format** (e.g. a JPEG or ArcView image) ☑;

iii) **a GIS file providing geo-referenced site boundary vectors and attribute tables** ❑.

b) Describe briefly the type of boundary delineation applied:
e.g. the boundary is the same as an existing protected area (nature reserve, national park, etc.), or follows a catchment boundary, or follows a geopolitical boundary such as a local government jurisdiction, follows physical boundaries such as roads, follows the shoreline of a waterbody, etc.

Refer item 9.

8. Geographical coordinates (latitude/longitude, in degrees and minutes):
Latitude: 33° 35' S to 33° 39' S
Longitude: 115° 22' E to 115° 28' E

9. General location:
Include in which part of the country and which large administrative region(s) the site lies and the location of the nearest large town.

Vasse-Wonnerup System is in the Shire of Busselton (local authority) in the State of Western Australia (population ca. 1.95 million in 2003). It is immediately east of the town of Busselton (Shire population ca. 29,000 in 2006). The Ramsar Site as originally nominated in 1990 consisted of non-freehold wetland (including the Vasse Estuary portion of Reserve 31188) within the boundaries of the Vasse and Wonnerup estuaries and Wonnerup Inlet, and an adjoining area of non-freehold wetland (formerly part of Wonnerup Estuary) between Wonnerup Estuary and Forrest Beach Road. The Vasse, Sabina, Abba and Ludlow Rivers and The Deadwater were not included in the Site. Dryland parts of Sabina Nature Reserve (Reserve 31188) and dryland parts of Unallocated Crown Lands that extended into the estuaries were also not included. In November 2000, the Site was extended to include:

- the remainder of Reserve 31188, which includes a part of the Sabina River;
- those parts of Tuart Forest National Park (Reserve 40250) that are between the Vasse – Wonnerup System Ramsar Site as originally nominated and Tuart Drive. This extension includes a length of the Abba River, however road reserves are not included;
- Nature Reserve 41568, which includes a substantial part of the northern shore of Vasse Estuary.

10. Elevation: (in metres: average and/or maximum & minimum)
Approximately 0 - 6 m (Australian Height Datum)

11. Area: (in hectares)
1115 ha

12. General overview of the site:
Provide a short paragraph giving a summary description of the principal ecological characteristics and importance of the wetland.

An extensive, shallow, nutrient-enriched, wetland system with widely varying salinities. Water levels in its two principal components, the Vasse and Wonnerup lagoons (former estuaries), are managed through the use of weirs (flood gates) with the aim of minimising flooding of adjoining lands and largely excluding seawater. The Site supports tens of thousands of resident and migrant waterbirds of a wide variety of species and the largest regular breeding colony of Black Swan (*Cygnus atratus*) in south-western Australia. The Site's close proximity to residential, farming and tourism areas presents a range of management issues and opportunities.

13. Ramsar Criteria:
Tick the box under each Criterion applied to the designation of the Ramsar site. See Annex II of the *Explanatory Notes and Guidelines* for the Criteria and guidelines for their application (adopted by Resolution VII.11). All Criteria which apply should be ticked.

1 •	2 •	3 •	4 •	5 •	6 •	7	8 •	9
❑	❑	❑	❑	☑	☑	❑	❑	❑

14. Justification for the application of each Criterion listed in 13 above:
Provide justification for each Criterion in turn, clearly identifying to which Criterion the justification applies (see Annex II for guidance on acceptable forms of justification).

Criterion 5 - It regularly supports 20,000 or more waterbirds. Waterbird data indicate that the Site continues to support peak numbers of 25,000 - 35,000 waterbirds in most years (Lane *et al.* 2007). More than 34,500 waterbirds have been counted in a single month (Dec. 1998) at Vasse-Wonnerup System.

Criterion 6 - It regularly supports 1% of the individuals in a population of one species or subspecies of waterbird. At least 1% of the South East Asia-Australasia population of Black-winged Stilt *Himantopus himantopus*, at least 1% of the Australian population of Red-necked Avocet *Recurvirostra novaehollandiae*, and at least 1% of the south-west Australian regional population of Australian Shelduck *Tadorna tadornoides* and Australasian Shoveler *Anas rhynchotis* use the Site in most years (Lane *et al.* 2007).

15. Biogeography
Name the relevant biogeographic region that includes the Ramsar site, and identify the biogeographic regionalisation system that has been applied.

a) biogeographic region:
Swan Coastal Plain

b) biogeographic regionalisation scheme (include reference citation):
Cummings B. and Hardy A. (2000). Revision of the Interim Biogeographic Regionalisation for Australia (IBRA) and Development of Version 5.1 – Summary Report. Unpublished report to Environment Australia, Department of Environment and Heritage, Canberra. (Available online at: http://www.ea.gov.au/parks/nrs/ibra/version5-1/summary-report/index.html).

16. Physical features of the site:
Describe, as appropriate, the geology, geomorphology; origins - natural or artificial; hydrology; soil type; water quality; water depth, water permanence; fluctuations in water level; tidal variations; downstream area; general climate, etc.

The Wonnerup and Vasse Estuaries are no longer true estuaries because inflow of seawater is largely prevented by floodgates installed on their outlet channels. The Estuaries now act as compensating basins for water discharging from the Ludlow, Sabina, Abba and Vasse Rivers. When the water level in the Estuaries rises above sea level, hydrostatic pressure opens the floodgates and allows water to flow out to Wonnerup Inlet and the sea. When the level drops the gates close, thereby preventing ingress of seawater. The Vasse-Wonnerup System is shallow; almost all the wetland area has a maximum water depth of less than 1 metre and large areas dry out in late summer. Water in the Vasse-Wonnerup System is fresh in winter and becomes saline in summer due to leakage past the floodgates and, since 1988, some seawater being allowed to enter (principally the Vasse Estuary). Groundwater flow might also contribute. Salinity in the Estuaries is generally less than 5 parts per thousand from June to August (due to river inflow), increasing during spring to reach about 15 parts per thousand by December/January, and seawater (35 parts per thousand) by February. In March/April the water in the estuaries can become hypersaline (sometimes exceeding 40 parts per thousand) due to evaporation (Sinclair Knight Merz 2003). The Vasse-Wonnerup System experiences periods of extremely poor water quality, particularly during summer and autumn, when large phytoplankton blooms (sometimes of toxic cyanophyta) necessitate the erection of public health warning signs (McAlpine *et al.* 1989, Sinclair Knight Merz 2003). The nutrient enriched conditions in the system fuel a cycle of phytoplankton blooms followed by bloom collapses which deplete dissolved oxygen during the decomposition process, often to critical levels for the aquatic biota. Periods of oxygen depletion exacerbate the water quality problems by increasing the release of further nutrients from the sediment (particularly phosphorous), contributing to further phytoplankton blooms. As the predominant phytoplankton in the system is often nitrogen fixing cyanobacteria, phosphorous is usually the limiting nutrient for phytoplankton growth. A coordinated approach is being undertaken to address the water quality problems in the system (see item 27).

The Vasse-Wonnerup System consists of broad expanses of open water (except when dry) with fringing samphire and rushes. In some areas *Melaleuca* woodlands occur behind the samphire and eucalypt woodlands are found on higher ground. However all the area has been severely disturbed at various times in the past and much of it is currently cleared for agriculture.

17. Physical features of the catchment area:
Describe the surface area, general geology and geomorphologic features, general soil types, and climate (including climate type).

The site is situated in the Perth Basin, on a narrow, flat plain of marine and alluvial sediments, and is separated from the ocean by a narrow system of low dunes. The urban area of Busselton, including a large canal estate residential subdivision, surrounds much of the Vasse Estuary, particularly on the northern side, while some land to the southern side of the Site retains remnant Tuart *Eucalyptus gomphocephalus* Forest vegetation. The remaining areas are mostly freehold agricultural land used primarily for cattle grazing.

18. Hydrological values:
Describe the functions and values of the wetland in groundwater recharge, flood control, sediment trapping, shoreline stabilization, etc.

The Vasse and Wonnerup Estuaries have an important role (artificial) in flood mitigation - protection of agricultural land and built assets.

19. Wetland Types

a) presence:
Circle or underline the applicable codes for the wetland types of the Ramsar "Classification System for Wetland Type" present in the Ramsar site. Descriptions of each wetland type code are provided in Annex I of the *Explanatory Notes & Guidelines*.

Marine/coastal: A • B • C • D • E • F • G • H • I • <u>J</u> • K • Zk(a)

Inland: L • M • <u>N</u> • O • P • Q • R • Sp • <u>Ss</u> • Tp Ts • U • Va • Vt • W • <u>Xf</u> • Xp • Y • Zg • Zk(b)

Human-made: 1 • 2 • 3 • 4 • 5 • 6 • 7 • 8 • 9 • Zk(c)

b) dominance:
List the wetland types identified in a) above in order of their dominance (by area) in the Ramsar site, starting with the wetland type with the largest area.

J, Ss, N, Xf

20. General ecological features:
Provide further description, as appropriate, of the main habitats, vegetation types, plant and animal communities present in the Ramsar site, and the ecosystem services of the site and the benefits derived from them.

Remnant natural vegetation of the system is fairly uniform in arrangement (Tingay and Tingay 1980). The samphire belt is dominated by *Sarcocornia blackiana* and *Halosarcia pergranulata*. The rush and sedge zone is dominated by *Juncus kraussii* but *Lepidosperma* cf. *leptostachyum* and *Carex divisa* are also common. The tree zone behind the rushes comprises *Melaleuca rhaphiophylla*, *M. hamulosa* and *M. cuticularis* in either single-species or mixed stands. *Gahnia trifida* and *Juncus pallidus* occur in the understorey. *Melaleuca* woodlands often give way to open woodlands of *Eucalyptus rudis*. The vegetation of Tuart Forest National Park is dominated by open-forest of mature Tuart *Eucalyptus gomphocephala*. Tall shrubs and small trees of Western Australian peppermint *Agonis flexuosa* occur as understorey in the forest. There are also some very small areas (< 1ha) of seasonal freshwater *Melaleuca* swamp. *Eucalyptus rudis* trees and some sedges occur along the Sabina and Abba Rivers. The Tuart Forest National Park and Nature Reserves that were added to the Site in 2001 have contributed substantially to the conservation values of the Site by providing protected buffer zones for the Site's wetlands and some seasonal feeding habitat for waterbirds. Tree hollows in these areas provide important breeding sites for Australian Wood

Duck *Chenonetta jubata*, Australian Shelduck *Tadorna tadornoides* and possibly other duck species. Adult ducks have been observed moving their young from the forest to the wetlands.

