Government of **Western Australia**
Department of **Water**

Leschenault Estuary water quality improvement plan

Looking after all our water needs

October 2012

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Department of Water

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Summary

All south-west Western Australian estuaries, especially those in areas with extensive artificial drainage, are affected by eutrophication due to agricultural and urban land uses. The Water Quality Improvement Plan (WQIP) was developed from an understanding of water quality condition in receiving water bodies and of catchment land uses and nutrient sources. WQIPs provide a series of management actions across the landscape with the aim of improving water quality. WQIPs are currently being implemented in the Peel-Harvey, Swan-Canning, and Vasse-Wonnerup/Geographe Bay catchments.

The Leschenault estuary, one of the larger waterbodies in WA, is a valuable natural asset in terms of waterbirds, fringing and aquatic vegetation, and fish habitat. The estuary also supports a wide range of recreational activities for local residents and for a large tourism sector. The estuary and associated water bodies provide an aesthetic backdrop to the City of Bunbury and Australind.

The estuary drains the catchments of the Wellesley, Brunswick, Ferguson, Collie and Preston rivers as well as receiving runoff from adjacent land and agricultural drains. The estuary's catchment area is in excess of 1900 km^2 . The estuary environment includes the main body the estuary, which is very shallow (less than 2 m deep) with an area of 27 km^2, and the salt water portions of the Brunswick and Collie rivers . The Preston river has been modified by the development of the Port of Bunbury, and is connected to the main body of the estuary. A man made cut opposite the confluence of the Collie and Brunswick rivers connects the estuary to the ocean.

With the present land uses, the Leschenault Estuary and associated waterways are showing signs of stress. In the estuarine portions of the Preston, Brunswick and Collie rivers and at the Leschenault Estuary's northern end, symptoms of estuary decline are evident as demonstrated by excessive algal growth and lack of oxygen, which has lead to fish deaths and odours. Lower freshwater inflows in recent years have exacerbated these symptoms.

There is considerable community concern about the potential for these symptoms to increase due to changes in land use, urbanisation and intensification of agriculture. The water quality could worsen with the reduced rainfall and runoff and higher temperatures associated with a drying climate, and with increased water abstraction.

The Greater Bunbury area, which includes the City of Bunbury and shires of Harvey, Dardanup and Capel (encompassed within the *Greater Bunbury region scheme*) is one of the most populous areas in the state's south-west. It is forecast to grow from 61 000 to between 100 000 and 150 000 residents by 2031 (WAPC 2005; DoP pers. comm.). The projected urban development and intensification of land uses will be close to the estuary and have the potential to increase nutrient runoff to the waterways and the estuary.

The *Leschenault Estuary water quality improvement plan* (WQIP) is a partnership response, the aim of which is to improve the estuary's current water quality (and that of the streams and rivers in its catchment), and to prevent further deterioration. The WQIP presents a consolidated understanding of water quality issues in the catchment and estuary, identifies

sources of pollutants (particularly nitrogen and phosphorus) and provides solutions in the form of management actions supported by cost/benefit analyses.

Although the WQIP mainly seeks to improve water quality by reducing nutrient and organic matter pollution and the symptoms thereof (e.g. algal blooms and fish kills), other important components of the plan include ensuring that industrial contaminants are minimised, acid sulfate soil impacts are prevented and river health and function is improved.

It is important to recognise that a WQIP requires extensive consultation, coordination and action among key government agencies, local government authorities, industry representative bodies and the community.

Many of the actions required to improve water quality in the Leschenault Estuary – with its history of water quality problems, large diversified catchment and extensive planned expansion of industrial and residential areas – are principally a government responsibility with respect to land use planning, location of industrial estates, waste and pollution management, urban design and water management. Substantial changes in agricultural practice are also required, especially on the coastal plain.

The WQIP's development was supported by scientific studies similar to those conducted for previous WQIPs, and included extensive nutrient and water balance catchment modelling. Long-term water quality monitoring data, aquatic vegetation surveys and sediment nutrient processes informed the assessment of estuarine condition. Catchment water quality, flow data, land use mapping and surveys of land use practices informed the development of catchment models.

For the purposes of modelling and reporting, the Leschenault catchment has been divided into 16 subcatchments: 15 of which drain to the estuary and the remaining one into both the ocean and the Leschenault Inlet (in Bunbury, which was once connected to the Leschenault Estuary). Nutrient load reduction targets were calculated for each subcatchment to meet water quality objectives aligned with the Swan Coastal Plain water quality criteria for total nitrogen (TN) of 1.0 mg/L and for total phosphorus (TP) of 0.1 mg/L in the coastal plain rivers, and with the ANZECC upland river guidelines for TN of 0.45 mg/L and TP of 0.02 mg/L for the subcatchments draining the Darling Scarp.

The reporting subcatchments were classified by comparing the estimated nutrient concentration in runoff against the water quality targets for TN and TP.

The classification is as follows:

- *protection* – for all reporting subcatchments currently meeting both the nitrogen and phosphorus targets
- *intervention* – for all reporting subcatchments that meet the phosphorus, but not the nitrogen target
- *recovery* – for all reporting subcatchments meeting neither the nitrogen nor the phosphorus target.

The chosen water quality objectives and the classification scheme for reporting subcatchments provide a framework for water quality management in the Leschenault catchment that does the following:

- sets nutrient concentration targets for Leschenault Estuary tributaries that take into account subcatchment character
- recognises the importance of preventing a shift from acceptable water quality to poor water quality, as well as achieving improvements in areas that have already declined
- aims to improve the ecological health of the waterway reaches associated with each reporting subcatchment
- places a high value on protecting the quality of inflows to the Leschenault Estuary.

Only one catchment falls into the ‘protection’ category – Brunswick Upper 2. All the other upland subcatchments are in the ‘intervention’ category, while all the reporting subcatchments on the Swan Coastal Plain fall into the ‘recovery’ category with the exception of Parkfield Drain, which is in the ‘intervention’ category (see table below). Note that water quality within reporting subcatchments can be quite variable, depending on local physiography, hydrology and land use.

Name	Type	Winter TN concentration	TN target	Winter TP concentration	TP target	Classification
Brunswick Upper 2	Upland	0.19	0.45	0.004	0.02	Protection
Upper Preston	Upland	0.49	0.45	0.011	0.02	Intervention
Thomson Brook	Upland	0.48	0.45	0.012	0.02	Intervention
Brunswick Upper 1	Upland	0.52	0.45	0.013	0.02	Intervention
Mid Preston	Upland	0.68	0.45	0.015	0.02	Intervention
Preston - Donnybrook	Upland	0.73	0.45	0.017	0.02	Intervention
Upper Ferguson	Upland	0.68	0.45	0.019	0.02	Intervention
Collie Lower 2	Upland	0.66	0.45	0.020	0.02	Intervention
Parkfield Drain	Lowland	1.8	1.0	0.072	0.1	Intervention
Lower Ferguson	Lowland	1.5	1.0	0.11	0.1	Recovery
Coast	Lowland	2.5	1.0	0.16	0.1	Recovery
Wellesley	Lowland	1.6	1.0	0.16	0.1	Recovery
Lower Preston	Lowland	1.5	1.0	0.18	0.1	Recovery
Collie Lower 1	Lowland	1.5	1.0	0.18	0.1	Recovery
Estuary Foreshore	Lowland	2.0	1.0	0.19	0.1	Recovery
Mid Brunswick	Lowland	1.2	1.0	0.20	0.1	Recovery

The following table shows the load reductions required to meet concentration targets, and current and predicted nutrient loads based on catchment modelling.

Loads and targets	Leschenault Estuary	Coast
Nitrogen		
Current load (tonnes/yr)	312	14
Future load (tonnes/yr)	323	15
Acceptable load (tonnes/yr)	211	6
Load reduction target (reduce by x tonnes/yr)	101	8
Load reduction target (% of current load)	32%	58%
Phosphorus		
Current load (tonnes/yr)	27.8	1.1
Future load (tonnes/yr)	29.4	1.2
Acceptable load (tonnes/yr)	17.1	0.6
Load reduction target (reduce by x tonnes/yr)	10.7	0.5
Load reduction target (% of current load)	38%	43%

Although the load reduction targets may seem ambitious in a 10-year timeframe, the nitrogen and phosphorus loads reaching the estuary require reduction as a matter of urgency. The impending growth of the Greater Bunbury area is projected to increase the current loads to the estuary, particularly in the subcatchments already in the ‘recovery’ or ‘intervention’ categories.

The WQIP outlines a range of management actions which, if taken together, have the potential to improve current water quality, prevent further decline and also deliver a range of water efficiencies and human health outcomes. Further detail of where in the landscape these management actions should be undertaken in each subcatchment is contained in an accompanying report, *Implementing the Leschenault Estuary water quality improvement plan.* The management actions are listed below.

Nutrient and contaminant reduction

Management of diffuse source agricultural nutrients:

1. Improve fertiliser management throughout the catchment
2. Use approved soil amendments on sandy soils
3. Develop and use slow-release phosphorus fertilisers
4. Use subtropical perennial pastures for broadacre dryland grazing
5. Implement annual horticulture best-management practices
6. Implement riparian management and reinstate the ecological function of waterways
7. Improve irrigation practices: convert from flood irrigation to water efficient (eg centre-pivot) irrigation

Management of point source agricultural nutrients:

8. Improve effluent management of dairy sheds

9 Treat effluent from feedlots to national or international best-practice standards

Management of diffuse urban nutrients:

10 Reduce nutrient use and export risk in urban areas (includes improved fertiliser use)

11 Ensure new urban developments include water sensitive urban design, such as biofiltration, raingardens, swales, and nutrient stripping in subsurface drainage

12 Undertake strategic retrofitting of water sensitive urban design in existing urban areas

Management of point source urban nutrients:

13 Reduce WWTP discharge to catchment waterways. Appropriate management of WWTP effluent re-use on woodlots, golf courses or other recreational grounds. Industrial, agricultural and other re-use options for WWTP discharge to be developed

14 Replace septic systems with low-nutrient-emission aerobic treatment units or connect to the reticulated deep-sewerage system

15 Reduce or eliminate discharges to waterways from DEC-licensed premises

16 Support full implementation of *Better urban water management* across local government areas

A cost/benefit analysis was used to provide capital costs for recommended actions where costs were available. Not all best-management practices (BMPs) were included due to lack of data either on effectiveness or costs associated with their implementation. It is recommended that all BMP implementation be accompanied by measurement of effectiveness to support future planning. The development and description of BMPs has been based on extensive consultation, especially with the Department of Agriculture and Food (DAFWA) and industry groups for agricultural interventions. The recommended BMPs are therefore feasible and likely to be implemented. Scenario modelling using the calibrated Source Catchments (formerly WaterCast) model and available data on effectiveness showed which combination of BMPs could be used in each subcatchment to meet the water quality objectives. Many of the BMPs confer economic benefits (e.g. fertiliser management), water efficiency improvements, ecological and human health benefits (e.g. septic tank removal) as well as the reduction of nutrient losses.

The single-most effective management practice to reduce nutrient losses to waterways, especially from agriculture, is fertiliser management. In many parts of the coastal plain catchment, phosphorus fertilisation rates are very much higher than the agronomic need, which represents substantial financial losses to the farming enterprise and unnecessary environmental harm. The *Fertiliser Partnership* encourages best practice in fertiliser application through soil testing and independent fertiliser advice. The use of soil amendments to raise the PRI so that phosphorus fertilisers are retained in soils and not leached to waterways is a component of the agreement. Up to 50% of the phosphorus load reduction required in the estuary subcatchments can be achieved by fertiliser management and the use of soil amendments.

Environmental water management

Water flows in streams and rivers and water use within a catchment affect water quality, especially in a catchment such as the Leschenault with water storages and extensive irrigation infrastructure. This plan considers the setting of environmental flows in the context of overall water allocation planning and a future scenario in which demands for water are increasing at the same time as river flows are decreasing. The setting of environmental flows for rivers is well established in Australia but the science of developing environmental flows for estuaries is in its infancy. Preliminary consideration of an environmental flow regime for the Leschenault suggests that any exploitation of the remaining undeveloped surface water resource (the Brunswick River) would have a negative impact on the estuary. Management actions are:

17 Determine ecological water requirements for the estuary and estuarine sections of the lower Collie, lower Preston and lower Brunswick rivers

18 Complete a surface water allocation plan for the Preston catchment

19 Improve integration of water planning throughout the catchment such that water quality outcomes are optimised

Assess condition and measure progress

Assessing the current condition of the estuary and catchment streams has been made possible by long-term streamflow and nutrient concentration datasets and the establishment of indicators of estuarine health sensitive to change. An essential part of estuary management and of WQIPs is a long-term monitoring program to report changes in condition and improvements in response to management actions, including:

20 Undertake water quality monitoring of catchment streams to allow calculation and reporting of nutrient trends and loads

21 Perform regular water quality monitoring of the Leschenault Estuary including the riverine reaches for physical variables and nutrients

22 Establish and report estuarine condition assessments

23 Undertake priority research to improve knowledge of the Leschenault Estuary system

24 Review progress towards implementation of management actions after two years and against water quality targets after five years

WQIP implementation

As the WQIP’s implementation requires a partnership response, the recommendation is to:

25 Establish a governance structure led by the Department of Water to implement the WQIP across state government agencies, local government authorities, industry bodies, the Leschenault Catchment Council and the community

1 Introduction

1.1 Setting the scene

What is the water quality improvement plan?

The *Leschenault Estuary water quality improvement plan* (WQIP) is a partnership response that aims to improve the Leschenault Estuary's water quality, and that of its catchment, streams and rivers. The WQIP presents a consolidated understanding of water quality issues in the catchment and estuary, identifies sources of pollutants (particularly nitrogen and phosphorus) and provides solutions to protect the receiving aquatic systems.

Why do we need a WQIP for the Leschenault Estuary?