The Vasse-Wonnerup system provides an important coastal habitat for waterbirds: 34 536 were counted there in December 1998 (Lane *et al.* 2007). The wetlands supported 16 773 ducks, 3 013 swans and 10 968 waders in 1998-99. The minimum number of transequatorial migratory waders that made use of the Vasse-Wonnerup during 1998-99 was 3 448. More than 80 species of waterbird have been recorded in the system (exceeded in Western Australia only at the Swan Canning and Peel Harvey Estuaries), including five darters and cormorants, 13 herons and allies, 11 ducks and allies, seven rails, 30 shorebirds and seven gulls and terns. The following species are particularly abundant:

Grey Teal *A. gracilis* 14 000 Jan 1989
Australian Shelduck *Tadorna tadornoides* 6 108 Nov 1989
Black-winged Stilt *Himantopus himantopus* 5 000 Jan 1986
Pacific Black Duck *Anas superciliosa* 4264
Red-necked Avocet *Recurvirostra novaehollandiae* 4 000 Jan 1986
Black Swan *Cygnus atratus* 3 460 Nov 1976
Sharp-tailed Sandpiper *Calidris acuminata* 2 300 Jan 1986
Curlew Sandpiper *C. ferruginea* 1 200 Jan 1986
Wood Sandpiper *Tringa glareola* 61 Jan 1986
Long-toed Stint *C. subminuta* 44 Jan 1986

Other species occurring in significant numbers include:

Australian Pelican *Pelecanus conspicillatus* 750 Feb 1986
Australasian Grebe *Tachybaptus novaehollandiae* 350 Feb 1986
Great Egret *Casmerodius alba* 237 Feb 1985
Yellow-billed Spoonbill *Platalea flavipes* 140
Eurasian Coot *Fulica atra* 4 000 Jan 1986
White-faced Heron *Egretta novaehollandiae* 250
Australasian Shoveler *Anas rhynchotis* 500
Whiskered Tern *Chlidonias hybrida* 180
White-winged Tern *C. leucoptera* 70

Twenty-one waterbird species are known to breed at the site, including the largest regular breeding colony of Black Swans in south-western Australia (see item 22). Waterbird count data are from Royal Australasian Ornithologists Union (now Birds Australia) and Western Australian Department of Conservation and Land Management (now Dept. Environment and Conservation) ground and aerial surveys 1981-91, Tingay *et al.* (1977), Jaensch (1986), Jaensch *et al.* (1988), Lane (1990, 1997a, 1997b, 2002), R. Jaensch, unpublished data (1989), Halse *et al.* (1990), Lane *et al.* (2007).

21. Noteworthy flora:
Provide additional information on particular species and why they are noteworthy (expanding as necessary on information provided in 14, Justification for the application of the Criteria) indicating, e.g., which species/communities are unique, rare, endangered or biogeographically important, etc. *Do not include here taxonomic lists of species present – these may be supplied as supplementary information to the RIS.*

There are no nationally rare, threatened or endemic wetland plants known at the Site. Problematic exotic plants including Bulrush *Typha orientalis* and Arum Lily *Zantedeschia aethiopica* are established in and around the Sabina and Abba Rivers.

22. Noteworthy fauna:

Provide additional information on particular species and why they are noteworthy (expanding as necessary on information provided in 14. Justification for the application of the Criteria) indicating, e.g., which species/communities are unique, rare, endangered or biogeographically important, etc., including count data. *Do not include here taxonomic lists of species present – these may be supplied as supplementary information to the RIS.*

The Site supports the largest regular breeding colony of Black Swan *Cygnus atratus* in south-western Australia. More than 150 pairs of swans nest in most years and breeding is often successful. The system frequently supports >1% of the relevant Ramsar populations of Black-winged Stilts *Himantopus himantopus*, Red-necked Avocets *Recurvirostra novaehollandiae*, Australian Shelduck *Tadorna tadornoides* and Australasian Shoveler *Anas rhynchotis*. Another five shorebirds have been recorded in numbers greater than 1% of the SE Asia-Australasia Flyway population in some years: Wood Sandpiper *Tringa glareola*, Sharp-tailed Sandpiper *Calidris acuminata*, Long-toed Stint *C. subminuta*, Curlew Sandpiper *C. ferruginea* and Greenshank *Tringa nebularia* (see item 20). The Site's migratory shorebirds are listed under the Japan - Australia Migratory Bird Agreement (JAMBA) and the China – Australia Migratory Bird Agreement (CAMBA) and are specially protected by the Australian Government Environment Protection and Biodiversity Conservation Act (1999).

The Australasian Bittern *Botaurus poiciloptilus* and the Painted Snipe *Rostratula benghalensis* have been recorded on occasion at the Site. As at 2007, both these species are listed as "Vulnerable" under the State Wildlife Conservation Act 1950 and the painted snipe as "Vulnerable" under the Australian Government EPBC Act 1999.

The native Water Rat *Hydromys chrysogaster* has been recorded at the Site, in several locations.

23. Social and cultural values:

a) Describe if the site has any general social and/or cultural values e.g., fisheries production, forestry, religious importance, archaeological sites, social relations with the wetland, etc. Distinguish between historical/archaeological/religious significance and current socio-economic values:

The major social value is that parts of the wetland are used for summer grazing by cattle; this is considered compatible with maintaining the ecological character of the wetland. The Ludlow Tuart Forest is of historical interest because it was among the first areas to be gazetted as State Forest in Western Australia, and was the site of the first formal training school for forest managers in the State. Several historic buildings are situated beside the wetland, notably Wonnerup House (National Trust). Timber floodgates were installed on the outlet channels of the Vasse and Wonnerup Estuaries in 1908 and were replaced in 1928. They were again replaced in 2004 with concrete structures. The heritage value of the 1928 structures is recognised, and their construction was documented and photographed prior to their demolition, and parts were saved for inclusion in a proposed interpretive centre (Sinclair Knight Merz 2003).

The Sabina and Abba Rivers are listed as important mythological Aboriginal heritage sites associated with the Waugal and specially protected by the Western Australian Aboriginal Heritage Act (1972).

Part of the Site (and the adjoining Tuart National Park) is listed on the Register of the National Estate, on the basis of its significant conservation and heritage value. This listing covers the Wonnerup Estuary and the north-eastern half of the Vasse Estuary, including farmland between the wetlands and the Tuart National Park. As such, all development proposals must be referred to the Heritage Commission under the Australian Heritage Council Act 2003.

b) Is the site considered of international importance for holding, in addition to relevant ecological values, examples of significant cultural values, whether material or non-material, linked to its origin, conservation and/or ecological functioning?

If Yes, tick the box ❑ and describe this importance under one or more of the following categories:

i) sites which provide a model of wetland wise use, demonstrating the application of traditional knowledge and methods of management and use that maintain the ecological character of the wetland:

ii) sites which have exceptional cultural traditions or records of former civilizations that have influenced the ecological character of the wetland:

iii) sites where the ecological character of the wetland depends on the interaction with local communities or indigenous peoples:

iv) sites where relevant non-material values such as sacred sites are present and their existence is strongly linked with the maintenance of the ecological character of the wetland:

24. Land tenure/ownership:

a) within the Ramsar site:

The Site as originally nominated included (but was not limited to) the Vasse Estuary wetland portion of Sabina Nature Reserve (Res 31188); an area of Crown leasehold land at the north-eastern end of the Site, and wetland portions of some Unallocated Crown Lands. Areas of freehold land that extended into the estuaries were not included. Land added to the Site in 2001 comprised Nature Reserve (the remainder of Sabina Nature Reserve; and all of Reserve 41568) and National Park (part of Tuart Forest National Park: Reserve 40252). The Nature Reserves and National Park are vested in the Conservation Commission of Western Australia (appointed by the State Government). The purpose of Reserves 31188 and 41568 is "Conservation of Flora and Fauna" and the purpose of Reserve 40250 is "National Park".

b) in the surrounding area:

Surrounding areas include freehold (privately owned) land, Unallocated Crown Land and Crown Reserves for purposes other than conservation.

25. Current land (including water) use:

a) within the Ramsar site:

The principal land use at the Site is nature conservation and education (see item 28). The Site also plays a vital role in flood protection for the town of Busselton.

b) in the surroundings/catchment:

A major residential canal estate is being developed on the northern side of Vasse Estuary and there are residential subdivisions on the southern side. The remainder of the Vasse Estuary and most of the Wonnerup Estuary is surrounded by farmland used principally for cattle grazing and potato cropping (Wonnerup Estuary). There is little recreational use of the wetlands.

26. Factors (past, present or potential) adversely affecting the site's ecological character, including changes in land (including water) use and development projects:

a) within the Ramsar site:

Past management of water levels in the system has been largely satisfactory for waterbirds.

Excessive algal blooms in the lower estuary channels have at times resulted in sudden, mass fish deaths, mostly during the summer period. The principal cause of the deaths is thought to be temporary declines in dissolved oxygen concentrations due to night-time respiration of algal blooms (Lane et al. 1997). A coordinated approach is being undertaken to address this problem (see item 25).

The replacement timber floodgates which had been in operation since 1928, were themselves replaced in 2004. The new reinforced concrete floodgates were constructed within about 20 m of previous positions. To ensure that construction did not impact on the Site's ecological character, an environmental management plan was prepared (Sinclair Knight Merz 2003) and implemented.

b) in the surrounding area:

Urban (housing estate) development has continued to expand in the immediate vicinity of the Site and there is continual pressure to allow land developments that may impact on the Site (EPA 1999, 2000).