All south-west estuaries, especially those in areas with extensive artificial drainage, are severely affected by eutrophication due to agricultural and urban land uses. The nutrient-related problems in the Peel-Harvey and Leschenault estuaries were recognised when both systems were proclaimed under the *Waterways Conservation Act 1976*. WQIPs have been developed for some of the other most severely affected estuarine systems in the south-west: the Peel-Harvey, Swan-Canning, Vasse-Wonnerup/Geographe Bay and more recently the Hardy Inlet.

Under the present land uses, the Leschenault Estuary and associated waterways are showing signs of stress. In the estuarine portions of the Preston, Brunswick and Collie rivers and also at the Leschenault Estuary's northern end, symptoms of estuary decline and collapse are evident as excessive algal growth (including toxic species), lack of oxygen leading to fish deaths and odours. Ecosystem decline also manifests as large-scale macroalgal blooms along the estuary shores. These incidents have the potential to increase due to changes in land use, urbanisation and intensification of agriculture. The poor water quality could worsen with the reduced rainfall and runoff and higher temperatures associated with climate change, and by increased water abstraction.

Although highly altered in its nature and showing signs of eutrophication, the main body of the estuary is still believed to be in good condition (relatively) due to a good marine exchange (in the lower part) and a generally well-oxygenated water column. While the winter median concentrations of total nitrogen (TN) and total phosphorus (TP) are low compared with some other south-west estuaries, the estuary receives a significant input of nutrients: average annual loads of approximately 312 tonnes of nitrogen and 28 tonnes of phosphorus. These nutrient loads are substantial, and may lead to a further decline in water quality within the estuary as nutrients are built up in the sediments (Marillier 2010). The Leschenault Estuary has the potential to develop regular algal blooms as seen in other Swan Coastal Plain estuaries, such as the Vasse-Wonnerup, Peel-Harvey and Swan-Canning systems.

The Greater Bunbury area, which includes the City of Bunbury and shires of Harvey, Dardanup and Capel (encompassed within the *Greater Bunbury region scheme*) is one of the most populous areas in the state's south-west. It is forecast to grow from 61 000 to between 100 000 to 150 000 residents by 2031 (WAPC 2005; DoP pers. comm.). The projected urban development and intensification of land uses will be close to the estuary and has the potential to increase nutrient runoff to the waterways and the estuary, unless appropriate land use planning and management measures are undertaken.

1.1 Why are nutrients and other contaminants a matter of concern?

Any adverse changes in the natural water quality of waterways and estuaries implies impacts from localised or catchment-based land uses through point source or diffuse pollution. Although water quality deterioration may arise following natural events such as heavy storms, most serious long-term and larger-scale water quality problems arise as a result of human activities (Giller & Malmqvist 1998) whether directly or indirectly. As described by Giller and Malmqvist (1998), pollution sources can be divided into two categories: those affecting the physical environment in which organisms live (e.g. nutrients and temperature) and those being directly toxic to the organisms themselves (e.g. heavy metals, organochlorines). Table 1-1 provides an overview of key pollutants found, or likely to be present, in the Leschenault waterways and their known effects.

Nutrients

South-west estuaries have evolved under naturally low nutrient (oligotrophic) conditions (EPA 2007) and thus are particularly vulnerable to nutrient enrichment (Brearley 2005). Yet they may be subject to large nutrient loads if intensive land uses are established around them.

Excess nutrients in aquatic ecosystems disturb the delicate ecological balance by increasing primary production above natural conditions, resulting in the proliferation of weeds, micro and macroalgal blooms, benthic green algae and cyanobacteria – all of which overgrow and destroy natural benthic communities (Giller & Malmqvist 1998). Algal blooms can also degrade estuarine and river systems directly through:

- the depletion of oxygen, following algal decomposition, which can result in plant and fish deaths
- the release of toxins, such as those from cyanobacteria, which can cause serious illnesses in and the death of humans, livestock and wildlife (Giller & Malmqvist 1998).

Long-term exposure to excessive nutrients can drastically degrade biodiversity in aquatic ecosystems (EPA 2007), and thus render the waterbody unsuitable for recreational fishing and other water-related activities, in turn reducing tourism opportunities and revenue as well as land values (because of the lowered amenity).

There is a limited understanding of the nutrient cycling and residency time of nutrients and other contaminants in the Leschenault Estuary. However, elevated concentrations of nutrients are likely to have affected the abundance and distribution of macroalgae and seagrass beds. Observed during the past two decades, seagrass meadow losses may be having a serious impact on the system’s ecology, given their important role as a nursery for invertebrate fauna and fish, which birds, larger fish and dolphins rely on for food. A recent study of fish and crab assemblages, Veale et al. (2010), revealed declining goby populations and colonisation of two tropical species of hardyhead, indicating the Leschenault Estuary's benthic environment may be deteriorating.

Other contaminants and associated risks

Anthropogenic activities result in the release of many contaminants to the air, land or water. These contaminants can be readily transported in surface and groundwater to rivers and estuaries. Contaminants derived from both urban and rural land uses can include metals; toxic organic waste (garden and household chemicals); oxygen-demanding materials (biodegradable organic matter); pathogenic microorganisms (bacteria, viruses); hydrocarbons; low-level organic compounds such as pesticides, herbicides, polycyclic aromatic hydrocarbons (PAHs); organochlorines (OC); anionic surfactants and polychlorinated biphenyls (PCBs) (Table 1-1). Disturbance of acid sulfate soils and sediments can mobilise contaminants, particularly metals.

Currently there is a limited understanding of the presence of contaminants (besides nitrogen and phosphorus) in the estuary and lower sections of the Collie, Brunswick and Preston rivers. However, studies in the Swan and Canning rivers and stormwater drains (Nice et al. 2009; Evans 2009; Foulsham et al. 2009; EPA 2007) have established the presence of non-nutrient pollutants (e.g. organic chemicals, pesticides including DDT and Dieldrin, hydrocarbons and heavy metals) from human activities relating to urban, agricultural and industrial land uses. A similar list of contaminants is therefore expected in the Leschenault waterways due to the presence of similar land uses (present and historic).

From agricultural land, farming practices can contribute a variety of contaminants to the aquatic environment. For instance, Nash (2004) discusses recent studies of metal contamination of drainage from irrigated pastures as a result of fertiliser application. Metal contamination of water may occur in situations involving soil and streamwater acidification. It is important to recognise the risks associated with non-nutrient contaminants entering the estuary and its associated rivers.

1.2 Approach and supporting projects

This plan has been supported with projects funded over a five-year period through the South West Catchments Council (SWCC) and the Leschenault Catchment Council (LCC) under the National Heritage Trust I and 2 between 2004 and 2008.

The Department of Water has:

- implemented a comprehensive flow and water quality monitoring program for the catchment and estuary
- undertaken nutrient status and trend analyses to determine catchment condition
- developed a nutrient and hydrology model of the Leschenault catchment that quantifies nutrient loads and sources
- undertaken sediment studies in collaboration with Geoscience Australia.

Past and future water quality data will be used to assess and report on catchment and estuarine condition and measure progress towards the WQIP's targets and objectives, as discussed in Section 10.

Table 1-1: Freshwater pollution sources, potential effects and constituents of concern (taken from WWAP 2009 and modified with Foulsham et al. 2009; EPA 2007; Williams et al. 2007; Government of Western Australia 2003; Steele 2006 and US EPA <www.epa.gov/international/toxics/pop.html>)

Pollution type	Sources	Potential effects	Constituents of concern
1 Organic matter	Animal waste, industrial wastewater and domestic sewage.	Depletion of oxygen from the water column as it decomposes, stresses or suffocates aquatic life.	Biological oxygen demand (BOD), dissolved organic carbon (DOC), dissolved oxygen (DO)
2 Pathogens and microbial contaminants	Domestic sewage, cattle and other livestock, natural sources.	Spreads infectious diseases through contaminated drinking water supplies leading to diarrhoeal disease and intestinal parasites.	*Shigella* (causing dysentery), *Salmonella*, *Cryptosporidium*, faecal coliform (coliform), *Escherichia coli* (mammal faeces – *E. coli*)
3 Nutrients (primarily nitrogen and phosphorus)	Principally runoff from agricultural lands and urban areas but also from some industrial discharge.	Over-stimulates growth of algae, which then decomposes, depleting water of oxygen and harming aquatic life. Groundwater can become contaminated by nutrients and affect the suitability of water supplies. Excessive nitrate in water supply is a potential human health risk (Mason 1996) especially to infants under six months, causing the condition known as methanoglobin-induced anaemia or 'blue baby syndrome'. High concentrations of nitrate in drinking water are also detrimental to livestock, for instance reducing vitality, increasing stillbirth and decreasing milk productivity (source: <www.nitrate.com/nitrate3.htm>, downloaded in Oct 2010).	Total N (organic + inorganic), total P (organic + inorganic), individual N species (NH_4, NO_2, NO_3, organic N), soluble P (orthophosphate), DO
4 Salinisation	Leached from alkaline soils by over-irrigation or by over-pumping coastal aquifers resulting in saltwater intrusion.	Salt build-up in soils which kills crops or reduces yields. Renders freshwater supplies undrinkable.	Electrical conductivity, chloride, major cations (Ca, Mg, etc.), anions
5 Acidification (precipitation or runoff)	Drainage or water abstraction wherein soils containing sulfides oxidise to form acid. Acid mine drainage (from mines and tailing dams).	Risk maps of potential acid sulfate soils have been prepared at coarse scale for the area. Much of the low-lying areas around the estuary and parts of the coastal plain have a high acidification risk. Consequences are release of metals into the water and formation of black monosulfidic oozes that consume oxygen. Incidences of actual acid sulfate soils have been recorded around the estuary associated with disturbance of the groundwater table.	pH, metals, H_2S, monosulfidic oozes

Pollution type	Sources	Potential effects	Constituents of concern
6 Heavy metals	Industries, road runoff, farming (e.g. found in fertilisers) and mining sites.	Persists in freshwater environments such as river sediments and wetlands for long periods. Accumulates in the tissues of fish and shellfish. Can be toxic to both aquatic organisms and humans who consume them.	Pb, Cd, Zn, Cu, Ni, Cr, Hg, As (particularly in groundwater)
7 Toxic organic compounds, persistent organic chemicals (POCs) and micro-organic pollutants[1]	Wide variety of sources from industrial sites, cars, farmers, home gardeners, municipal wastewaters.	A range of toxic effects in aquatic fauna and humans from mild immune suppression to acute poisoning or reproductive failure. POCs are toxic chemicals that adversely affect human health. POCs persist for long periods of time in the environment and can accumulate and pass from one species to the next through the food chain (US EPA 2010). Pesticides (herbicides, insecticides, fungicides, algicides etc.) have a great potential for mobilisation in the aquatic environment due to their high solubility, relative persistence and non-absorbency to soil particles (Foulsham et al. 2009). Most pesticides bioaccumulate in the fatty tissues of aquatic organisms, which consequently further bioaccumulates in animals higher up the food chain (fish, birds, humans) (Foulsham et al. 2009) with consequent negative effects on their health. They can build up to toxic levels in the bodies of organisms that consume them, a phenomenon that impacts species high in the food chain. Organochlorines vary widely in toxicity but are generally considered to be highly toxic, with Aldrin, Heptachlor and Dieldrin being the most toxic (Klemm 1989). Organochlorine pesticides result in impaired learning behaviour, slow reflexes and reduction in reproductive success. Birds are particularly at risk due to the thinning of shells and decreases in clutch size (Mason 1996). Insecticides are extremely toxic to aquatic organisms.	PAHs, PCBs, herbicides, pesticides (lindane, DDT, PCP, Aldrin, Dieldrin, Endrin, Isodrin, hexachlorobenzene)
8 Endocrine disruptive compounds/ chemicals (EDCs)	Septic tanks, WWTPs, feedlots, medical waste, agricultural and urban runoff and industrial discharges.	Endocrine-disrupting compounds (EDCs) alter the function of the endocrine system and can have adverse effects in an organism, its progeny or within its population (Williams et al. 2007). Many contaminants, singularly or cumulatively, are considered to be endocrine disrupting, with chronic effects on aquatic organisms (Foulsham et al. 2009).	Besides natural hormones, EDCs include a range of pharmaceuticals, and other organic compounds such as surfactants, chemical constituents of plastics and a number of POPs. EDCs are often difficult to detect and require targeted investigations

Pollution type	Sources	Potential effects	Constituents of concern
9 Thermal	Fragmentation of rivers by dams and reservoirs slowing water and allowing it to warm. Industry cooling towers and other above-ambient-temperature discharges.	Changes in oxygen concentrations and decomposition rate of organic matter in the water column. May shift the species composition of the receiving waterbody.	Temperature
10 Silt and suspended particles	Natural soil erosion, bushfires, agriculture, road building, deforestation, construction and other land use changes.	Reduces water quality for drinking and recreation and degrades aquatic habitats by smothering them with silt, disrupting spawning and interfering with feeding. In respect to the estuary and associated waterways, other impacts include: • reducing light availability • infilling of pools and summer refuges, thus reducing habitat for aquatic species including native fish and crayfish • releasing, under anoxic conditions, phosphorus readily available for plant and algae uptake • storing contaminants and pathogens.	Total suspended solids, turbidity

[1]List includes a suite of endocrine disrupters, antioxidants, plasticisers, fire retardants, insect repellents, solvents, insecticides, herbicides, fragrances, food additives, prescription drugs and pharmaceuticals (e.g. birth control, antibiotics), non-prescription drugs (e.g. caffeine, nicotine and derivatives, stimulants).

The Department of Water and DAFWA, with funding from the Australian Government's Coastal Catchment Initiative project, have also completed extensive studies to determine:

- land uses in the catchment
- nutrient inputs to agricultural and urban lands.