There is mining of titanium minerals (Ludlow Titanium Minerals Mine) in a section of State Forest adjoining Tuart Forest National Park and approximately 1.8 km east of the northern end of Wonnerup Estuary (Cable Sands Pty. Ltd. 2002; EPA 2003).

27. Conservation measures taken:

a) List national and/or international category and legal status of protected areas, including boundary relationships with the Ramsar site: In particular, if the site is partly or wholly a World Heritage Site and/or a UNESCO Biosphere Reserve, please give the names of the site under these designations.

Part of the wetland is included in Nature Reserve 31188. In addition, since the Site was originally nominated in 1990, one new Nature Reserve (41568) on the edge of Vasse Estuary has been declared and additional reserves are in the process of being gazetted.

Parts of the Site are listed on the Register of the National Estate.

b) If appropriate, list the IUCN (1994) protected areas category/ies which apply to the site (tick the box or boxes as appropriate):

Ia ❑;Ib ❑; II ❑; III ❑; IV ❑; V ❑; VI ❑

c) Does an officially approved management plan exist; and is it being implemented?:

In 1997, community concern about sudden, mass fish deaths, death of fringing vegetation and loss of pasture production on adjoining land led to the formation of the Vasse Estuary Technical Working Group, which has reviewed the history of the management of the estuaries, and made a number of recommendations to reduce mass fish deaths in an environmentally acceptable manner (Lane *et al.* 1997). To reduce the incidence and severity of fish deaths, several measures have been used in the past: artificial openings of the Wonnerup Inlet sand bar each summer, increased harvesting of fish by professional netters, and partial openings of the flood gates to allow fish to escape and to raise the water level of Vasse Estuary. Since 1998, daily visual monitoring of fish behaviour and water quality in the lower reaches of the system has occurred during the spring and summer period to anticipate and prevent mass fish deaths (White 1999, Elscot 2000).

A monitoring program that aims to detect changes in the distribution and health of fringing vegetation of the Vasse Estuary, relative to the water regime and salinity (which is affected by floodgate openings), has been developed and permanent transect areas have been established (Froend 1999, Froend *et al.* 2000). A snap-shot survey of macrophytes within both estuaries has also been undertaken with the assistance of Murdoch University (Wilson *et al.* 2007).

No management plan or interim management guidelines currently exist for Reserves 41568 and 31188. A formal management plan for Tuart Forest National Park (see item 26) is currently being prepared (DEC 2006).

d) Describe any other current management practices:

Land Conservation District Committees and individual landowners are taking action to reduce nutrient discharge from farmland in the catchment. Action Plans have been prepared to guide landowners undertaking revegetation and rehabilitation along the tributary Vasse, Abba, Sabina and Ludlow rivers (GeoCatch 2000, 2002). Guidelines for the management of farmland adjacent to the wetlands have also been developed (Agriculture WA 2002). The Geographe Catchment Council (GeoCatch), The Department of Water (formerly the Water and Rivers Commission) and the Shire of Busselton are working cooperatively, with community support, to implement the Lower Vasse River Cleanup Program. The program, which aims to improve the ecological health of the Lower Vasse River (which is located immediately upstream of the Site), involves a number of key components including: rehabilitation and revegetation to restore river ecology; dredging to remove nutrient rich sediment; use of a modified clay product to reduce phosphorous availability in the system thereby limiting algal blooms; and the implementation of best management practices for stormwater. The program will assist to improve water quality within the Site.

The DoW is in the process of developing a detailed hydraulic model for the Vasse-Geographe catchment under funding from the Coastal Catchments Initiative (Hall et al. 2006, DoW 2006). This hydraulic model is the first phase in developing a predictive model for water quality for the Vasse-Geographe catchment. It is expected the program will also assist to improve water quality within the Site.

Control of foxes *Vulpes vulpes* is undertaken regularly by monthly baiting in Tuart Forest National Park reduce fox predation on ducks that nest in the Tuart forest and walk their young to the wetlands. A program has been established to control the spread of Arum Lily *Zantedeschia aethiopica*.

28. Conservation measures proposed but not yet implemented:
e.g. management plan in preparation; official proposal as a legally protected area, etc.

A conservation strategy has been prepared for the Busselton wetlands, which includes the Site (Western Australian Planning Commission 2005). There are plans to reserve further areas adjacent to the Site. A management plan for Tuart Forest National Park is being prepared as a condition of approval of the Ludlow Titanium Minerals Mine (DEC 2006).

DairyCatch (i.e. Western Dairy, GeoCatch and the Western Australian Department of Agriculture and Food) provided funding support for dairy farmers to develop and implement best practice effluent plans in 2006. Effluent plans will assist landholders to significantly reduce the quantity of nutrients and bacteria that drain from their property into local waterways and receiving water bodies. Four 'Monitor Farms' have been developed to measure costs and benefits of best practice.

29. Current scientific research and facilities:
e.g., details of current research projects, including biodiversity monitoring; existence of a field research station, etc.

The Western Australian Department of Environment and Conservation (formerly Department of Conservation & Land Management) is monitoring waterbirds, water levels and fish behaviour in the estuaries. The Department of Water is monitoring water quality. There are no research facilities. See also item 26.

30. Current communications, education and public awareness (CEPA) activities related to or benefiting the site:
e.g. visitors' centre, observation hides and nature trails, information booklets, facilities for school visits, etc.

A bird hide at Malbup Creek has been upgraded and a self-guided walk-trail commencing from Layman Picnic Area runs parallel to Malbup Creek and partially along the lower reaches of the Abba River within the Tuart Forest National Park. Interpretive signage located at the Layman Picnic area provides information on the extent and importance of the wetlands while interpretive signs describe the ecology of the rare Western Ringtail Possum *Pseudocheirus occidentalis*, which is present at the site. Pamphlets describing the birdlife of the estuaries have been prepared (Lane 1997a,b).

A school-based education program, led by the Western Australian Department of Environment and Conservation (DEC; formerly Department of Conservation & Land Management), exploring - among other things - the forest/wetland interface, has been in place since 1994. In the past, DEC has also conducted waterbird identification and "Frog Watch" activities at the Site.

31. Current recreation and tourism:
State if the wetland is used for recreation/tourism; indicate type(s) and their frequency/intensity.

The Site is used for low-impact, nature-based recreation activities, predominantly bird watching. Wonnerup Inlet is a popular recreational fishing location. See also item 30.

32. Jurisdiction:
Include territorial, e.g. state/region, and functional/sectoral, e.g. Dept of Agriculture/Dept. of Environment, etc.

<u>Territorial:</u> The State Government of Western Australia.
<u>Functional:</u> The Conservation Commission of Western Australia (vesting of reserves) and the Western Australian Department of Environment and Conservation (formerly Department of Conservation & Land Management) (management of reserves and Unallocated Crown land).

33. Management authority:
Provide the name and address of the local office(s) of the agency(ies) or organisation(s) directly responsible for managing the wetland. Wherever possible provide also the title and/or name of the person or persons in this office with responsibility for the wetland.

The Blackwood District (based in Busselton) of the Central Forest Region, Western Australian Department of Environment and Conservation (formerly Department of Conservation & Land Management).

34. Bibliographical references:
Scientific/technical references only. If biogeographic regionalisation scheme applied (see 15 above), list full reference citation for the scheme.

Cable Sands (2002) Ludlow Titanium Minerals Mine: Environmental Review and Management Program. Cable Sands Pty Ltd (WA), Bunbury.

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Lane JAK (1997b) Where to Watch waterbirds on the Vasse-Wonnerup wetlands (pamphlet). Department of Conservation and Land Management, Western Australia. Pp. 1-4.

Lane JAK, Clarke AG, Pearson GB (2007) Waterbirds of the Vasse-Wonnerup Wetlands in 1998-2000 and Some Comparisons with Earlier Data. Unpublished report by the WA Department of Environment and Conservation.

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Appendix C Resource Management Information

Specific and general resource information helpful to wetland and wetland catchment management

Resource Management Information	Holding Authority
State Wetlands Database [www.naturebase.net/projects/wetlands_database.html]	Department of Environment & Conservation (WA)
Monitoring the Ecological Character of Australia's Wetlands of International Importance (Ramsar) 1997	
Waterbird monitoring data for the south-west and the Vasse-Wonnerup wetlands 1981-1992	
Waterbirds on the Floodplains of the Vasse and Wonnerup Estuaries 1998	
Wetland Vegetation Monitoring and Mapping of the Vasse-Wonnerup Estuary 1980 and 2000	
Management of the Vasse Wonnerup System in relation to Sudden Mass Fish Deaths 1997	
Monitoring Fish Behaviour in the Lower Vasse-Wonnerup Wetland System 1999 and 2000	
Macroalgae and macrophytes of the Vasse-Wonnerup Lagoons 2006	
The Wise Use of Wetlands – Managing Wildlife Habitat 1991	
Framework for Mapping, Classification and Evaluation of Wetlands in Western Australia 2007	
Management Plan for the Geographe bay/Leeuwin-Naturaliste/Hardy Inlet Marine Park (release date 2007)	
Wetlands Management & Restoration Manual (release date 2007)	
Issue Paper: Tuart Forest National Park Management Plan 2006 [www.naturebase.net/pdf/national_parks/management/]	
Water Quality Monitoring Data for the Vasse-Geographe Catchment	Department of Water (WA)
Geographe Bay Catchment Nutrient Trends and Status 2006	
Hydrological data for the Vasse-Geographe catchment	
State Salinity Strategy 2000 [www.naturebase.net/content/view/450/951/]	
State Water Quality Management Strategy 2000 [http://portal.environment.wa.gov.au/]	
Storm Water Management Manual [http://portal.water.wa.gov.au/portal/page/portal/WaterManagement]	
Statewide River Water Quality Assessment 2004 [http://apostle.environment.wa.gov.au/idelve/srwqa/index.jsp]	
Busselton Wetlands Conservation Strategy 2005 [www.wapc.wa.gov.au/Publications/712.aspx]	WA Planning Commission
Liveable Neighbourhoods 2004 [www.planning.wa.gov.au/Publications/]	
Acid Sulphate Soils http://www.wapc.wa.gov.au/Publications/213.aspx	
Wetlands Buffer Guidelines: overseeing implementation of guidelines for the determination of wetland buffers [www.planning.wa.gov.au/Publications/]	
Busselton Urban Growth Strategy 1999	Shire of Busselton
Biodiversity Incentive Strategy for Private Land in the Busselton Shire	
Shire of Busselton District Town Planning Scheme No. 20 1999	
Floodplain Development and Management Policy 1994	
Vasse Estuary Structure Plan 1998	
Rural Strategy 1992	
Busselton Regional Flood Study 1987	Water Corporation (WA)
Geographe Catchment Management Strategy [www.geocatch.asn.au/pages/framesnatres.html]	GeoCatch
Geographe Catchment Weed Plan [www.geocatch.asn.au/pages/framesnatres.html]	
Action Plans for the Vasse, Ludlow, Sabina and Abba Rivers [www.geocatch.asn.au/pages/framesnatres.html]	
Lower Vasse River Clean-up Program [http://www.geocatch.asn.au/pages/framesnatres.html]	
Macroalgae and macrophytes of the Vasse-Wonnerup Lagoons	
Fish Fauna of the Vasse River [wwwscieng.murdoch.edu.au/centres/fish/curres/Freshwater.html]	
Code of practice for Timber Plantations in Western Australia	Forest Products Commission (WA)
Guidelines for Management of Farmlands Adjacent to the Busselton Wetlands 2002 [www.agric.wa.gov.au/]	Department of Agriculture & Food (WA)
Declared plant and weed pests protection program weed lists [www.agric.wa.gov.au/]	
Dairy Effluent Management Guidelines [www.agric.wa.gov.au/]	
Ask First - A Guide to Respecting Indigenous Heritage Places and Values 2002 [www.ahc.gov.au/publications/indigenousheritage/index.html]	Australian Heritage Council

Resource Management Information	Holding Authority
Guide to Wetland Management in the Perth and Near Perth Swan Coastal Plain Area 1993	Environmental Protection Authority (WA)
Environmental Condition of the Vasse-Wonnerup System and Discussion of Management Options 1989	
Environmental Water Requirements to Maintain Wetlands of National and International Importance 2001	Department of Environment & Water Resources (Australian Government)
National Indicators for Wetland Ecosystem Extent Distribution and Condition 2006 [www.nrm.gov.au/monitoring/indicators/index.html]	
Australian Wetlands Database [www.environment.gov.au/water/wetlands/database/index.html]	
National Plan for Shorebird Conservation in Australia 1993 [www.environment.gov.au/biodiversity/migratory/waterbirds/pubs/natplanshore.pdf]	
Wildlife Conservation Plan for Migratory Shorebirds 2006 [www.environment.gov.au/biodiversity/ migratory/waterbirds/shorebird-plan/index.html]	
Shorebird Conservation Toolkit [www.shorebirds.org.au/]	Birds Australia
OzEstuaries database [www.ozcoasts.org.au/]	Geoscience Australia, NLWRA, Coastal CRC
National Water Quality Guidelines [www.environment.gov.au/water/quality/nwqms/volume1.html]	ANZECC / ARMCANZ
Floodplain Management in Australia: Best Practice, Principals and Guidelines 2000	CSIRO
Climate data	Bureau of Meteorology
National Indicators for Wetland Ecosystem Extent, Distribution and Condition (release date 2007)	QLD Dept. Natural Resources & Water
Ramsar Handbooks for the Wise use of Wetlands 2006 [www.ramsar.org/lib/lib_handbooks_e.htm]: - Integrating wetland conservation and wise use into river basin management; - Guidelines for the allocation and management of water for maintaining the ecological functions of wetlands; - Wetland issues in Integrated Coastal Zone Management; - Integrated Framework for wetland inventory, assessment and monitoring; - Strategic Framework and guidelines for the future development of the List of Wetlands of International Importance; - Assessing change in ecological character	Ramsar

<u>Acronyms</u>

ANZECC/ARMCANZ: Australian and New Zealand Environment & Conservation Council and the Agriculture & Resource Management Council of Australia & New Zealand.
Coastal CRC: The Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (national co-operative).
CSIRO: Commonwealth Scientific & Industrial Organisation.
NLWRA: National Land and Water Resources Audit, National Heritage Trust (Australian Government).
Ramsar: Ramsar Convention Secretariat, Switzerland.

Appendix D Macroinvertebrates of the Vasse-Wonnerup Catchment.

Table D1. Macroinvertebrates in the mid-upper reaches of the Ludlow River (reproduced from WRM 2006).

Abundances are $\log_{10}$ scale classes: 1 = 1 individual, 2 = 1- 10, 3 = 11 – 100, 4 = 101 - 1000, 5 = >1000.

Cons. Cat. = conservation category where: C = common taxa recorded from other states/territories; I = indeterminate; I* = indeterminate but probably occurs only in SW; S = endemic to SW but commonly occurring; L = endemic to SW but with a restricted distribution; Exot = exotic/introduced; VU = listed as vulnerable due to habitat loss and fragmentation of populations (CALM Priority 4; IUCN Redlist 2004).

†Taxonomy of family and/or genera under review (Brenton Knott, UWA, pers. comm.).

TAXA			Cons Cat	Mid and Upper Ludlow River and Tiger Gully Sites							
				1	2	3	4	5	6	7	8
TURBELLARIA		Turbellaria sp.	**C**	--	--	--	--	--	--	1	--
TEMNOCEPHALA		Temnocephalida sp.	**C**	--	--	--	--	--	1	--	--
NEMATODA		Nematoda spp.	**C**	--	3	--	--	--	--	--	4
ANNELIDA				--	--	--	--	--	--	--	--
OLIGOCHAETA		Oligochaeta spp.	**C**	2	3	2	3	--	2	3	3
HIRUDINEA		Glossophonidae spp.	**C**	--	2	--	--	--	--	3	--
		Hirudinidae sp.	**C**	--	--	1	--	--	--	--	--
MOLLUSCA	**Hyriidae**	*Westralunio carteri*	**L, VU**	--	--	--	--	--	--	--	--
	Ancyclidae	*Ferrissia (pettancylus) petterdi*	**C**	--	--	1	2		3	3	4
	Planorbidae	*Glyptophysa (Glyptophysa)* sp.	**I**	--	3	--	2	2	1	2	1
ARTHROPODA											
ARACHNIDA											
ACARIFORMES											
ACARINA		Unidentified larvae/nymphs	**I**	--	--	1	2	1	--	2	--
ORIBATIDA		Oribatida spp.	**I**	2	--	--	--	--	--	1	--
PROSTIGMATA	**Halacaridae**	Halacaridae sp.	**I**	--	--	--	--	--	1	--	--
	Arrenuridae	*Arrenurus* sp.	**C**	--	--	--	--	--	--	2	--
	Eylaidae	*Eylais* sp.	**I**	--	--	--	--	--	--	2	--
	Hydrachnidae	*Hydrachna* sp. (nymph)	**I**	--	--	--	--	--	--	1	--
	Hygrobatidae	*Procorticacarus* sp.	**C**	--	--	--	--	--	--	2	--
		Australiobates sp.		--	--	--	--	--	--	--	--
	Limnesiidae	*Limnesia longigenitalis*	**C**	--	--	--	--	--	--	2	--
	Pionidae	Pionidae sp. (nymph)	**S**	--	--	--	--	--	--	--	1
	Trombidioidea	Trombidioidea sp.	**I**	--	--	--	--	--	1	--	--
PARASITIFORMES				--	--	--	--	--	--	--	--
MESOSTIGMATA		Mesostigmata spp. (terrestrial?)	**I**	--	--	--	--	--	--	2	--
CRUSTACEA											
DECAPODA	**Parastacidae**	*Cherax plebejus*	**S**	--	--	--	--	2	3	--	--
		Cherax quincecarinatus	**S**	--	--	3	--	--	--	--	2
		Cherax sp.	**S**	2	--	--	--	--	--	2	--
		Palaeomonetes australis†	**C**	--	--	--	--	--	--	--	--
CLADOCERA		Cladocera spp.	**I**	1	3	--	4	--	--	3	3
COPEPODA		Cyclopoida spp.	**I**	4	4	3	4	3	3	5	4
OSTRACODA		Ostracoda spp.	**I**	2	5	2	3	2	2	4	3
AMPHIPODA	**Perthidae**	*Austrochiltonia subtenuis*	**S**	--	--	--	--	--	--	1	--
		Perthia branchialis†	**S**	--	--	--	--	--	--	2	3
		Perthia acutitelson†	**S**	--	--	--	--	--	--	1	--
		Perthia sp.†	**S**	--	--	--	--	--	--	--	--
COLLEMBOLLA		*Entomobryoidea* spp.	**C**	1	--	--	3	--	--	1	--
		Poduroidea spp.	**C**	--	--	--	--	--	--	--	--
INSECTA											
DIPTERA	**Ceratopogonidae**	Ceratopogoniinae sp.	**I**	1	--	--	--	--	--	--	--
		Forcypomiinae sp.	**I**	--	--	--	--	--	--	1	--
	Chironomidae	Chironomidae spp. (pupa)	**I**	--	--	--	2	2	2	3	--
	Chironominae	*Chironomus* aff. *alternans*	**C**	--	3	3	--	2	1	3	3
		Cryptochironomus griseidorsum	**C**	2	--	--	1	2	--	2	--
		Dicrotendipes sp. V47	**S**	--	--	1	--	--	--	--	--