This WQIP has been developed in accordance with the *Framework for marine and estuarine water quality protection* (DEWHA 2002), which was developed as a nationally consistent approach to protecting the marine and estuarine environment from the effects of land-based pollution.

The framework includes identification of:

- the environmental values of the coastal water in question – in this instance the estuary and its associated waterways
- the catchment that discharges to that coastal water
- the water quality issues (e.g. algal blooms, sedimentation, non-nutrient contaminants) and subsequent water quality objectives
- the total maximum load of pollutant/s to be achieved to attain and maintain the water quality objectives
- the allocation of the total maximum load of pollutant/s to diffuse and point sources of pollution

- the river-flow objectives to protect identified environmental values, having regard for matters such as natural low flows, flow variability, floodplain inundation, interactions with water quality and the maintenance of estuarine processes and habitats
- management measures, timelines and costs in implementing the plan
- the grounds for a ‘reasonable assurance’ from jurisdictions to provide security for investments to achieve the specified pollutant-load reduction and environmental flow targets.

1.3 Objectives and aims of the water quality improvement plan

The need for a coordinated and strategic approach to mitigate water quality deterioration in general, and nutrient loads in particular, is becoming critical to ensure the Leschenault Estuary and its associated waterways do not become more eutrophic and degraded and reach a tipping point requiring too significant an investment to enable recovery.

The WQIP’s aim is thus to identify the values supported by the estuary and associated waterways (Section 2) and the factors threatening those values (Section 3), as well as to provide strategic and prioritised management recommendations to improve the water quality of these important assets.

The WQIP will:

- guide planning and development to minimise the impacts of new nutrient and non-nutrient contaminant sources
- provide recommended agricultural and urban BMPs in terms of location, scale and cost – the implementation of which would reduce nitrogen and phosphorus loads to the waterways
- provide complementary strategies to restore the ecological function of the streams and rivers and prevent the additional loss of habitat and function in both the streams and estuary (these include minimising non-nutrient contamination and acid sulfate soil impacts, and interventions to restore waterway health).

Protecting the ecosystem from further degradation, and improving ecosystem health in degraded waterways, will ensure the system can support activities such as fishing and crabbing, water-related sports (swimming, kite- and wind-surfing and boating) and other recreational activities such as picnicking, walking, bird watching and sightseeing.

The water quality objectives, expressed in terms of nitrogen and phosphorus concentrations in subcatchments representing sections of the major waterways (Figure 1-1), are discussed in Section 4. The modelling used to estimate the required load reductions in each subcatchment to achieve the water quality objectives is presented in Section 5. Different subcatchments within the Leschenault have different nutrient sources and thus management priorities regarding nutrient pollution. Section 6 provides a suite of management tools to reduce nutrient loads entering the waterways. A cost/benefit analysis of implementing the management measures over a 10-year timeframe is included.

This approach will enable management information and recommendations for each area to be tailored for use by state government agencies, catchment or community groups, NRM groups, Land Conservation District Committees (LCDCs), agricultural user groups and local government planning staff. An accompanying report, *Implementing the Leschenault Estuary water quality improvement plan* (DoW 2012) provides detailed advice for each subcatchment.

Section 9 discusses the WQIP's implementation and lists all the actions recommended in this report, including management actions for agricultural and urban land uses, management of environmental flows, required studies to fill data and knowledge gaps, and monitoring to assess the plan's impacts.

Section 10 discusses monitoring for water quality improvement to determine if the actions introduced have been successful or not.

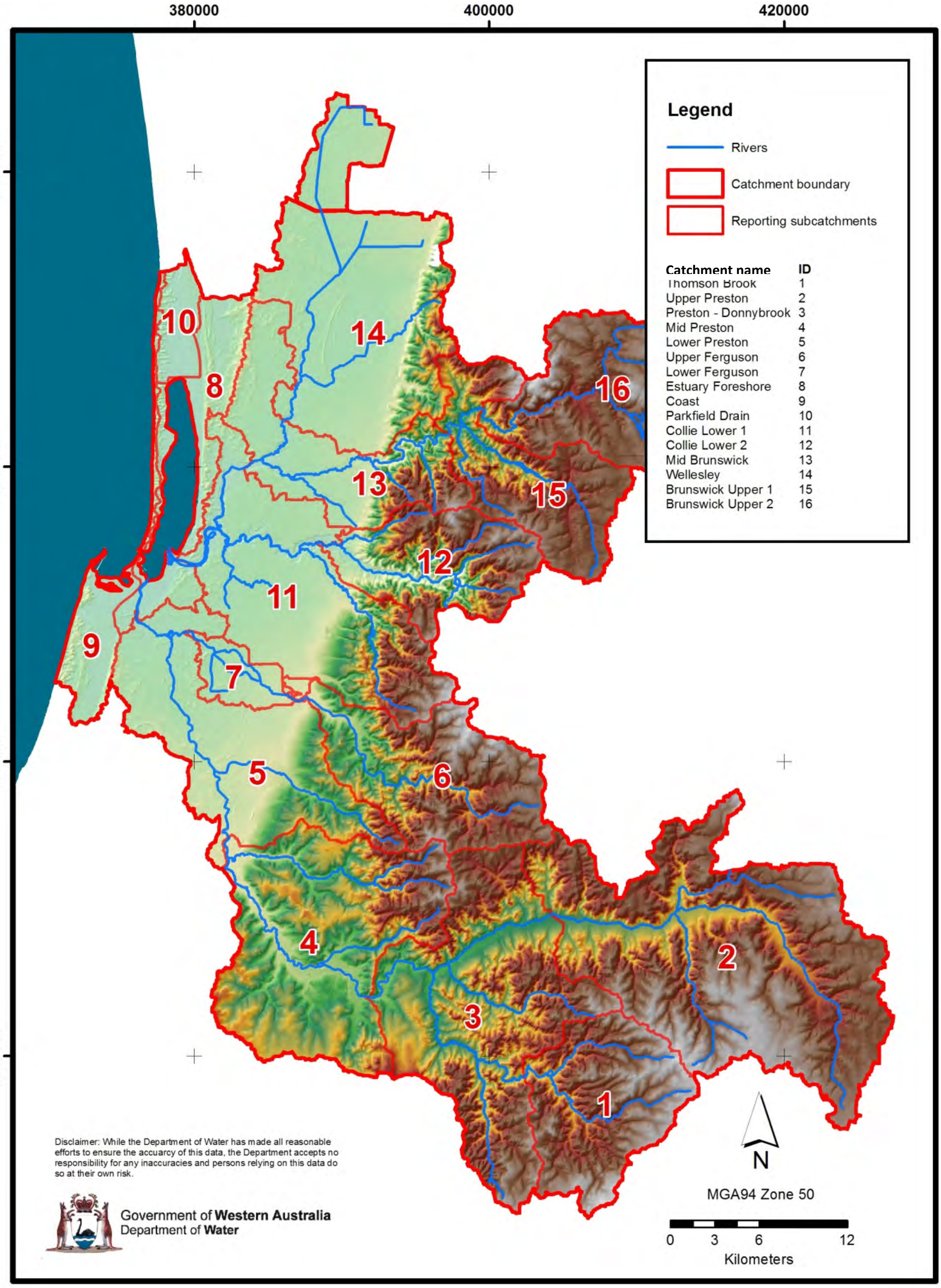


Figure 1-1: Reporting subcatchments of the Leschenault catchment

2 Environmental values

2.1 Estuary characteristics and setting

The Leschenault Estuary is located approximately 150 km south of Perth (Figure 2-1) and is one of the larger waterbodies in southern Western Australia, covering an area of approximately 27 km^2. It is about 14 km long, 1.5 to 2.5 km wide, and is very shallow – being 1.2 to 2 m deep. It is the only estuary in the state located behind a shore-parallel dune barrier. It has shallow platforms of sand and muddy sand along the eastern side, while the western side has deep mud (Hillman et al. 2000).

The Collie and Preston rivers, which discharge directly into the estuary, also encompass flows from the Wellesley, Brunswick and Ferguson rivers. Rainfall in the catchment and river flow to the estuary is seasonal and generally greater in the winter months. Summers are hot and dry.

The Leschenault Estuary is permanently connected to the ocean by an artificially constructed entrance channel known as The Cut. Situated opposite the mouth of the Collie River, The Cut was constructed in 1951 in preparation for the inner harbour's development. This isolated the estuary basin from its natural ocean entrance, which was closed to prevent sedimentation in the old Bunbury Port. A second smaller marina-like waterbody known as the Leschenault Inlet is all that remains of the old entrance channel. Water levels in the marina are controlled by a set of flood gates.

During the past century the Leschenault Estuary has been significantly modified by human activity, as shown in Figure 2-2. Originally there was only one waterbody called the Leschenault Inlet Estuary. Now the system is divided into two waterbodies:

- the Leschenault Inlet: once the mouth of the Preston River, this is now a semi-confined waterbody/lagoon that has significant recreational and social importance to the City of Bunbury
- the Leschenault Estuary: the larger waterbody, into which the Collie and Preston rivers flow. It is now connected to the ocean via The Cut, a man-made opening through the barrier-dune system, established to manage flood flows after Bunbury Port was built.

In the context of this WQIP, references to the Leschenault Estuary or estuary describe the larger waterbody. Note that the estuarine portions of the Brunswick, Collie and Preston rivers, as defined by the saltwater extent, will be considered as the estuary (see Figure 2-1). These areas may also be referred to as the riverine portion of the estuary.

Details relating to catchment characteristics are documented in Appendix A and include geography and topography, climate, hydrology, history of the catchment and changes to the estuary and land use, the economy and driving forces.

The estuary lies parallel to the coast with the Collie and Preston rivers discharging at its southern end near The Cut, and the Parkfield Drain discharging at its northern end. This results in a marked gradient in salinity from south to north (Brearley 2005) and unlike other estuaries, there is no simple river-to-sea transition.

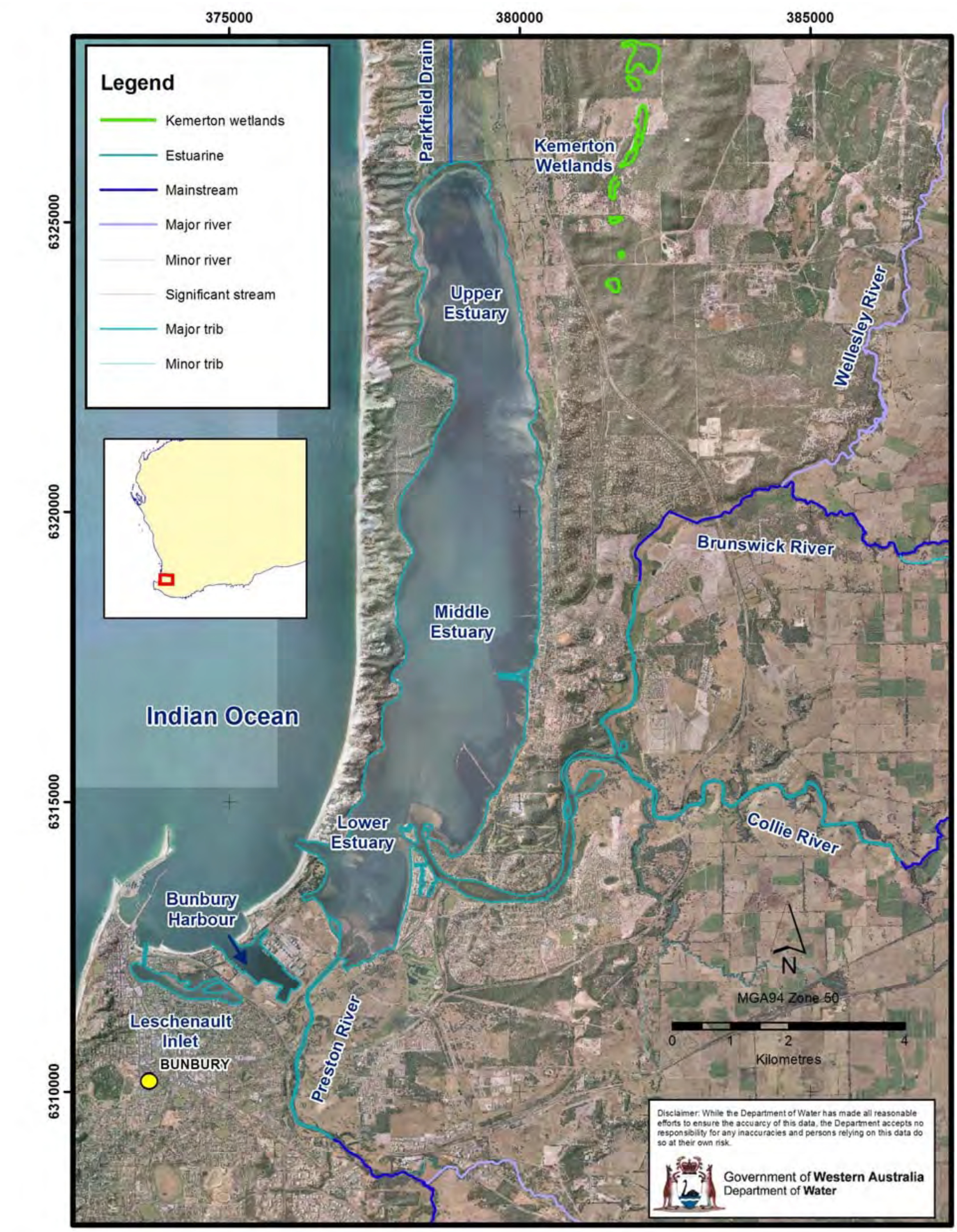


Figure 2-1: The Leschenault Estuary and its catchment

The estuary is likely to be altered further with the planned realignment of the lower Preston River to enable the Bunbury Port area's expansion. This will affect the present delta and possibly the estuary's ecology.

The estuary also has a complicated Holocene sea-level history which has resulted in the complexity of its shores. The western shores have a varied assemblage of stratigraphic and hydrologic situations (Semeniuk et al. 2000). Groundwater seepage is also occurring along the estuary's shoreline (Brearley 2005), particularly on the north-west and east foreshores. The estuary is diurnally micro-tidal, wave dominated and wind-current driven. It hosts an array of landforms and vegetation types in and around it.

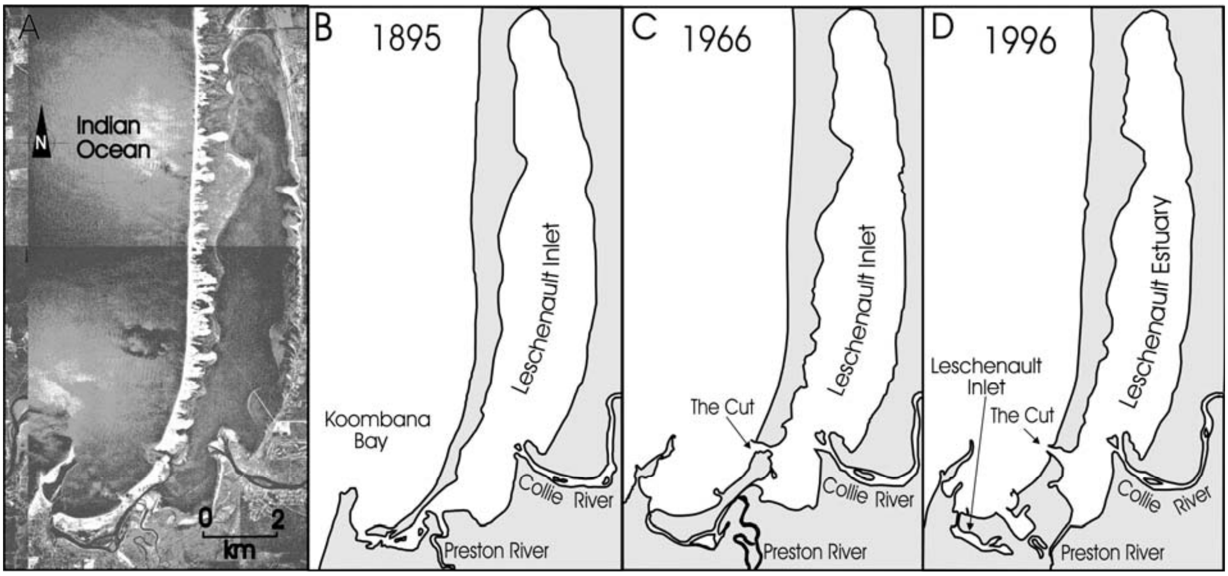


Figure 2-2: Alterations to the estuary over time due to anthropogenic activities (extracted from Semeniuk et al. 2000a)

2.2 Environmental values of the estuary and waterways

Under the *Framework for marine and estuarine water quality protection* (DEWHA 2002), environmental values are defined as:

- aquatic ecosystems
- primary industries (irrigation and general water uses, stock drinking water, aquaculture, and human consumption of aquatic foods)
- recreation and aesthetics
- drinking water
- industrial
- cultural and spiritual values.

2.2.1 Ecological values of the aquatic ecosystems

> The values of aquatic systems are difficult to quantify and may never be fully appreciated unless lost (Joint Government and Fertiliser Industry Working Group 2007).

Ecological values

The Leschenault Estuary supports a range of important ecological values (discussed below). It is important to note that while the Royal Society of Western Australia (2001) extensively reviewed some of the estuary's values, there is no other single report summarising the values *per se*, so this section will attempt to summarise the key values identified in the available literature. It is believed that major information gaps still exist for the Leschenault Estuary system and associated waterways and that further investigation is required to obtain a better and more up-to-date understanding of the ecological health of these assets.

Peripheral vegetation

The Leschenault Estuary's shores and wetlands peripheral to the estuary support five broad types of fringing vegetation (Semeniuk et al. 2000):

- saltmarsh, comprising sandfire and rushes
- estuarine fringing forests, typically of small saltwater sheoak, saltwater paperbark, paperbark, and swamp paperbark
- shallow water-fringing vegetation
- sandy-rise vegetation
- freshwater vegetation in habitat areas close to substantial freshwater input.

A more detailed classification of the estuary's habitats listing 19 smaller-scale types can be found in Wurm and Semeniuk (2000).

This peripheral vegetation has been identified as being of state significance (Semeniuk et al. 2000). The estuary supports a diversity of ecologically-important habitats including seagrass beds, tidal mud, sand flats, saltmarshes, fringing sedgelands, heathlands and *Melaleuca* woodland, with their associated biodiversity (McComb et al. 2001). In addition it supports the presence of the white mangrove, *Avicennia marina* subsp*. marina,* a relic of an earlier tropical period and the only occurrence south of Shark Bay (EPA 1993).

Estuary vegetation

Within the estuary, the aquatic vegetation is composed of at least three recorded species of seagrass: *Halophila ovalis, Ruppia megacarpa* and *Heterozostera tasmanica*, and at least seven species of macroalgae (green and brown): *Chaetomorpha* sp., *Graciaria* sp., *Ulva* sp. and *Acetabularia* sp.*,* as well as two species of *Phaeophyta* (Hillman et al. 2000). The distribution and abundance of macrophytes are influenced by depth, substrate and salinity (Semeniuk et al. 2000). Within the estuary's shallow banks, a large proportion of the total macrophyte biomass is accounted for by seagrass beds, primarily *H. ovalis*, which suggests the estuary's overall water quality and clarity is better than in some other estuaries (Hillman et al. 2000; Semeniuk et al. 2000). The estuary's southern section, essentially marine, has a low macrophyte biomass dominated by *H. ovalis*. On the other hand, the northern section of the estuary (north of Waterloo head) has a high macrophyte biomass dominated by the brown algae, *Hormophysa triquetra*; the green algae, *Chaetomorpha linum;* and the charophyte*, Lamprothamnium papulosum (*Hillman et al*.* 2000*). H. ovalis* overall contributes to the greatest biomass of all macrophytes (Wurm & Semeniuk 2000). It grows rapidly and survives well in unstable environments and places where sediments are continually being deposited. Nevertheless, drastic changes in seagrass distribution and abundance have been recorded and compared for selected sites in the estuary by Semeniuk V and C (2005b). This reinforces previous observations by Wurm and Semeniuk (2000) of a general decrease in abundance during the 1982 to 1987 period commensurate with a decreasing biomass of invertebrates throughout the estuary. Semeniuk et al. (2000a) suggest that changes in the estuarine biotic assemblages during the 1982 to 1988 period are due to the greater marine influence after construction of The Cut, medium-term changes in the volume of runoff, and changes in hydrochemistry and nutrient concentrations. The decline of seagrass distribution is of concern because seagrass meadows stabilise coastal sediments and trap and recycle nutrients.

Pen et al. (2000) indicate that from a statewide perspective, an array of peripheral and aquatic habitats are exclusive to the Leschenault Estuary; and combined with the complex variety of estuarine coastal landforms, the peripheral vegetation habitats are regionally significant.

Nursery habitat

Seagrass meadows, along with other aquatic vegetation and mangrove areas, are important nursery habitats in the estuary. Seagrass leaves and stems are used as attachment surfaces by algae and sessile invertebrates. On its leaf blade *Halophila ovalis* supports encrusting epibionts such as bryozoa, sepulid worms, tubular worms, egg cases and diatoms – creating an important habitat and nursery for a multitude of invertebrates and fish species. Indeed, together with algal cover, *H. ovalis* provides abundant food for herbivorous invertebrates and fish and leads to the production of large amounts of detritus, constituting an important component of the diets of certain benthic invertebrates and some teleost fish (Potter et al. 2000; SKM 2007).

Crabs, molluscs, prawns and many fish species (Hodgkins et al. 1979; Schwinghammer 1982) use seagrass meadows as nurseries, many of which are important to the recreational fishing industry (EPA 1993; Semeniuk et al. 2000). Crabs prefer seagrass meadows for refuge and foraging but will also use muddy, weedy or sandy habitat (McKenna 2004). This species is a target of recreational fishers along with three species of whiting (*Sillaginodes punctata*, *Sillago schomburgkii* and *Sillago burrus*) and tailor (*Pomatomus saltatrix*) (Potter et al. 2000). The juveniles of a species like the western trumpeter whiting (*S. burrus*) are known to occupy protected seagrass beds where they take advantage of both the sheltered environment and being able to prey on species that inhabit the seagrass community (McKay 1985).

Species of fish commonly found in the estuary are mullet, silver bream, tailor, sea garfish, striped perch, roach, whitebait and anchovy, as well as blue manna crabs and king prawns. Potter et al. (1997) document that the estuary contains a large abundance of fish species whose entire lifecycle is confined to the estuary, and that the composition of the fish fauna in the estuary’s shallows differs markedly from that of comparable waters in Koombana Bay into which the estuary discharges. Of the 42 species recorded in the 1990s by Potter et al. in the nearshore and shallow waters of the estuary (1997):

- 20 were marine using the estuary as a nursery area, being defined as marine estuarine-opportunists
- 13 were classed as estuarine, living entirely in the estuarine waters and completing their lifecycles in the estuary (of those seven are represented by marine populations)
- the most common species were the long-finned goby (*Favonigobius lateralis*), the hardyhead (*Atheronosoma elongata*) and gobbleguts (*Apogon rueppellii*).

It is important to note that Potter et al. (2000) estimated that species completing their lifecycles in the estuary made up 68% of the total number of individuals. This reinforces the importance of the Leschenault Estuary as a nursery area.

In the deeper waters of the estuary and Collie River, fish catches include larger species dominated by marine estuarine-opportunists and the Perth herring (*Nematalosa vlaminghi*) (Potter et al. 2000).

A recent study on the characteristics of fish and crab assemblages in the estuary between 2008–10 by Veale et al. (2010), when compared with the work of Potter et al. from 1996–97, indicates the following key changes:

- the colonisation of two tropical species of hardyhead
- the numbers of three goby species may be declining (e.g. the southern longfin goby, which ranked first in abundance and contributed to 36.5% of the total number of fishes caught in 1994, ranked only sixth and contributed to 8.1% in 2008–10), possibly due to the detrimental effects of benthic change.

Veale et al. (2010) thus suggest the Leschenault Estuary's benthic environment may be deteriorating and recommend further investigations and monitoring of benthic macroinvertebrate populations.

Small fish species also use the estuary as a spawning habitat, mainly in summer, and typically have a one-year cycle. Thus they are highly vulnerable to water quality decline, apoxia and toxic algal blooms.

The estuary also supports plankton, diatoms, foraminiferal fauna, molluscs, small benthic and epibenthic crustaceans, polychaetes, ophiuroids and the blue manna crab, *Portunus pelagicus.* Key issues and knowledge to date include:

- According to Semeniuk et al. (2000), the foraminiferal fauna in the estuary is exceptional, with extremely high diversity. The 118 species recorded to date exceeds most normal marine environments and is believed to be of global significance.
- Molluscs, small benthic and epibenthic crustaceans and polychaetes are showing decreases in population abundance commensurate with the decrease in seagrass cover throughout the estuary – documented by Wurm and Semeniuk (2000) between 1982 and 1997. The benthic fauna is the major food source for most fish in the estuary (Brearley 2005) and depends on the right flora of microscopic and larger algae, seagrasses and dead plant material or detritus.
- Ophiuroids are present in high numbers.

- The blue manna crab, *Portunus pelagicus,* is an important species within the estuary. The highest numbers occur between late spring through summer and into early autumn when salinities and water temperatures are at their highest. This species is described by Veal et al. (2010) to exhibit considerable variation in the timing and strength of recruitment and to display interannual variation in estuarine recruitment – factors likely influenced as much by conditions in the marine waters as in the estuary itself.
- The benthic invertebrates and fish found in the estuary are an important food source for wading birds and bottlenose dolphins, which feed off a range of fish within the estuary and estuarine reaches of the lower Collie, Preston and Brunswick rivers.

Birds

The Leschenault Estuary is an extremely important habitat for avifauna internationally, nationally and regionally. The natural setting of the estuary, its large size, the Leschenault Peninsula and the outlying wetlands provide a heterogeneous array of habitats that attracts a very large number and variety of waterbirds (Raines et al. 2001). Within the estuary itself, the shallow water and associated mudflats during low tide provide a variety of food sources (Cresswell 2000). The area is known to host at any one time up to 5000 permanent and migratory birds (Cresswell 2000). In total 130 bird species (listed in Appendix C) have been recorded on the estuary's western shore, in the Leschenault Peninsula Conservation Park and the area abutting it alone. Raines et al. (2000) carried out a 14-month study during 1987 and 1988 in collaboration with Birds Australia. They found the Leschenault Estuary was an important avifauna location and likely to be a critical component of the wetland network used by waterbirds within southern Western Australia. Indeed the estuary is a dry season refuge (mid spring and summer) for waterbirds, ranks among the top wetlands in the state's south-west in terms of numbers and richness of waterbird species (Semeniuk et al. 2000a), and is included in international migratory bird agreements. It is during the dry season that the greatest waterbird numbers occur (Raines et al. 2000). The Department of Conservation and Land Management (CALM, now DEC) (1998) recorded 62 species in the estuary and associated wetlands, of which 18 species were JAMBA- and CAMBA-listed and using the estuary along their migratory routes.

The estuary's northern section (north of Belvidere), which consists of extensive areas of samphire surrounded by closed sedgeland, was identified by CALM (1998) as being of high conservation value as habitat for waterbirds. This area is also important as a bird refuge between mid spring and late summer, due to freshwater seepages (CALM 1998) that create local freshwater to brackish pools in high tidal marshes that are used by avifauna and mammals alike. Other important feeding sites are the deltas of the Preston and Collie rivers.