TAXA			Cons Cat	Mid and Upper Ludlow River and Tiger Gully Sites							
				1	2	3	4	5	6	7	8
		Dicrotendipes conjunctus	C	3	--	--	3	--	--	--	--
		Harrisius sp. V27	I*	--	--	--	--	--	--	--	--
		Harrisius sp. V40	I*	--	--	2	--	--	--	--	--
		Parachironomous sp. VSCL35	I	--	--	--	--	--	--	--	--
		Paracladopelma sp. VCD10	I	--	--	1	--	--	2	2	--
		Polypedilum nubifer	C	--	--	--	3	1	1	--	--
		Polypedilum watsoni	C	--	--	--	--	--	--	--	--
		Polypedilum sp. V3	I	--	1	1	--	--	--	2	1
		Riethia sp. V4	I	--	--	--	--	--	--	--	--
		Riethia sp. V5	I	--	--	--	--	--	--	--	--
		Rheotanytarsus sp.	I	--	--	2	2	--	3	3	3
		Rheotanytarsus sp. V18	I	--	--	--	--	--	--	--	--
		Tanytarsus sp. 1	I	2	2	2	1	2	3	3	3
		Tanytarsus sp. 2	I	4	1	--	2	2	3	3	2
		Tanytarsus sp.	I	--	--	--	--	--	--	--	--
	Orthocladiinae	*Botryocladius bibulmun*	S	--	--	--	--	--	--	--	--
		Corynoneura sp.	C	3	1	--	1	--	2	2	--
		Cricotopus albitarsis	C	--	--	--	2	--	--	--	--
		Cricotopus annuliventris	C	3	--	2	3	3	3	3	3
		Limnophyes pullulus	C	2	1	1	--	--	2	--	--
		Thienemanniella sp.	C	3	1	2	3	3	4	3	3
	Tanypodinae	*Paramerina levidensis*	S	2	2	3	--	2	3	3	2
		Procladius paludicola	C	--	--	--	2	1	--	--	--
		Procladius villosimanus	C	--	2	--	--	2	2	--	--
	Culicidae	*Anopheles* sp.	C	2	--	--	1	1	1	2	1
		Culicidae spp.	I	--	--	--	--	--	--	2	--
		Culicidae sp. (pupa)	I	2	1	2	1	2	2	2	--
	Empididae	Empididae spp.	I	--	--	--	--	--	1	2	2
	Muscidae	Muscidae sp. (pupa)	I	1	--	--	--	--	--	--	--
	Psychodidae	Psychodidae sp.	I	--	--	--	--	--	--	1	--
	Simulidae	*Austrosimulium* sp.	C	--	--	2	--	--	--	1	--
		Simulium ornatipes	Exot	3	--	--	4	4	3	3	5
		Simulium ornatipes (pupa)	Exot	--	--	--	3	1	--	--	2
	Tabanidae	Tabanidae sp.	I	--	1	--	--	--	--	--	--
	Tipulidae	Tipulidae spp.	I	2	1	2	--	--	1	2	2
		Athericidae sp.	I	--	--	--	--	--	--	--	--
ODONATA											
ZYGOPTERA		Zygoptera sp. (juvenile)	I	--	--	--	--	--	--	1	--
ANISOPTERA	**Telephlebiidae**	*Austroaeschna anacantha*	S	--	--	--	--	--	--	--	--
	Hemicorduliidae	*Hemicordulia* sp. (immature)	C	--	--	--	--	--	--	--	--
TRICHOPTERA	**Hydrobiosidae**	*Taschorema pallescens*	S	--	--	--	--	--	--	--	--
	Hydropsychidae	*Smicrophylax australis*	S	--	--	--	--	--	--	--	--
	Hydroptilidae	*Acritoptila/Hellyethira* spp.	I*	3	3	--	3	--	3	3	2
		Oxyethira sp.	I*	2	--	--	--	--	--	--	--
		Hydroptilidae spp. (juvenile)	I	3	--	--	--	--	--	--	2
	Leptoceridae	*Oecetis* sp.	I*	--	2	--	2	2	2	2	2
		Notalina spira	C	1	--	--	--	--	--	--	--
		Triplectides australis	C	2	2	--	2	2	2	2	2
		Leptoceridae spp. (juvenile)	I	--	2	--	2	1	--	2	--
EPHEMEROPTERA	**Baetidae**	*Cloeon* sp.	C	--	--	1	--	--	--	--	--
	Caenidae	*Tasmanocoensis tillyardi*	C	--	--	--	--	--	--	--	--
	Leptophlebiidae	?*Neboissophlebia* sp.	I*	--	--	--	--	--	--	--	--
		Leptophlebiidae spp.	I*	--	--	--	--	--	--	--	--
HEMIPTERA	**Corixidae**	*Agraptocorixa parvipunctata*	C	--	--	--	--	--	--	--	2
		Agraptocorixa sp. (female)	C	--	--	--	2	1	--	--	--
		Micronecta robusta	C	1	--	--	--	--	--	1	--

TAXA			Cons Cat	Mid and Upper Ludlow River and Tiger Gully Sites							
				1	2	3	4	5	6	7	8
		Micronecta sp. (juvenile)	C	--	--	--	--	--	--	2	--
		Sigara truncatipala	C	--	1	--	2	--	2	2	1
		Sigara sp. (female)	C	2	2	--	1	--	2	2	--
		Corixidae spp. (juvenile)	C	2	3	--	2	2	2	4	3
	Mesoveliidae	Mesoveliidae sp.	I	--	--	--	--	--	--	1	--
	Notonectidae	*Anisops thienemanni*	C	--	2	--	2	--	--	2	2
		Anisops sp. 1	?C	--	--	--	2	--	--	--	--
		Anisops sp. (females & juveniles)	C	2	2	--	3	2	2	3	3
	Veliidae	*Microvelia* sp.	I	2	--	--	--	--	--	--	--
		Veliidae spp. (juvenile)	I	2	--	--	1	--	--	--	--
COLEOPTERA	**Dytiscidae**	*Allodessus bistrigatus*	C	1	--	--	--	--	--	--	--
		Antiporus femoralis	C	1	--	--	--	--	--	1	1
		Antiporus gilberti	C	--	--	--	1	--	--	--	1
		Antiporus sp. (larva)	I	--	--	--	1	--	--	1	--
		Lancetes lanceolatus	C	--	2	--	--	--	2	--	--
		Limbodessus inornatus	S	3	2	--	1	1	--	2	2
		Limbodessus shuckhardi	C	--	--	--	--	--	--	--	--
		Megaporus howitti	C	--	1	--	1	--	1	1	--
		Megaporus solidus	C	--	--	--	--	--	--	--	--
		Megaporus sp. (larva)	I	--	--	--	--	--	--	1	1
		Necterosoma darwini	S	2	1	--	1	1	2	--	2
		Necterosoma sp. (larva)	I	3	--	2	2	2	2	3	3
		Paroster sp. (female)	I	1	--	--	--	--	--	1	--
		Platynectes aenescens	C	1	--	--	--	--	--	--	--
		Platynectes decempunctalis (var. *polygrammus*)	C	2	1	--	--	1	2	1	--
		Platynectes sp. (larva)	I	3	1	2	3	2	3	2	2
		Rhantus suturalis	C	3	3	2	1	2	3	2	2
		Rhantus sp. (larva)	I	--	2	--	1	--	--	1	2
		Sternopriscus brownii	S	1	1	--	--	--	--	--	--
		Sternopriscus multimaculatus	C	2	--	--	--	--	--	--	--
		Sternopriscus sp. (larva)	I	2	2	--	--	2	--	--	--
		Tribe Bidessini spp. (larva)	I	--	--	--	--	--	--	1	--
	Gyrinidae	*Macrogyrus* sp.	I	--	--	--	--	--	--	--	--
	Hydraenidae	*Octhebius* sp.	I	--	--	--	--	--	--	--	--
	Hydrochidae	*Hydrochus* sp.	I	--	--	--	--	--	--	--	--
	Hydrophilidae	*Enochrus eyrensis*	C	1	--	--	--	--	--	--	--
		Limnoxenus zealandicus	C	2	1	--	1	--	--	--	--
		Limnoxenus sp. (larva)	C	2	1	--	2	2	1	2	2
		Paracymus pygmaeus	C	3	1	--	1	1	--	2	--
		Paracymus ?spenceri	C	2	--	--	--	--	--	--	--
		Tribe Anacaenini sp. (larva)	I	--	--	--	1	--	--	--	--
		Hydrophilidae spp. (larva)	I	2	--	--	--	--	--	--	--
			Number of species	**52**	**41**	**25**	**49**	**35**	**42**	**69**	**42**

Appendix E Abundance and Relative Density of Fishes in the Vasse River and Diversion Drain

Table reproduced from Morgan and Beatty (2004).

Sampling details				Species density per m² (total number in parenthesis)									
Site	**Date**	**Coordinates**	**Area sampled (per m²)**	Western pygmy perch	Nightfish	Western minnow	Mud minnow	Swan River goby	Western hardyhead	Sea mullet	Mosquitofish	Goldfish	**Total**
Below Old Butter Factory slot-boards	9-Dec	S 33.6532 E 115.35	200	0.010 (2)				0.375 (75)	6.900 (1380)		0.050 (10)		7.335 (1467)
Below Old Butter Factory slot-boards	25-Mar	S 33.6532 E115.35	2500	0.003 (8)	0.002 (6)			0.024 (60)			0.200 (10)	0.014 (35)	0.0476 (119)
Above Butter Factory slot-boards	9-Dec	S 33.6528 E 115.3496	300	0.053 (16)				0.183 (55)	1.000 (300)			0.120 (36)	1.357 (407)
Rotary park	9-Dec	S 33.6528 E 115.3478	270					0.111 (30)	1.111 (300)	0.011 (3)	0.222 (60)		1.456 (393)
Shire Offices	9-Dec	S 33.6577 E 115.3482	140	0.064 (9)				0.179 (25)			1.071 (150)	0.036 (5)	1.35 (189)
Strelley St Bridge	23-Mar	S 33.6587 E 115.3507	200	0.015 (3)				0.400 (80)			5.750 (1150)		6.165 (1233)
Below Vasse River Diversion Drain valve	24-Mar	S 33.6868 E 115.3651	54	6.296 (340)	0.019 (1)	0.111 (6)		0.389 (21)			6.685 (361)		13.5 (729)
Above Vasse River Diversion Drain valve	24-Mar	S 33.6867 E 115.364	200			0.165 (33)		0.225 (45)			2.500 (500)		2.89 (578)
Vasse River Diversion Drain	24-Mar	S 33.6861 E 115.3163	420					0.643 (270)			4.762 (2000)	0.036 (15)	5.440 (2285)
Stuart Rd waterpoint	25-Mar	S 33.8399 E 115.3154	40				0.125 (5)						0.125 (5)
Total mean density			**4324 m²**	**0.08743**	**0.002**	**0.009**	**0.001**	**0.153**	**0.458**	**0.0007**	**1.094**	**0.021**	**1.826**
Total number				**78**	**7**	**39**	**5**	**661**	**1980**	**3**	**4731**	**91**	**7895**

Appendix F General Foraging and Breeding Habitats of Waterbirds

Note: information on foraging and breeding habitats has been sourced largely from Phillips and Muller (2006) and Pizzey (2007) with additional information from Lane *et al.* (2007). Data more specific to the Vasse-Wonnerup Site is currently lacking.