Raines et al. (2000) determined that waterbirds used most habitats within the estuary and outlying wetlands for unique purposes, which highlights the importance of preserving all foreshore habitats and outlying wetlands around the estuary. For instance, while the open water habitats (e.g. sandbars and shallow water) in the estuary support the larger part of the waterbird population and are mostly used for feeding, the fringing wetland habitats (e.g. wet and dry saltmarshes and pools) support a greater density and larger variety of waterbirds. These wetlands are used equally for feeding and roosting and support significant breeding (Raines et al. 2000).

It is important to note that the outlying wetlands adjoining the estuary on the coastal plain – such as Myalup and Benger swamps and the Kemerton wetland suites – appear to be a complementary part of a wider Leschenault Estuary wetland system. Benger Swamp and the Kemerton wetland suites support a large variety of species, including five species not recorded in the estuary. An observed 70% of all breeding activity occurs in the outlying wetlands.

Figure 2-3: Nesting site for ibis (left); habitat for wading birds (right) (photos: Mike Whitehead)

Ecological values of the rivers

The waterways are important for supporting freshwater-dependent ecosystems and associated biota. The Brunswick, Preston and Collie rivers support native fish species and invertebrates such as the marron (*Cherax tenuimanus*) and the native freshwater mussel (*Westralunio carteri)*, which all require good water quality and habitat conditions. *W. carteri* is currently listed as Priority 4 under the DEC Wildlife Conservation (Specially Protected Fauna) Notice 2008 and as Vulnerable under the International Union for Conservation of Nature red list of threatened species. Siltation and secondary salinisation are responsible for the mussel's decline. This species and other invertebrates are vulnerable to water pollutants and sedimentation (de Graaf et al. 2010; Wetland and Research Management 2009b) but also low rainfall, reduced surface and groundwater inflow and environmental degradation. Fish, marrons and mussels are an important food source of a range of animals such as birds, water rats (*Hydromys chrysogaster)* and the long-neck tortoise (*Chelonida oblonga*).

A survey of the fish fauna at nine sites in the Brunswick River and sites in the upper Collie River (Morgan & Beatty 2006) found four of the eight endemic freshwater fish species recorded in the south-west – nightfish, western pygmy perch, western minnow and freshwater cobbler. The first three species were widespread across the basin, while the last was found at only a few sites in the Brunswick River, but the report notes the species is found throughout the Collie basin. A survey of the fish fauna at seven sites in the Preston River basin (Morgan & Beatty 2006) found four of the eight endemic freshwater fish species – nightfish, western pygmy perch, western minnow and freshwater cobbler.

Table 2-1: Summary of key ecological values of the Leschenault Estuary

Value	Description
Geological	• Unique because it is the only estuary in the south-west formed behind a shore-parallel dune barrier and wholly Holocene in age. Other estuaries in the south-west have Pleistocene ancestry. • Regionally significant because of the geomorphic setting and estuarine style (Semeniuk et al. 2000a) and nationally significant in terms of geoheritage (Semeniuk & Whithers 2000). • Point Douro, at the mouth of the Collie River, is described by WAPC (2005b) as being of geoheritage significance, standing out as a unique estuarine delta which is not present in other intra-estuarine deltas in Western Australia.
Scientific education  *Royal Society Science Week (photo: Joanna Hugues-Dit-Ciles*)	• Important for palynology. • Classic area for studies of the ecology of estuarine peripheral vegetation, with the system ranking as one of the most significant in southern and south-western Australia (Semeniuk et al. 2000). • Peripheral to the estuary is a complex of shore and wetland types as described by Pen et al. (2000).
Biodiversity	• Three species of seagrass and seven species of macroalgae (Semeniuk et al. 2000). • A rich array of invertebrates: 31 species of molluscs, 21 species of small benthic crustaceans and several species of larger crustaceans including the blue manna crab (*Portunus pelagicus*), 15 species of polychaete and a normally oceanic ophiuroid echinoderm (Semeniuk et al. 2000a). • Forty-two species of fish recorded in the shallow and nearshore water. The estuary contains a high abundance of fish species whose entire lifecycle is confined to the estuary. • The foraminiferal fauna has been identified as exceptional with 118 species recorded: this is unusually rich and diverse for an estuary and potentially of global significance (Semeniuk et al. 2000a). • The state's southern-most occurrence of the white mangrove, *Avicennia marina.* • Supports 18 species of JAMBA and CAMBA migratory birds and in total 50 waterbird species, as well as a total of 130 bird species.

Value	Description
Peripheral vegetation and habitat  *Samphire along Buffalo Road (photo: Mike McKenna, DoW 2007)*	• The varied nature of the Leschenault Estuary's shores results in an array of peripheral vegetation, which has been identified as being of state significance (Pen et al. 2000). • Numerous tidal and subtidal benthic habitats. • Two areas of the estuary – the northern part (north of Waterloo Head) and Vittoria Bay near The Cut – are considered to be very important areas for waterbirds and mangroves and worthy of marine nature reserve status (CALM 1998), as well as being of high conservation value in carrying a very extensive area of samphire surrounded by closed sedgelands – providing an important habitat for waterbirds (EPA 1983). • The Collie River islands (Bar, Snake and Alexander) provide a refuge for both local and migratory waterbirds (WRC 2001). Bar Island is a particularly good habitat for seabirds such as cormorants, banded stilts, pelicans, gulls, great egrets, white faced herons, terns, oyster catchers, black swans and black ducks.
Seagrass beds  *Halophila ovalis* (photo: Joanna Hugues-dit-Ciles)	• Three species of seagrass: *Halophila ovalis, Ruppia megacarpa* and *Heterozostera tasmanica*. • *H. ovalis* is the most widespread species in the estuary, inhabiting western and eastern platforms, and the subtidal muddy northern flat. *R. megacarpa* inhabits shallow intertidal depressions (Semeniuk et al. 2000a). • Important fish nursery and provide a food source for plant-eating waterfowl (Hodgkins et al. 1979). *Note: as reported by Semeniuk et al. (2000), benthic fauna and seagrass cover were relatively abundant at the start of the biota surveys over the period 1982–87, and appear to have declined towards 1987. In 1997–98 seagrass and invertebrate fauna again were in low abundance.*
White mangrove: *Avicennia marina*  *Mangroves in the Leschenault Inlet (photo: Ben Deeley)*	• Small remnant stands and relic of an earlier tropical period and the only area south of Shark Bay (EPA 1993). • The presence of this species in the estuary and inlet is scientifically important in the region and is a feature of national significance, given it is the southern-most occurrence in the state (Semeniuk & Withers 2000).

<table>
<tr><th>Value</th><th>Description</th></tr>
<tr><td>Birds

Pelicans (photo: Joanna Hugues-Dit-Ciles)

White egret (photo: Mike Whitehead)</td><td>• The estuary and associated wetlands are of considerable importance for waterbirds, with more than 62 species recorded (CALM 1998).
• Up to 5000 birds are present at any one time on the open water and fringing tidal salt marsh and the estuary (Brearley 2005).
• Eighteen species of JAMBA and CAMBA migratory birds and in total 50 waterbird species.
• The estuary ranks from a state perspective in:
- the top 5% of wetlands of importance to waterbirds in terms of species richness, richness of species scheduled under international migratory bird agreements and median numbers of waterbirds (Raines et al. 2000)
- the top 10% of wetlands in terms of numbers of waterbirds scheduled on international migratory bird agreements (Raines et al. 2000)
- the top 15 % for maximum numbers of waterbirds counted in any one survey (Raines et al. 2000)
- the top 1% of wetlands of importance for numbers of Caspian tern (Sterna caspia) (Raines et al. 2000)
- second-largest summer population of pelicans (Schwinghammer 1978) of all the estuaries from Perth to Esperance
- in the top 5% wetlands of importance for numbers of Australian pelican (Pelicanus conspicillatus), little pied cormorant (Phalacrocorax melanoleucos), darter (Anhiga melanogaster), Australian shelduck (Tadorna tadornoides), common greenshank (Tringa nebularia) and silver gull (Larus novaehollandiae)
- the top 5% of ranked wetlands in southern Western Australia in terms of median numbers of waterbirds, reflecting its constant use
- the second-largest white egret population of any estuary in south-western Australia (Schwinghammer 1978; EPA 1993) although more recent observations suggest breeding sites have been unused for the past decade.</td></tr>
<tr><td>Bottlenose dolphins (Tursiop sp.)

Photo: Holly Smith, Murdoch University</td><td>• Bottlenose dolphins are known to spend time in the Leschenault Estuary, inlet and lower section of the Collie and Preston rivers.
• The dolphin deaths in 2009 and more recently in December 2010 are a cause for concern. Maintaining the health of the estuary and its associated waterways is important to ensure a healthy dolphin population.</td></tr>
</table>

Appendix B provides further information on the ecological values of the Leschenault catchment's rivers.

2.2.2 Social and economic values

Aesthetic value and land value

The estuary is important aesthetically within the *Greater Bunbury region scheme* (GBRS). It provides an important scenic backdrop for the localities of Leschenault and Australind, as well as a large number of housing developments constructed along its eastern shores and on the floodplains of the lower Collie and Brunswick rivers. Properties along the estuary, and the waterways with views of the water, are highly sought after and attract many people to live in the area.

Tourism and amenity values

Tourism in south-west Western Australia is primarily focused around the coast, its estuaries and coastal waterways. The Leschenault Estuary, Leschenault Inlet and their associated foreshores provide a major recreational hub for the population of the GBRS area (Waterways Commission 1992) as well as visitors to the region (WAWRC 1987) (see Figure 2-4). Yet water resources suitable for recreational purposes are diminishing, thus the preservation of existing regional recreational assets is of great importance.

The recreational areas surrounding the estuary and the Collie, Brunswick and Wellesley rivers, which are mostly public open space, Crown land reserves or shire reserves (under System 6 and the GBRS), may eventually be managed under the auspices of a regional park (presently being considered under the revised GBRS). A small section of the lower Preston River within the GBRS is already considered within the 'Ocean to Preston River Regional Park' and is recognised for its potential as an important recreational public open space.

The Leschenault Peninsula Conservation Park, Cathedral Avenue foreshore, Pelican Point and the shores of the lower Collie and Brunswick rivers are at present the key recreational assets abutting the Leschenault Estuary and are well used by local residents and tourists alike, who enjoy a range of public facilities such as playgrounds, picnic tables, walking trails, toilets, barbecues, boat ramps and fishing platforms. The water-related activities include swimming, canoeing, kayaking, kite- and wind-surfing, crabbing and fishing.

The main recreational sites tend to be located in the lower reaches of the rivers and the estuary, which are also the areas where most algal bloom incidents and fish kills take place. To continue using the rivers and estuary for water-related activities, these areas must have water that meets appropriate health quality standards.

The growing regional population will result in heavier use of these assets by local residents and visitors alike, which will require careful management.

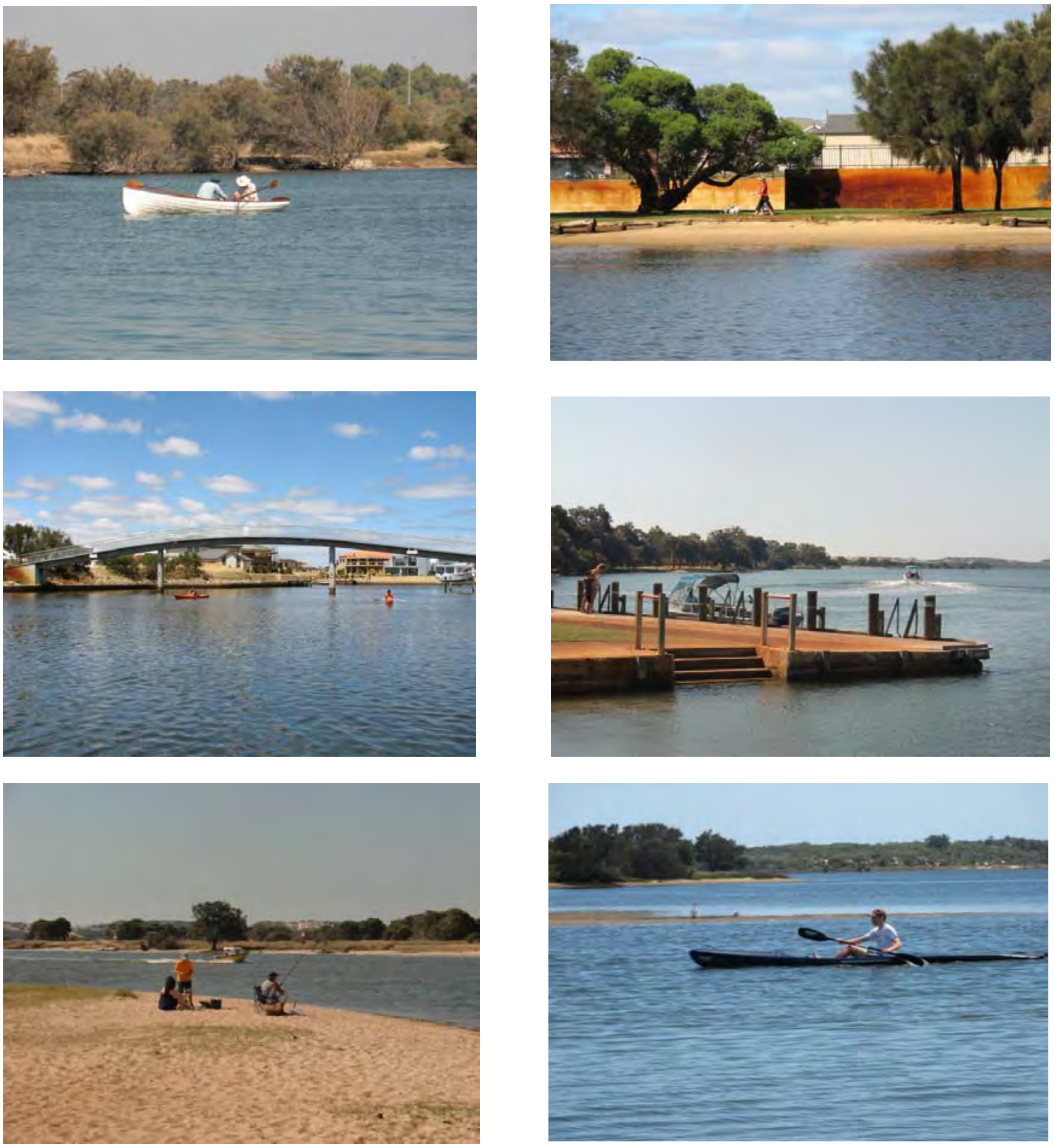


Figure 2-4: Recreational activities in the Leschenault Estuary (photos: Joanna Hugues-dit-Ciles)

Bottlenose dolphins (Tursiop *sp.*)

The Leschenault Estuary and Inlet, and the lower Collie, Brunswick and Preston rivers, are important home ranges of local resident bottlenose dolphins. Research carried out between 2007–09 – dolphin population monitoring, abundance and habitat modelling – in a study area between Binningup and Peppermint Grove (including Leschenault Estuary and Inlet) informed scientists that out of the 129 sightings recorded (Figure 2-5), 50 individuals were sighted in the estuary and of that 17 used the estuary almost exclusively (rarely venturing out into Koombana Bay and beyond). Those 17 included seven adult males, five juveniles and five calves (Holly Smith, Murdoch University PhD candidate, pers. comm. February 2010).

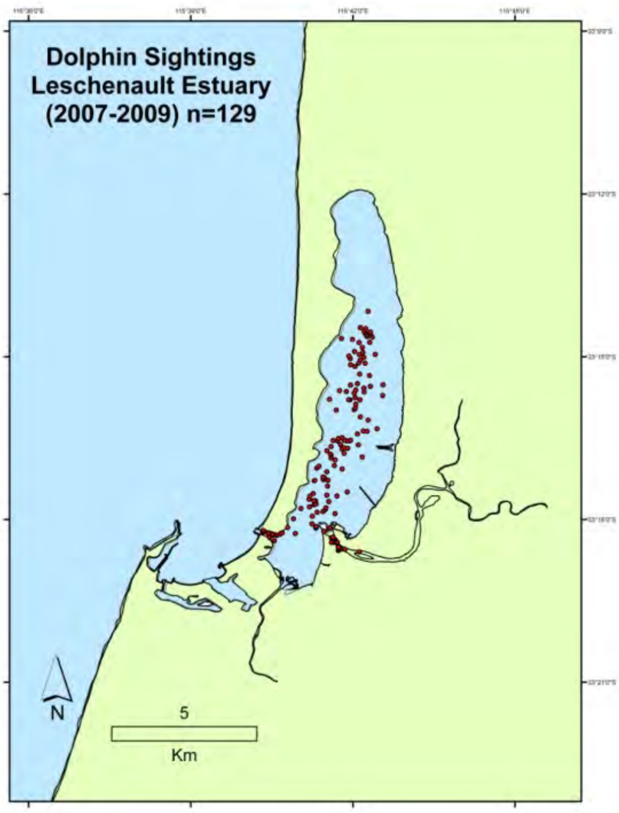


Figure 2-5: Sightings of dolphins between 2007–09 in the estuary and Preston and Brunswick rivers (map: courtesy Holly Smith, PhD candidate, Murdoch University)

This charismatic species is a tourism drawcard for south-west Western Australia and thus an economic asset to the region. Bunbury is known internationally for its dolphin population and many tourism guidebooks list dolphins as its key attraction. The Dolphin Discovery Centre attracts around 60 000 international, national and regional visitors annually – bringing an estimated $10 million income into the local economy (Phil Coulthard, Dolphin Discovery Centre, pers. comm. April 2010). Other tourism operators are also centred around dolphins: the Bunbury dolphin tours (includes estuary and Collie River), Bunbury snorkelling tours and a kayaking rental operator.

The dolphin deaths in 2009 and more recently in December 2010 are cause for concern. Maintaining the health of the estuary and its associated waterways is important to ensure a healthy dolphin population.

Commercial and recreational fishery

In the 19th century commercial fishing began in the Leschenault Estuary, persisting through the 20th century until 2001 when the government bought back commercial fishing licences (Lenanton 2003). Up to 1998, the estuary was an important commercial fishery, with an estimated catch of up to 85 tonnes/year (Malseed et al. 2000).

Recreational fishing (17 targeted species) and crabbing are now regular activities on the estuary. This brings significant economic returns to the Bunbury area by drawing many visitors (local, regional and interstate) (Malseed et al. 2000). Crabbing is the biggest drawcard of the recreational fishing industry. A 1998 creel survey (animals caught) (Malseed et al. 2000) indicated that 86% of boat-based recreation was targeting blue manna crabs and 88% of shore-based recreation was also targeting the crabs – amounting to a total of 48 tonnes of blue crabs being caught in 1998. Ensuring the estuary's ecological viability will enable this sought-after species to maintain its current and future population.

The marron fishery is an iconic and important licensed recreational fishery for the state's south-west (de Graaf et al. 2010). This is particularly true for rivers in the Leschenault catchment. Indeed de Graaf et al. (2010) indicate that approximately 60% of river fishing effort is focused on four rivers in the south-west – one of them being the Collie (the others being the Warren, Blackwood and Murray). The authors also found that the critical factors influencing the marron's range through time was due to environmental factors (e.g. declining rainfall in the south-west) and anthropogenic impacts (loss of in-stream and riparian habitat, broadscale land clearing, development of land for agriculture and surface water management, as well as clearing of land in the upper catchments of rivers leading to salinisation of the water beyond the marron's tolerance level.

Other economic values afforded by the waterways

WAPC has declared the Harvey Water Irrigation Area (HWIA) to be an area of state significance to agriculture (Harvey Water 2008). Most of the Leschenault catchment is irrigated from the Collie River which feeds the Wellington Dam, from which water is supplied through the Collie Irrigation Scheme to the HWIA. Harvey Water(2009) estimate that HWIA accounts for 40% of the irrigation area in WA. In addition to dairy, the HWIA also supports beef grazing and horticulture.

Figure 2-6: Irrigation channel in the Lower Collie catchment (photo: Joanna Hugues-Dit-Ciles)

In the Preston catchment, the Glen Mervyn Dam located on Lyalls Mill Stream (a tributary of the Preston River) supplies irrigation water to more than 60 commercial growers and a number of domestic users located along the river between the dam and Argyle. It is estimated this irrigation water sustains a $10 million dollar horticulture industry. This regionally significant dam is also used for recreational purposes and activities include water-skiing, swimming, fishing, picnicking and camping.

The catchment waterways also provide drinking water for beef and dairy cattle throughout the catchment.

2.2.3 Summary of key values of the estuary and its associated waterways

Appendix B records the environmental values for each individual subcatchment, while Appendix D describes the sites of international, national, state and regional significance discussed in the preceding section.

Overall the Leschenault Estuary:

- is unique in southern Western Australia because it is the only estuary formed behind a shore-parallel dune barrier and wholly Holocene in age
- has an estuarine hydrologic structure different to other local estuaries given it does not have a simple river-to-sea gradient
- is potentially globally significant for its microfauna (foraminifera diversity)
- supports 18 species of JAMBA- and CAMBA-listed migratory birds by providing habitat along their migratory path
- provides habitat for breeding and a dry season refuge for many numbers and species of waterbirds
- is nationally significant for its geoheritage and being the southern-most occurrence of the white mangrove
- is of statewide significance for its peripheral vegetation
- is the aesthetic backdrop for Bunbury, Australind and Leschenault
- supports a wide range of recreational activities (picnicking, swimming, fishing, crabbing, wind- and kite-surfing, canoeing, kayaking and boating).

Most recreational activities and supporting commercial operations are ecosystem-based, including fishing, crabbing, bird watching, boating (including kayaking and canoeing), tourism and educational activities. The ecosystem health of the estuarine waters supports these beneficial activities but is also affected by them. Monitoring and protecting ecosystem health will ensure recreational activities can continue.

3 Leschenault Estuary and waterways condition

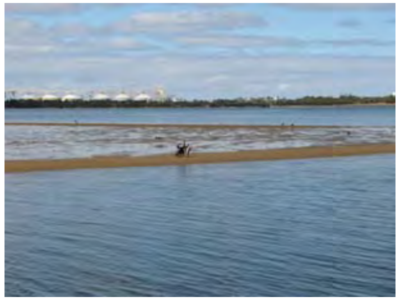
3.1 A history of water quality decline

Public concerns for water quality in the estuary and associated waterways are not recent and have been documented in various publications (DoW 2005; McKenna 2007; Waterways Commission 1992). As early as 1965 the Bunbury and Districts Water Advisory Committee was formed to preserve the purity of the estuary's waters and improve its foreshores (Waterways Commission 1992). This group was the precursor to the Leschenault Inlet Management Authority (LIMA), a statutory body created by the state government in 1977 to administer the *Waterways Conservation Act 1976*. The proclaimed area for management under this Act included the estuary and margins, the lower reaches of the waterways (except the Preston River) and a small portion of the catchment. In 2000, a small group named the Leschenault Inlet and Estuary Restoration Group was formed in response to siltation and water quality concerns (McKenna & Derrington 2005), but it later dissipated. LIMA was repealed in 2000 by Machinery of Government reforms, however the members amalgamated with the Leschenault Catchment Coordinating Group to form the Leschenault Catchment Council (LCC) which is an incorporated non-statutory organisation.

The environmental and water quality issues are summarised in Table 3-1 and discussed in the following sections. Most of the algal blooms and fish kills have been caused by episodic events: summer storms and first flushes that cause material (e.g. organic wastes, fertilisers and eroded sediments accumulated in the drains and paddocks) to be washed into the waterways, with its subsequent decay resulting in low oxygen concentrations (Richard Pickett, DoW, pers. comm; McKenna & Derrington 2005, unpublished).

Table 3-1: Environmental conditions of concern in the Leschenault Estuary (information extracted from McKenna 2004; Hills et al. 1991; Ramsay 2006; McCombe et al. 2001; Wurm & Semeniuk 2000; Donohue et al. 1994; McKenna & Derrington 2005, unpublished; Klemm 1989; Semeniuk V & C 2005a and 2005b).

<table>
<tr><th>Environmental issue</th><th>Summary of issue</th></tr>
<tr><td colspan="2">Leschenault Estuary</td></tr>
<tr><td>Water quality
</td><td>• Before The Cut, the system was mostly brackish during winter. However, the increased marine exchange through The Cut has resulted in the estuary becoming predominantly marine.
• Salinity concentrations are higher in the estuary’s northern part: in summer this area becomes hypersaline.
• Reduction of freshwater input as a result of the Wellington and other dams in the catchment restricting flows.
• Competitive water demand between the environment and human use.
• Reduction of catchment runoff due to climate change and declining rainfall.
• Reduction of freshwater flushing from rivers in the estuary has resulted in more prolonged salt wedges. Stratification of the water column results in areas becoming hypoxic or anoxic, which leads to the release of nutrients from the bottom sediments and thus provides conditions favouring algal blooms and fish death.
• Nutrient enrichment has led to the loss of seagrass over large areas due to the decrease in water clarity and smothering due to increased algae biomass.

Picture: The Cut (photo: Joanna Hugues-Dit-Ciles).</td></tr>
<tr><td>Sedimentation
</td><td>• Increased sedimentation.
• Estuary has a high sediment-trapping capacity: this affects aquatic life and the distribution of aquatic plant and associated fauna.
• Hills et al. (1991) report a higher calcium content in the estuary sediments compared with those from other south-west systems, and this might reduce the potential for phosphorus release from these sediments.
• Organic enrichment of surface sediment is higher than in the Peel Harvey and comparable with part of the eutrophic Harvey Estuary (McComb et al. 2001).
• Rate of phosphorus release in the water column is low compared with the Peel Harvey and Swan Canning (McComb et al. 2001).
• Potential for sediment phosphorus release is believed to be relatively small in the estuary following studies between 1988–90 (McCombe et al. 2001).

Picture: Sand bar at the mouth of the Collie River (photo: Ken Okamitsu, LCC, Nov 2010)</td></tr>
</table>

Loss of fringing vegetation along the estuary 	• Significant and ongoing loss of fringing vegetation as a consequence of urbanisation and unregulated public access. • Between 1941 and 1989 half of the original fringing vegetation was lost (350 ha) via clearing for development. • This was reduced by half again following development of the Pelican Point canals and the Lakes Estate as well as the further development of land around Bunbury Port. • This ongoing and incremental habitat loss is likely to have a significant impact on the estuary's ecosystems and the fauna depending on them, in particular waterbirds. *Picture: Ongoing native vegetation clearing along the estuary for industrial development – in this case less than 5 m from the water's edge (photo: Joanna Hugues-Dit-Ciles)*
Loss of aquatic vegetation and associated biota	• Donohue et al. (1994) reported a macrophyte biomass composed of a healthy mix of seagrass and macroalgae, indicating that water quality was good – particularly in comparison with the Peel-Harvey and Swan-Canning systems. However, they also reported fluctuations in the mixture of macroalgae in the northern half, suggesting a response to greater nutrient levels. • A detailed comparative study carried out in 2005 by Semeniuk V and C (2005b) using long-term data (1982–87) showed significant changes in the estuary's ecology: - decline in macrophyte (seagrass and macroalgae) total biomass, with seagrass generally in low abundance and at some sites absent within the estuary (compared with previous studies) and *Halophila ovalis* dominating - decrease in biodiversity and invertebrate fauna with fundamental changes in the assemblages of molluscs, polychaetes and crustaceans (mollusc species declined from 31 to three at 21 sampling sites; polychaete species declined from 15 species to six species recorded). • This decreasing trend is consistent with a previous study by Wurm and Semeniuk (2000) who also observed a link between the decrease in invertebrates and macrophytes from comparative surveys undertaken in April 1997 and May 1998, and 1982–87. • Semeniuk et al. (2000a) suggest that changes in the estuarine biotic assemblages are due to the greater marine influence after The Cut was constructed, medium-term changes in the volume of runoff, and changes in hydrochemistry and nutrient concentrations.