*Wetland types within Vasse-Wonerup Ramsar Site (refer Section 2.2):
i = Seasonal / brackish saline lagoons,
ii = Estuarine mud flats,
iii = Freshwater / brackish deltas (mouths of the Ludlow, Abba & Sabina rivers),
iv = Freshwater swamps and channels of tributary streams (lower reaches of the Abba & Sabina rivers).

Common Name	Scientific Name	*Where found at Site				Preferred Foraging Habitat	Preferred Food	Breeding Habitat
		i	ii	iii	iv			
Ducks & allies (Family Anatidae)								
Blue-billed duck	*Oxyura australis*	✓				Somewhat secretive; open water but often also near dense cover of vegetation.	Aquatic invertebrates and plants.	Bulrushes, dense shrubs. Not known to breed at the Vasse-Wonnerup Site.
Musk duck	*Biziura lobata*	✓				Open water, bare margins.	Fish, aquatic invertebrates, aquatic plants.	Tussocks, reed beds.
Black swan	*Cygnus atratus*	✓		✓		Inundated grass and weed beds, *Ruppia* beds, open water and bare margins.	Pasture plants, submerged macrophytes.	Reed beds, floating vegetation in shallow water; samphire heaths at the northern end of the Vasse estuary and north and north-west sections of the Wonnerup estuary provide important annual nesting areas. Swans use samphire to construct large nest mounds.
Australian shelduck	*Tadorna tadornoides*	✓	✓	✓		Open water, bare margins.	Aquatic invertebrates and plants.	Grass and weeds, sometimes in trees or beneath shrubs in saltmarsh. Often far from water.
Australasian wood duck	*Chenonetta jubata*				✓	Timbered water courses.	Aquatic invertebrates and plants.	Tree hollows.
Pacific black duck	*Anas superciliosa*	✓		✓	✓	Areas with plentiful aquatic vegetation or flooded grass and weeds; wet pasture.	Invertebrates and plants.	Stumps, hollow trees or in grass and low vegetation.
Australasian shoveler	*Anas rhynchotis*	✓		✓		Inundated grass, macrophyte beds, open water and bare margins.	Aquatic invertebrates.	Grass and weeds near freshwater wetlands, occasionally tree hollows.
Grey teal	*Anas gracilis*	✓		✓	✓	Cosmopolitan.	Aquatic plants, seeds and invertebrates.	Tree hollows or among grass or reeds near water.
Chestnut teal	*Anas castanea*	✓		✓		Open water, bare margins, mud flats, samphire.	Invertebrates and plants.	Mostly in tree hollows mainly in coastal areas or on islands or shores. Not known to breed at the Vasse-Wonnerup Site.
Pink-eared duck	*Malacorhynchus memranaceus*	✓		✓		Shallow waters and margins of estuary.	Plankton	Stumps and tree hollows. Not known to breed at the Vasse-Wonnerup Site.
Hardhead	*Aythya australis*	✓		✓		Open water, bare margins, emergent vegetation.	Aquatic invertebrates, crustaceans and plants.	Reeds, rushes, shrubs or boles of trees close to water.
Grebes (Family Podicipedidae)								
Hoary-headed grebe	*Poliocephalus poliocephalus*	✓				Open water, bare margins.	Zooplankton, macroinvertebrates	Floating mass of water weeds.

Common Name	Scientific Name	*Where found at Site i	ii	iii	iv	Preferred Foraging Habitat	Preferred Food	Breeding Habitat
Darters (Family Anhingidae								
Darter	*Anhinga melanogaster*	✓		✓	✓	Open water.	Fish, aquatic invertebrates.	Trees or shrubs over water. Not known to breed at the Vasse-Wonnerup Site.
Cormorants (Family Phalacrocoracidae)								
Little pied cormorant	*Phalacrocorax melanoleucos*	✓		✓	✓	Open water.	Fish, aquatic invertebrates.	Shrubland, mainly freshwater wetlands. Not known to breed at the Vasse-Wonnerup Site.
Pied cormorant	*Phalacrocorax varius*	✓		✓		Open water.	Fish.	Coastal rocky or sandy islands, or in estuaries in trees. Not known to breed at the Vasse-Wonnerup Site.
Little black cormorant	*Phalacrocorax sulcirostris*	✓		✓	✓	Open water.	Fish, aquatic invertebrates	Shrubland in freshwater wetlands. Not known to breed at the Vasse-Wonnerup Site.
Great cormorant	*Phalacrocorax carbo*	✓		✓	✓	Open water.	Fish	Shrubland or trees in or near water. Not known to breed at the Vasse-Wonnerup Site.
Pelicans (Family Pelecanidae)								
Australian pelican	*Pelecanus conspicillatus*	✓		✓		Open water - fresh, brackish or marine.	Fish, aquatic invertebrates	Low, secluded sandy islets or shores among scattered vegetation. Not known to breed at the Vasse-Wonnerup Site.
Herons, Egrets, Bitterns (Family Ardeidae)								
White-faced heron	*Egretta novaehollandiae*	✓		✓	✓	Floating vegetation, grass and weeds, bare margins.	Fish, crustaceans, aquatic invertebrates.	Shrubland or trees, not necessarily near water. Not known to breed at the Vasse-Wonnerup Site.
Little egret	*Egretta garzetta*	✓		✓	✓	Shrubland, grass and weeds, bare margins.	Fish, aquatic invertebrates, vertebrates.	Trees near vegetated wetlands; fresh, brackish, marine or saline. Not known to breed at the Vasse-Wonnerup Site.
Eastern reef egret	*Egretta sacra*	✓				Sea coast, rarely encountered in south-west estuaries and considered a vagrant at the Vasse-Wonnerup Site.	Small fish, crustacea, molluscs.	On ground under scrub or rock ledges. Does not breed at the Vasse-Wonnerup Site.
White-necked heron	*Ardea pacifica*	✓		✓	✓	Infrequently occurring in the Vasse-Wonnerup - occasional influx from the north of the State.	Fish, aquatic invertebrates, vertebrates.	Trees, 6-18m over water. Does not breed at the Vasse-Wonnerup Site.
Great egret	*Casmerodius albus*	✓		✓	✓	Rushes, floating vegetation, grass and weeds, bare margins.	Fish, aquatic invertebrates, vertebrates.	Shrubland or flooded trees. Not known to breed at the Vasse-Wonnerup Site, but does breed at the nearby McCarley's and Egret swamps.
Nankeen night heron	*Nycticorax caledonicus*	✓		✓	✓	Shallow margins or estuaries and rivers, mudflats. Roosts by day in low trees/tall shrubs near water	Fish, aquatic invertebrates, vertebrates.	High up in trees, usually over water. Not known to breed at the Vasse-Wonnerup Site.
Australasian bittern	*Botaurus poiciloptilus*	✓		✓	✓	Wetlands and occasionally estuaries; prefers wetlands with tall, dense vegetation and still shallow water. Rare in the Vasse-Wonnerup.	Knowledge gap - likely invertebrates and small vertebrates.	Deep, dense vegetated reaches over shallow water. Does not breed at the Vasse-Wonnerup Site.
Grey heron	*Ardea cinerea*					Vagrant (one-off record in May 2002).	Fish, aquatic invertebrates, vertebrates.	Does not breed at the Vasse-Wonnerup Site.