Algal bloom 	• 1988: significant algal bloom with nuisance macroalgae *Rhizoclonium* (McKenna & Derrington 2005, unpublished) and *Cladophora* for over a week in Victoria Bay (Waterways Commission 1992). Similar phytoplankton blooms were also recorded in 1987 and 1989 (Waterways Commission 1992). • 1994: large summer blooms of dinoflagellates (red tides) and diatoms. • Reports of nuisance algae have taken place since 1995 (McKenna & Derrington 2005, unpublished). • Chlorophyll-a concentrations from 2000–06 ranged from undetectable limits of <0.0005 mg/L to the extreme value of 0.092 mg/L in the lower Preston River (30 times greater than the recommended ANZECC guideline). • In October 2009 a large algal bloom occurred along the estuary's north and eastern shores, dominated by non-toxic algae *Cladophora ruppia*, *Ulva* sp., *Rhizoclonium* sp. and *Enteromorpha* sp. • *Dynophysis acuminata* were detected in October and November 2008, and August 2010, above recommended levels of 3 cells/mL (Christine Webb, DoW, pers. comm.) *PIcture: Algal bloom (non-toxic) on the Leschenault Estuary (photo: Mike Whitehead, October 2009)*
Collie River	
Water quality 	• Reduction of flows and flushing capacity due to the Wellington Dam, resulting in the greater extent and duration of a salt wedge (McKenna & Derrington 2005, unpublished). During summer a salt wedge travels some 4 km up the Collie River. • Physico-chemical and biological signs of nutrient enrichment. • Lower reach is generally oxygen depleted (Ramsey 2006), reflecting significantly diminished mixing and the predominance of saline stratification. • Saline stratification prevents oxygen exchange between surface and bottom waters, promoting anoxia of bottom waters. • Decomposition of organic material washed from episodic storms consumes remaining oxygen, depleting levels below 5 mg/L and in extreme cases below the 2 mg/L critical to the river's ecology. Common occurrence leading to fish kills. • Severe anoxia drives the release of ammonium which, in turn, has the potential to convert to ammonia which is highly toxic and potentially lethal to stream ecology (McKenna 2004). • Lower Collie acts as a sink for sediment and nutrient discharges from incoming rivers (Brunswick and Wellesley) (McKenna 2004). *Picture: Wellington Dam scour release (photo: Joanna Hugues-Dit-Ciles)*
Algal bloom	• Algal blooms occur in most years (Ramsey 2006). • Phytoplankton blooms of *Heterosigma akshiwo* (potentially a fish-killing species) occurred near the confluence with the Brunswick in April and May 1994 (McComb et al. 2001).

<table>
<tr><td>Fish kills
</td><td>

May and June 1994: large fish kill of thousands of black bream and other estuarine fish in the lower Brunswick and lower Collie linked to oxidation of acid sulfate soils (Rose 2004).
1999: large fish kill possibly due to extreme turbidity and suspended solids (Rose 2004).
June 2002: approximately 10 fish dead – deaths likely due to a minor sewerage spill and a substantial rain event flushing the system. Thirty to 40 fish seen gasping at the surface. High organic material, low salinity, low oxygen, increased bacteria number.
June 2003: approximately 50 fish dead – deaths likely due to a Karlodinium micrum bloom in response to organic loading after a storm event.
May 2004: approximately 450–500 fish dead in lower Collie and Brunswick rivers: likely due to a combination of Listonella anguillarium bacterial infections, K. micrum bloom, potential acid sulfate soil pulse and organic inputs in response to a storm event.

Picture: Fish kill in 2004 (photo: DoW)</td></tr>
<tr><td>River foreshore
</td><td>

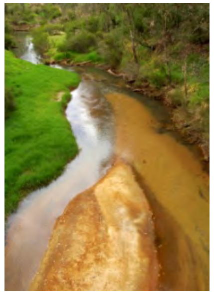
Limited riparian vegetation.
Degraded riparian vegetation.
Bank erosion resulting in nutrient input and sedimentation.

Picture: Lower Collie foreshore near Eaton showing degraded riparian vegetation (photo: Ken Okamitsu, LCC)</td></tr>
<tr><td colspan="2" align="center">Brunswick River</td></tr>
<tr><td>Water quality
</td><td>

1999: extreme turbidity in the lower reaches believed responsible for a fish kill, with high suspended solids recorded.
Evidence of nutrient enrichment with phosphorus particularly in the Wellesley (Donohue 1994).
Lower reach generally oxygen depleted (Ramsey 2006), described to have bottom waters in a state of chronic hypoxia by Rose (2004), reflecting significantly diminished mixing and the predominance of saline stratification.
Lower Brunswick has excessive nutrients, which is a permanent feature (except for winter and early spring) resulting in algal blooms in most years (Ramsey 2006; Rose 2004).

Wellesley River, main tributary to the Brunswick, showing impacts of uncontrolled cattle access (photo: Mike McKenna, DoW)</td></tr>
</table>

Algal bloom	• First river in Western Australia with a harmful dinoflagellate present. • Sampling from 2000–06 in the lower Brunswick found chlorophyll-a concentrations more than 80% of the time exceeded the ANZECC trigger value with an average sample concentration approaching 0.014 mg/L. • Algal blooms most years in summer and autumn (Ramsey 2006) with diatom and *Dinophyta* species dominant, in particular the dinoflagellate *Karlodinium micrum*, which is potentially a fish-killing species. Some of these blooms had densities exceeding 50 000 cells/mL. Emergence of harmful cyanophytes. • Shift away from diatom-dominated systems to larger presence of *Dinophyta* species.
Fish kills 	• May and June 1994: large fish kill of thousands of black bream and other estuarine fish in lower Brunswick and lower Collie linked to oxidation of acid sulfate soils (Rose 2004). • 1999: extensive fish kill due to extreme turbidity (Rose 2004). • May 2002: approximately 90 fish dead; deaths likely due to first flush causing high organic matter, sediment loads and low oxygen after a storm event (McKenna 2007). • May 2004: approximately 2 tonnes of fish dead in lower Collie and lower Brunswick likely due to a combination of *Listonella anguillarium* bacterial infections, *Karlodinium micrum* bloom, potential acid sulfate soil pulse and organic inputs in response to storm events. • Summer 2002 and 2004: fish kills following storm events, with an occurrence of *L. anguillarium* which contributed to the deaths (Ramsey 2006). *Fish kill (photo: Christine Webb, DoW, 2004)*
Foreshore vegetation degradation and sedimentation 	• Brunswick River is a highly degraded system. • Minimal foreshore is fenced, with associated stock and grazing pressure degrading both the banks, and decline of the native understorey and foreshore vegetation (Taylor 2006). • Due to sediments from catchment and riverbank erosion, the river pools of the Brunswick River are now all full of sediment. Historical mapping by Commander Stokes in 1841 indicate these pools were 2–5 m deep with interconnecting shallows (DoE circa 2003). Leads to loss of pools for summer refuge. *Picture: Brunswick River foreshore near South West Highway (photo: Ken Okamitsu, LCC, December 2010)*

Preston River	
Water quality 	• Lower reach generally oxygen depleted (Ramsey 2006), reflecting significantly diminished mixing and the predominance of saline stratification. Saline stratification prevents oxygen exchange between surface and bottom waters, promoting anoxia of bottom waters. • Decomposition of organic material washed from episodic storms consumes remaining oxygen, depleting concentrations below 5 mg/L and in extreme cases below 2 mg/L critical to the river's ecology. Common occurrence leading to fish kills (Ramsey 2006). • The Preston River is one of the few remaining larger rivers in southern Western Australia not unduly impacted by secondary salinisation (Water Corporation 2002). • Sedimentation arising from river foreshore erosion and land erosion in the catchment. *Picture: Sediment bar on the Preston River (photo: LCC)*
Algal blooms 	• A significant algal bloom was recorded near Lowden in summer 1997 (Water Corporation 2002). • Between 2000–06 chlorophyll-a concentrations reached extreme values of 0.092 mg/L in the river's lower part (Ramsay 2006). • Summer and autumn blooms, typically presenting as variations in the water colouration from common blooms of *Chrysophyta* species. • Middle and lower reaches of the river unsatisfactory from spring to autumn with frequent potentially toxic algal blooms. Species of concern are potentially ichthyotoxic fish-killing species and *Prorocentrum cordatum,* which can cause diarrhetic shellfish poisoning in humans. *Picture: Karlodinium micrum (photo: Sarah Grigo, DoW)*
Fish kills	• None yet recorded (McKenna 2007).
Other contaminants	Dieldrin contamination in the 1980s. A study of the river's waters by Atkins in 1980–81 showed Dieldrin levels were among the highest in rivers in south-western Australia: the heavy use of these chemicals for horticulture was blamed for the levels found. A follow-up study in 1985–86 showed a decrease in organochlorine residue in the river (Klemm 1989) as it became diluted out of the system after its use decreased before deregistration in 1987.
Redirection of the Preston River 	• The proposed redirection of the river associated with the Bunbury Port expansion would potentially affect sedimentation levels, acid sulfate soils, turbidity and water quality within the new channel and the deltaic habitat as the receiving environment. *Map showing the proposed redirection of the Preston River to the right of its present location (map extracted from Thomson McRobert Edgeloe 2007).*

Foreshore vegetation degradation and sedimentation	• Serious habitat and foreshore degradation, and decline of *Eucalyptus rudis* as a result of several interrelated factors including increased salinity, infestation with leaf miner, dieback and clearing. • Severe erosion and bank collapse along the waterway as a result of mostly agricultural and farming pursuits.  *Dying trees on the Preston River*  *Severe bank erosion issue along the Preston River (photos: Cathie Derrington)*
Leschenault Inlet	
Water quality and algae 	• Heavy metals, metalloids and nutrients found in sediment likely derived from urban drainage. • Nutrient accumulation in sediments above average levels; 2005 snapshot survey showing elevated levels (Semeniuk V and C 2005a). • Occasional blooms of low toxicity with harmless diatoms *Skeletonema, Chaetoceros* and *Asterionella* sp. Presence of harmless dinoflagellates *Katodinium, Oxyrrhis* and *Peridinium* sp. • Prolific growth of macroalgae in the summer months. • High tidal exchange prevents the accumulation of elevated soluble nutrient concentrations within the water column. *Picture: Urban drainage in an industrial area in Bunbury ending in the inlet (photo: Joanna Hugues-Dit-Ciles)*
Land use pressure 	• The inlet is surrounded by intensive urban land use, housing and industrial developments. Thus the inlet is highly modified with a high proportion being artificially retained; remnant foreshore is only associated with the mangrove population on the northern foreshore. *Leschenault Inlet surrounded by urban residential and industrial areas, including Bunbury Port (photo: Joanna Hugues-Dit-Ciles)*

3.2 Current water quality condition

In the previous section environmental and water quality issues were discussed. As a basis for the WQIP, the current condition of the estuary and the estuarine portions of the rivers were assessed against national and international benchmarks.

Estuaries are complex dynamic environments responding to large changes in seasonal salinity and temperature. Each estuary will respond to nutrient inputs differently – depending on shape, size, depth, river flows, ocean connectivity and so on. Determining estuary condition requires examination of the various functional areas to determine:

- whether the ecosystem is maintaining its biodiversity
- whether it is stable in its biological and chemical processes over time
- whether it is resilient to change.

Based on the current understanding of the estuaries of south-west Western Australia, it is known that considering nutrient concentrations alone is not enough to determine the estuary's health. The degree to which nutrients are stored and processed in the sediment and the rate at which nutrients are taken up and transported in biological growth such as algae and seagrass is relevant. For example, in some cases low nutrient concentrations in estuarine waters may simply mean the nutrients have been taken up into algae and the estuary is experiencing nuisance algal blooms.

The term 'eutrophication' is used to describe a waterbody where high concentrations of nutrients have led to increases in plant growth, sometimes to the point of collapse. To account for this, more recent approaches to determining eutrophic status not only consider nutrient concentrations but also dissolved oxygen (DO) concentrations and algal and plant growth.

Department of Water monitoring and investigation programs for the Leschenault Estuary and the estuarine sections of the Collie, Brunswick and Preston rivers have focused on estuarine water quality, catchment water quality, sediment nutrient processes, and micro and macroalgal observations – from which the condition of the estuary can be assessed.

3.2.1 Estuarine water quality

The water quality of the Leschenault Estuary and estuarine sections of the Collie, Brunswick and Preston rivers was monitored at the sites shown in Figure 3-1 and listed in Table 3-2.

For assessing ecosystem integrity, the ANZECC (2000) guidelines focus on the structural components of aquatic communities (biodiversity) and key ecological processes (e.g. community metabolism). However, the guidelines recognise that chemical and physical water quality variables are important surrogates for assessing and/or protecting ecosystem integrity, and thus provide guidelines for chemical and physical water quality indicators as well as biological indicators. The guideline values are considered to be 'trigger values' for ecosystem protection. If a waterbody's water quality reaches a 'trigger value' then a management response to improve the water quality or at least stop it from getting worse should be put in place. The default ANZECC guideline values for chlorophyll-a, nutrients, DO and acidity (pH) for south Western Australia are listed in Table 3-3. The median values of data collected at the estuary sites (Figure 3-1) are shown in Table 3-4.