Common Name	Scientific Name	*Where found at Site i	ii	iii	iv	Preferred Foraging Habitat	Preferred Food	Breeding Habitat
Ibis, Spoonbills (Family Threskiornithidae)								
Glossy ibis	*Plegadis falcinellus*	✓		✓	✓	Shallow water over soft or muddy substrate; either freshwater or sheltered marine. Infrequently occurring in the Vasse-Wonnerup.	Invertebrates.	Among reeds, rushes, shrubs or trees in fresh or brackish wetlands. Not known to breed at the Vasse-Wonnerup Site.
Australian white ibis	*Threskiornis molucca*	✓		✓	✓	Grass and weeds, shallow waters.	Fish, other vertebrates, invertebrates.	Dense trees and shrubs, usually over water (often near water level), or in bulrushes.
Straw-necked ibis	*Threskiornis spinicollis*	✓		✓	✓	Grass and weeds, shallow waters.	Fish, other vertebrates, invertebrates.	Shrubs, reeds; can form large colonies; breeding often triggered by flooding. Not known to breed at the Vasse-Wonnerup Site.
Royal spoonbill	*Platalea regia*	✓		✓	✓	Open, shallow water. Considered a vagrant at the Vasse-Wonnerup Site.	Fish, aquatic invertebrates.	Shrubland over or near water. Does not breed at the Vasse-Wonnerup Site.
Yellow-billed spoonbill	*Platalea flavipes*	✓		✓	✓	Open, shallow water.	Fish, aquatic invertebrates.	Shrubland or trees near freshwater wetlands.
Osprey, Kites, sea Eagles, Harriers (Family Accipitridae)								
Osprey	*Pandion haliaetus*	✓		✓	✓	Open water - marine, estuarine and fresh waters; lagoons, river mouths, saltmarsh. Rests on prominent trees.	Fish, small birds and other vertebrates.	Tall trees (usually in dead crowns), or on islands; builds massive nest of sticks, seaweed, rope etc that may be added to over many seasons.
Whistling kite	*Haliastur sphenurus*	✓	✓	✓	✓	Tidal inlets, mudflats, estuary margins, timbered watercourses.	Small mammals and other vertebrates and carrion.	Tall trees; builds large nest that may be added to over many seasons. Not known to breed at the Vasse-Wonnerup Site.
White-bellied sea eagle	*Haliaeetus leucogaster*	✓		✓	✓	Open water - marine, estuarine and fresh waters; lagoons, river mouths, saltmarsh. Rests on prominent trees.	Knowledge gap - fish and waterbirds believed to make up a large proportion of the diet.	Tall trees (usually in dead crowns) usually over water, or on ground on islands or remote coastal cliffs; builds massive nest of sticks that may be added to over many seasons.
Swamp harrier	*Circus approximans*	✓		✓	✓	Open water - marine, estuarine and fresh waters; lagoons, river mouths, saltmarsh.	Small mammals and other vertebrates and invertebrates.	Builds low nest of grasses, sticks etc on or near ground, in dense grasses, samphire or low vegetation. Not known to breed at the Vasse-Wonnerup Site.
Rails, Crakes, Water-hens, Coots (Family Rallidae)								
Buff-banded rail	*Gallirallus phillipensis*	✓		✓	✓	Wet paddocks, grass and weeds, samphire, estuary margins.	Invertebrates, worms, molluscs.	Shallow cup of grass or leaves in tussock, sedge, samphire or low vegetation.
Australian spotted crake	*Porzana fluminea*	✓		✓	✓	Secretive species; shallow water with floating vegetation, samphire, bulrushes, grass tussocks.	Aquatic invertebrates and plants.	Rushes, water ribbons, tussocks growing in or near water. Not known to breed at the Vasse-Wonnerup Site.
Spotless crake	*Porzana tabuensis*	✓		✓	✓	Mud or shallow water near reed beds, samphire. Secretive species.	Aquatic invertebrates and plants.	On or near ground in rushes or dense shrubland near wetland edges.
Purple swamphen	*Porphyrio porphyrio*	✓		✓	✓	Shrubland, reed beds, floating vegetation, bare margins, open water.	Aquatic plants and pasture plants.	Reed beds.
Dusky moorhen	*Gallinula tenebrosa*	✓		✓	✓	Grass and weeds, bare margins, open water.	Aquatic invertebrates and plants.	Reed beds.
Black-tailed native hen	*Gallinula ventralis*	✓		✓	✓	Infrequently occurs at the Vasse-Wonnerup. Estuary and river margins, paddocks, open woodland.	Invertebrates, molluscs, plants.	On ground among bushes. Not known to breed at the Vasse-Wonnerup Site.

Common Name	Scientific Name	*Where found at Site i	ii	iii	iv	Preferred Foraging Habitat	Preferred Food	Breeding Habitat
Eurasian coot	*Fulica atra*	✓		✓	✓	Open water, shallow margins of estuary and rivers, mudflats, samphire.	Aquatic plants.	Nest of sticks and vegetation on shallow water, stumps, logs, small islets. Not known to breed at the Vasse-Wonnerup Site.
Sandpipers, Knots, Stints & allies (Family Scolopacidae)								
Pin-tailed snipe	*Capella stenura*			✓		Rare vagrant at the Vasse-Wonnerup.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Black-tailed godwit	*Limosa limosa*		✓			Mudflats, tidal margins of estuaries, edges of freshwater wetlands, shallow river margins, saltmarshes.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Bar-tailed godwit	*Limosa lapponica*		✓			Mudflats, tidal margins of estuaries, edges of freshwater wetlands, salt-marshes, flooded pasture, occasionally shallow river margins.	Aquatic invertebrates	Transequatorial migrant. Does not breed at the Site.
Whimbrel	*Numenius phaeopus*		✓			Tidal flats, bare shallow margins, grass and weeds, flooded paddocks. Occasionally roosts in trees.	Aquatic invertebrates	Transequatorial migrant. Does not breed at the Site.
Marsh sandpiper	*Tringa stagnatilis*		✓			Mudflats, tidal margins of estuaries, edges of freshwater wetlands, saltmarshes.	Aquatic invertebrates	Transequatorial migrant. Does not breed at the Site.
Common greenshank	*Tringa nebularia*		✓			Mudflats, tidal margins of estuaries, edges of freshwater wetlands, saltmarshes	Aquatic invertebrates	Transequatorial migrant. Does not breed at the Site.
Wood sandpiper	*Tringa glareola*		✓			Tidal flats, bare shallow estuary margins, sandy beaches, saltmarshes.	Aquatic invertebrates	Transequatorial migrant. Does not breed at the Site.
Terek sandpiper	*Xenus cinereus*		✓			Mudflats, tidal margins of estuaries, edges of freshwater wetlands, saltmarshes.	Aquatic invertebrates	Transequatorial migrant. Does not breed at the Site.
Common sandpiper	*Actitis hypoleucos*		✓			Tidal flats, mud flats, bare shallow estuary margins, sandy beaches, pebbly or muddy edges of streams, grass and weeds.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Grey-tailed tattler	*Heteroscelis brevipes*		✓			Tidal flats, bare shallow margins, sandy beaches.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Great knot	*Calidris tenuirostris*		✓			Tidal mud flats, sandy beaches.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Red knot	*Calidris canutus*		✓			Tidal mud flats, sand flats, sandy beaches, saltmarshes occasionally flooded pasture.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Red-necked stint	*Calidris ruficollis*		✓			Tidal flats, mud flats, bare shallow estuary margins, sandy or pebbly beaches, saltmarsh.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Long-toed stint	*Calidris subminuta*		✓			Tidal flats, mud flats, bare shallow estuary margins, sandy beaches, muddy edges of streams, weed along tidelines.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.

Common Name	Scientific Name	*Where found at Site i	ii	iii	iv	Preferred Foraging Habitat	Preferred Food	Breeding Habitat
Pectoral sandpiper	*Calidris melanotos*		✓			Shallow freshwater (rather than mudflats), often with low grass or weeds, flooded pasture, occasional tidal areas and saltmarsh.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Sharp-tailed sandpiper	*Calidris acuminata*		✓			Mudflats, tidal margins of estuaries, edges of freshwater wetlands, samphire, flooded pasture.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Curlew sandpiper	*Calidris ferruginea*		✓			Mudflats, tidal margins of estuaries, edges of freshwater wetlands, samphire, flooded pasture.	Invertebrates.	Transequatorial migrant. Does not breed at the Site.
Ruff	*Philomachus pugnax*		✓			Shallows and tidal mud flats. Rare vagrant at the Vasse-Wonnerup Site.	Aquatic invertebrates.	Transequatorial migrant. Does not breed at the Site.
Painted Snipe (Family Rostratulidae)								
Painted snipe	*Rostratula benghalensis australis*			✓		Rare vagrant at the Vasse-Wonnerup Site. Shallow, freshwater wetlands with a thick cover of low vegetation.	Aquatic invertebrates and plants.	Does not breed at the Site.
Oystercatches (Family Haematopodidae)								
Pied oystercatcher	*Haematopus longirostris*		✓			Exposed sand, mud or rock.	Knowledge gap - likely invertebrates including molluscs and crustaceans.	Sand, shell-grit or shingle just above high-water mark on beaches or sand bars. Not known to breed at the Vasse-Wonnerup Site.
Stilts, Avocets (Family Recurvirostridae)								
Black-winged stilt	*Himantopus himantopus*		✓			Shallow fresh-saline waters, in both open areas and where there are dense grasses or emergents.	Molluscs, crustaceans, occasionally vegetative matter and seeds.	Islets or hummocks surrounded by water, reed fringes, samphire.
Banded stilt	*Cladorhynchus leucocephalus*	✓	✓			Shallow fresh-saline waters, sandflats, samphire.	Aquatic invertebrates and plants.	In colonies (some huge) on low islands in large inland salt lakes. Does not breed at the Site.
Red-necked avocet	*Recurvirostra novaehollandiae*		✓			Soft shallow muds of seasonal fresh to hyper-saline wetlands.	Molluscs, crustaceans, occasionally vegetative matter and seeds, occasionally small fish.	Bare ground or low vegetation. Not known to breed at the Vasse-Wonnerup Site.
Plovers, Dottrels (Family Charadriidae)								
Pacific golden plover	*Pluvialis fulva*		✓			Mudflats, estuary margins, beaches.	Invertebrates, plants, seeds.	Transequatorial migrant. Does not breed at the Site.
Grey plover	*Pluvialis squatarola*		✓			Mudflats, samphire, estuary margins.	Invertebrates, including molluscs and crustaceans.	Transequatorial migrant. Does not breed at the Site.
Red-capped plover	*Charadrius ruficapillus*		✓			Sand and mudflats along edges of estuaries, lagoons.	Invertebrates.	Open areas or in low vegetation near wetland margins, or exposed sandy beaches.
Greater sand plover	*Charadrius leschenaultii*		✓			Undisturbed wide sandy beaches, sandspits, samphire, mudflats.	Invertebrates, including molluscs and crustaceans.	Transequatorial migrant. Does not breed at the Site.
Black-fronted dotterel	*Elseyornis melanops*		✓			Shallow waters at margin of estuaries, mudflats, occasionally samphire.	Invertebrate, plants, seeds.	Sandy ground - either bare or among leaf litter - often far from water. Not known to breed at the Vasse-Wonnerup Site.
Red-kneed dotterel	*Erythrogonys cinctus*		✓			Shallow waters at margin of estuaries, mudflats.	Invertebrates.	Twigs in a depression on damp ground often under shrubs or between pebbles. Not known to breed at the Vasse-Wonnerup Site.

Common Name	Scientific Name	*Where found at Site i	ii	iii	iv	Preferred Foraging Habitat	Preferred Food	Breeding Habitat
Banded lapwing	*Vanellus tricolor*	✓				Mudflats, open grassland.	Invertebrates, plants, seeds.	Sandy ground - either bare or among leaf litter or low grasses - often far from water. Not known to breed at the Vasse-Wonnerup Site.
Gulls, terns (Family Laridae)								
Silver gull	*Larus novaehollandiae*	✓	✓	✓	✓	Cosmopolitan.	Omnivorous, scavenger.	Prefers off-shore islands but will breed in many habitats. Not known to breed at the Vasse-Wonnerup Site.
Caspian tern	*Hydropogne tschegrava*	✓		✓		Open, but sheltered marine and estuarine waters.	Fish, crustaceans.	On ground on islands, sandy cays and banks. Not known to breed at the Vasse-Wonnerup Site.
Crested tern	*Sterna bergii*	✓		✓		Open marine and estuarine waters.	Fish.	On ground on islands, sandy cays and banks. Not known to breed at the Vasse-Wonnerup Site.
Fairy tern	*Sterna nereis*	✓		✓		Sheltered coasts and estuaries, fresh or saline near-coastal wetlands.	Small fish.	Above high water on sheltered beaches, spits, sandbars; often in estuaries. Not known to breed at the Vasse-Wonnerup Site.
Gull-billed tern	*Sterna nilotica*	✓		✓		Sheltered coasts and estuaries, fresh or saline near-coastal wetlands, grassland. Rare vagrant at the Vasse-Wonnerup Site.	Fish, crustaceans, invertebrates, small vertebrates.	On ground on islands, sandy cays and banks. Does not breed at the Site.
Whiskered tern	*Chldonias hybridus*	✓		✓		Emergent and submerged vegetation in coastal wetlands and estuaries.	Fish, crustaceans, invertebrates, small vertebrates.	Often nests in temporary flooded inland wetland flats, claypans among inundated vegetation. Not known to breed at the Vasse-Wonnerup Site.
White-winged black tern	*Chlidonias leucopterus*	✓		✓		Sheltered coasts and estuaries, fresh or saline near-coastal wetlands, grassland.	Fish, insects, occasionally fogs.	Transequatorial migrant. Does not breed at the Site.
Honeyeaters, Australian Chats (family Meliphagidae)								
White-fronted chat	*Ephthianura albifrons*	✓				Damp ground with low vegetation, samphire, estuary margins.	Invertebrates.	Low down in tussocks, samphire or in low shrub.
Swallows, Martins (Family Hirundinidae)								
Welcome swallow	*Hirundo neoxena*	✓	✓	✓		Estuary and river margins.	Invertebrates.	Tree hollows, buildings. Not known to breed within the Site.
Tree martin	*Hirundo nigricans*	✓	✓	✓		Estuary and river margins, open woodland.	Invertebrates.	Tree hollows, buildings. Not known to breed within the Site.
Old World warblers (Family Sylviidae)								
Clamorous reed-warbler	*Acrocephalus stentoreus*	✓				Reed beds, bulrushes.	Invertebrates.	Reeds and rushes. Not known to breed within the Site.
Little grassbird	*Megalurus gramineus*	✓				Reed beds, bulrushes, samphire heathlands.	Invertebrates	Reeds, rushes and low dense shrubland.

Appendix G Community Consultation Questionnaire

QUESTIONNAIRE

YOUR NAME (optional)**:**

1. YOUR INTEREST OR CONNECTION WITH THE WETLANDS?:
e.g. local resident, landowner, fisherman, member of local or indigenous community group, scientific study

2. WHICH PARTS OF THE WETLAND DO YOU VISIT AND WHAT DO YOU DO THERE?:
e.g. farming, fishing, bird-watching, general recreation, scientific study

3. WHAT DO YOU VALUE ABOUT THE WETLANDS?:
e.g. provides summer grazing; provides water for irrigation; birdlife; heritage and cultural significance; peaceful and quiet location; adjoining tuart forest; views

4. WHAT CHANGES HAVE YOU NOTICED IN THE HEALTH OF THE WETLANDS, SURROUNDING LANDS OR WONNERUP INLET?:
e.g. algal blooms; water depth and clarity; salt water flooding; river flows; changes in native plants (saltmarsh, paperbarks, seagrass etc) and animals (fish stocks, turtles, crayfish, birds, mussels etc).

5. WHAT ISSUES OR PROBLEMS WOULD YOU LIKE ADDRESSED AND HOW BEST COULD THIS BE ACHIEVED?:
e.g. environmental protection; loss of amenity; residential / industrial development; tourism; loss of agricultural lands

6. OTHER:

7. WOULD YOU BE WILLING TO PARTICIPATE IN A GROUP MEETING OR WORKSHOP?:

Appendix H *Curriculum Vitae* of the Authors

Ms Susan Creagh

Susan has extensive experience in coordinating and undertaking research, monitoring and assessment of aquatic invertebrate and fish populations. In particular, analyses of structure and change in invertebrate populations as indicators of ecosystem 'health', *i.e.* assessment of ecosystem 'patterns'. Since graduating with a BSc (hons) from The University of Western Australia (UWA) in 1983, Susan has worked as a biologist for both academic and government organisations locally and overseas (Caltech, California, USA). For the last 12 years she has worked as a consultant aquatic biologist based at UWA. She has substantial knowledge of aquatic ecosystems with skills in macroinvertebrate taxonomy and the analysis of aquatic fauna biodiversity. Her experience includes the use of stable isotope analyses to elucidate ecosystem processes to aid in determining ecosystem 'health'. She has a sound knowledge of threatening processes to aquatic ecosystems including alteration to natural hydrology, salinisation and sedimentation and has worked on numerous impact assessment studies for mining companies and State government. She has had considerable involvement in fauna and cross-sectional channel surveys for Ecological Water Requirement assessments of the Augustus River (Collie), Upper Mayfield Drain (Waroona) and Marbling Brook (Avon), using the Flow Events Method (FEM). She has expertise in coordinating and conducting field research in remote areas of the State (Kimberley, Pilbara, Goldfields & Southern districts) and in statistical analysis and interpretation of biological data. Susan has authored over 30 technical reports and ten peer reviewed scientific papers.

Formal Education

1983: Honours in Zoology (Second Class Division A), The University of Western Australia (UWA).
Independent research on biochemical and morphological variation in commercial fishing stocks of Shark Bay snapper, *Chrysophrys unicolor*.

1979-1983: Bachelor of Science, The University of Western Australia; Majors in Zoology and Botany.

Relevant Career History

2004-current: Senior Consultant Biologist, *Wetland Research & Management*, Glen Forest, WA.
Senior Research Officer, Aquatic Research Laboratory, School of Animal Biology, UWA, Crawley, WA.

1998-2004: Senior Environmental Biologist, Streamtec Pty Ltd Ecological Consultants, Nedlands, WA (based at UWA).

1996-1998: Research Associate, Department of Zoology, UWA, Crawley, WA.

1995: Consulting Environmental Biologist, *ecologia* Environmental Consultants, Mt Lawley, WA.

1991-1994: Senior Research Assistant, Kerckhoff Marine Lab, Biology Department, California Institute of Technology, Corona del Mar, California, USA.

1988-1990: Postgraduate Studies, University of New South Wales, School of Biological Sciences, Kensington, NSW.

1986-1987: Research Officer, Water Authority of Western Australia, Leederville, WA.

1984-1985: Research Assistant, Department of Conservation and Environment, Perth, WA.

Dr Andrew W. Storey

Andrew has over twenty years experience in aquatic ecology, having worked in the UK, Papua New Guinea, Indonesia, East Timor and Australia, specialising in the ecology and management of fish, invertebrate and waterbird communities of tropical and temperate freshwater systems. Andrew has first hand knowledge of sampling and preparing protocols for monitoring change in the ecological character of Ramsar-listed wetlands in Australia. In association with Mr Jim Lane (DEC), Dr Storey published general monitoring protocols for Australia's Wetlands of International Importance (Ramsar). Dr Storey was integral to surveys and analyses of existing monitoring data and designing ongoing monitoring programmes for the Ramsar-listed sites of Toolibin Lake, Byenup-Muir and the Lower Ord River/Parry Lagoon area. The baseline monitoring he conducted at the Byenup-Muir wetlands was instrumental in the nomination and acceptance of the wetlands under Ramsar. Dr Storey was also involved in collecting and collating data on waterbird usage for publication in Wetlands of the Swan Coastal Plain during the early 1990s, which included working on Ramsar-listed wetlands. Dr Storey has been involved in setting QA/QC objectives for national monitoring programmes (NRH, LWRRDC) and was project manager on State funded studies to document the ecological, social and cultural values of the Fitzroy and Ord rivers in the Kimberley region. Over the last five years, Andrew has been involved in establishing Environmental Water Requirements (EWRs) for various river systems in the south west of Western Australia, using the Flow Events Method (FEM) He has also coordinated monitoring of the response of groundwater-dependent systems to changing water levels (aquatic fauna of Yanchep & Leeuwin cave systems) as a precursor to developing EWRs. Andrew sits on the Ord River Scientific Panel, which developed an Interim EWR for the Lower Ord River. He has also directed numerous biological surveys and assisted in Health and Ecological Risk Assessments on large mining operations. Andrew is joint coordinator on a River Restoration course and guest lecturer on an EWRs course run by Edith Cowan University, detailing EWRs for freshwater fish and groundwater-dependent cave fauna. He is a member of various committees, including Department of Environment and Conservation (WA) Threatened Ecological Communities Scientific Committee, Recovery Teams for Yanchep and Leeuwin caves, and Steering Committee for WWF project on managing Northern Rivers. He has authored over 75 technical reports and over 35 peer reviewed scientific papers.

Formal Education

BSc Degree (1981):	University of Ulster - 1st Class Honours in Biology/Ecology.
PhD (1986):	Reading University/Freshwater Biological Association, UK - Aquatic Ecology.

Relevant Employment History

1995 - current:	Principal Consultant, *Wetland Research & Management*, Glen Forest, WA.
	Adjunct Senior Lecturer, School of Animal Biology, The University of Western Australia (UWA), Crawley, WA.
1993-1995:	Senior Biologist, Environment Department, Ok Tedi Mining Ltd, Papua New Guinea.
1990-1993:	Research Scientist, WA Dept. CALM (now DEC).
1986-1990:	Research Fellow, Zoology Department, The University of Western Australia, Crawley, WA.
1986-1990:	Consultant Biologist, Streamtec Pty Ltd, Nedlands WA.