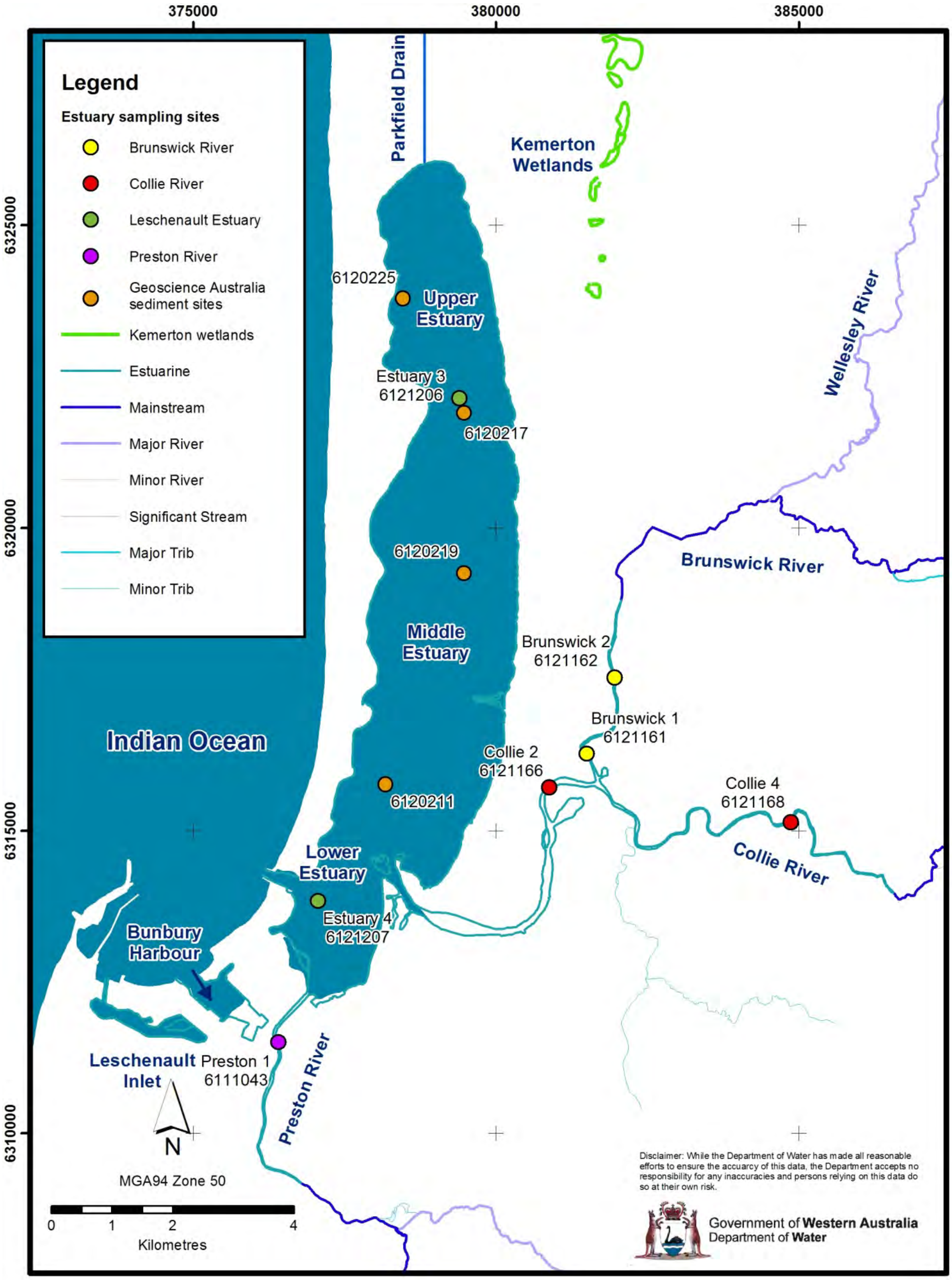


Figure 3-1: Leschenault Estuary, waterways and wetlands showing the estuary water quality sampling stations

Table 3-2: Estuary sampling sites

AWRC number	AWRC context	AWRC name
6121206	Leschenault Estuary	Est3
6121207	Leschenault Estuary	Est4
6121161	Brunswick River	Brunswick 1
6121162	Brunswick River	Brunswick 2
6121166	Collie River	Collie 2
6121168	Collie River	Collie 4
6111043	Preston River	Preston 1

Table 3-3: ANZECC trigger values for south Western Australia

Ecosystem type		*Chl a* (µg/L)	TP (µg/L)	FRP-P (µg/L)	TN (µg/L)	NOx-N (µg/L)	NH_4^+-N (µg/L)	DO (%)		pH	
								Lower limit	Upper limit	Lower limit	Upper limit
Upland river[a]		na	20	10	450	200	60	90	na	6.5	8
Lowland river[a]		3–5	65	40	1200	150	80	80	120	6.5	8
Freshwater lakes and reservoirs		3–5	10	5	350	10	10	90	no data	6.5	8
Wetlands[b]		30	60	30	1500	100	40	90	120	7.0[c]	8.5[c]
Estuaries		3	30	5	750	45	40	90	110	7.5	8.5
Marine	Inshore[d]	0.7	20[e]	5[e]	230	5	5	90	na	8	8.4
	Offshore	0.3[e]	20[e]	5	230	5	5	90	na	8.2	8.2

na = not applicable

FRP= filterable reactive phosphorus

a=all values derived during base river flow conditions, not storm events

b=elevated nutrient concentrations in highly coloured wetlands do not appear to stimulate algal growth

c=in highly coloured wetlands pH typically ranges 4.5–6.5

d=inshore waters defined as coastal lagoons (excluding estuaries and embayments and waters < 20m deep

e=summer (low rainfall) values, values higher in winter for Chl a (1.0 µg/L), TP (40 µg P/L), FRP (40 µg P/L)

Table 3-4: Comparison between estuary water quality data (median values) and the ANZECC guidelines. Salinity data also included. Data collected weekly, fortnightly or monthly from 1996 to 2010, mostly in the dry season.

		Chl a	**TP**	**FRP-P**	**TN**	**NOx-**	**NH_4^+-N**	**DO (%)**		**pH**		**Salinity**
		(µg/L)	**(µg/L)**	**(µg/L)**	**(µg/L)**	**(µg/L)**	**(µg/L)**	**Lower limit**	**Upper limit**	**Lower limit**	**Upper limit**	**(g/L)**
ANZECC guideline value		3	30	5	750	45	40	90	110	7.5	8.5	
6121206	Median	0.7	20	< 5	390	<10	26	25[1]	133[2]	8.0		40.4
(Estuary 3)	# samples	195	180	106	192	106	87	# days sampled 239		427		384
								# days < 90 93				
6121207	Median	< 1	19	< 5	220	<10	9	53[1]	131[2]	8.0		36.8
(Estuary 4)	# samples	153	164	86	175	85	111	# days sampled 132		417		375
								# days < 90 94				
6111043	Median	3.2	30	3	440	20	30	44[1]	148[2]	7.7		23
(Preston 1)	# samples	197	187	95	199	95	126	# days sampled 250		842		261
								# days < 90 144				
6121166	Median	6.9	70	8	775	41	105	1.2[1]	193[2]	7.6		31.6
(Collie 2)	# samples	200	193	103	204	103	206	# days sampled 995		1292		1149
								# days < 90 625				
6121168	Median	2.2	30	2.5	510	32	84	1.5[1]	200[2]	6.9		21.7
(Collie 4)	# samples	190	177	92	189	93	151	# days sampled 147		642		565
								# days < 90 142				
6121161	Median	6	90	16.5	980	90	67	0[1]	178[2]	7.3		12.3
(Brunswick 1)	# samples	176	173	108	184	108	132	# days sampled 288		363		342
								# days < 90 234				
6121162	Median	5	110	26	1100	155	48	0[1]	155[2]	7.4		1.2
(Brunswick 2)	# samples	175	192	132	191	132	136	# days sampled 170				132
								# days < 90 119				

[1] *minimum value observed*

[2] *maximum value observed*

The median values for data from the two sites in the main estuary comply with the ANZECC guidelines, except for DO. Many of the median values for the sites in the estuarine sections of the rivers exceed the ANZECC guidelines. The two sites in the Brunswick River estuary and Collie 2 (6121166) in the Collie River estuary have very poor water quality. They exceed the chlorophyll-a guideline by a factor of two, have high median nitrogen and phosphorus concentrations and periods of anoxia or hypoxia. The high ammonium concentrations most likely indicate sediment release of ammonia in low oxygen conditions.

However, many of the ecological problems in the Leschenault Estuary and estuarine reaches of the rivers are seasonal and not captured by examination of median values of all data. The lower Collie and Brunswick rivers have very poor water quality for most of summer and autumn. DO and salinity data are discussed in more detail below, followed by nutrient and algal data.

Dissolved oxygen and salinity

Before the 1950s, the Leschenault Estuary was connected to the ocean at its southern end by a narrow channel that discharged into Koombana Bay at Point McLeod. In winter the estuary would have been relatively fresh because it received runoff from the Collie and Preston rivers and drainage from the north.

Since construction of The Cut, the estuary has been a predominantly marine system. Salinities in the estuary vary between 30 and 45 ppt (seawater is 35 ppt). In the estuarine reaches of the Collie, Preston and Brunswick rivers salinities are more variable: from less than 10 to 35 ppt depending on river flows. The median values for the Brunswick River (Table 3-4) estuarine sites indicate these sites are less saline than the other sites.

The salt wedge is the interface between sea water pushed into the estuary by winds and tides and the fresh water from the rivers. Areas of the estuary that are not ‘well mixed’ become ‘salinity stratified’ with the lighter fresh water sitting on the more dense salt water. In summer, the salt wedge moves up the estuarine reaches of the rivers and these areas can become strongly stratified. In contrast, salinity stratification is less prevalent in the main body of the estuary, which is shallow and generally well mixed by the wind. Surface and bottom salinity data for the dry season are shown in Figure 3-2. The salinity stratification is clearly seen at all the river sites and is also apparent at Estuary 4 near The Cut.

The salinity gradient (south to north) in the main body of the Leschenault Estuary is uncharacteristic of permanently open estuaries due to its long narrow shape and the location of the Collie and Preston river inflows on its south side opposite The Cut. The river flows result in lower salinity conditions near the ocean entrance than in the middle and upper estuary. In summer, the upper estuary is affected by high rates of evaporation and can be hypersaline (>35 ppt) compared with the marine salinities of the lower estuary (Brearley 2005). The median salinity value (Table 3-4) is 40.4 ppt in the upper estuary and 36.8 ppt (similar to sea water) in the lower estuary near The Cut.

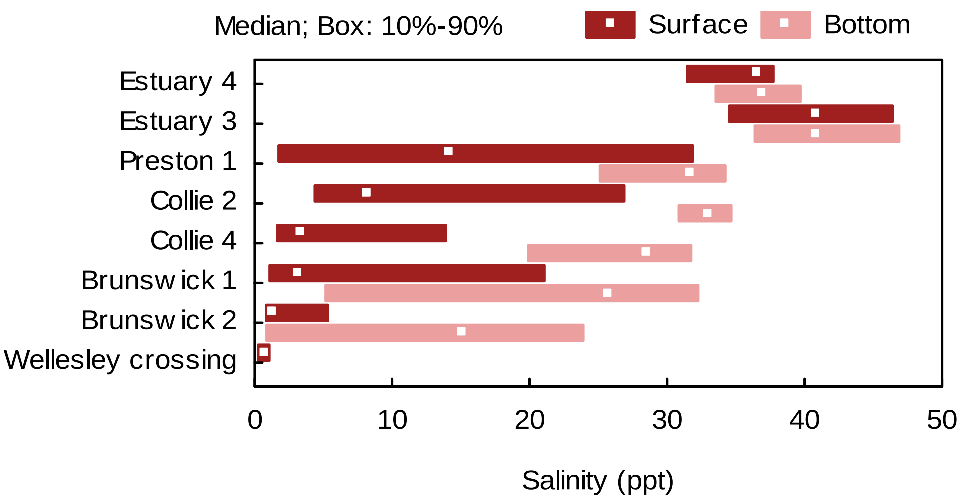


Figure 3-2: Median (point) and 80% of data for surface and bottom salinity for monitored sites in the estuary and estuarine reaches of the rivers. Data collected October to May (dry season) during 2006 to 2009.

Salinity and temperature stratification reduces water circulation and bottom waters can become depleted of oxygen due to breakdown of organic matter within the sediments.

Estuaries and rivers with large organic loadings frequently suffer oxygen depletion as sediment organic matter is decomposed by aerobic bacteria. Widespread de-oxygenation can also occur as algal blooms die and decompose.

Water oxygenation depends inversely on temperature and salinity. That is, the greater the water temperature and salinity, the lower the oxygen content. For this reason, the ANZECC guidelines give the DO guideline values as per cent saturation, with the acceptable range being between 90 and 110%.

For the data collected, the upper estuary site (Estuary 3) was generally well oxygenated, on a per cent saturation basis (shallow and well-mixed water column) whereas the lower estuary site (Estuary 4) had oxygen per cent saturation of less than 90% on 94 of the 132 days sampled, which indicates geochemical processes in this part of the estuary are consuming oxygen. The estuarine sites in the rivers also have many days of DO per cent saturation of less than 90%. The consequence of low DO in the lower Collie and Brunswick rivers on several occasions is summarised in Table 3-1.

However, fish and other biota are sensitive to the water oxygen concentration. At concentrations of less than 4 mg/L, considered hypoxic, biota become stressed. The surface and bottom oxygen concentrations for the sample sites are shown in Figure 3-3. Bottom waters have lower oxygen concentrations than surface waters at all sites. However, the differences between surface and bottom oxygen concentrations are greatest at the two sites in the Collie River and at Brunswick 1. This is the area of the estuary with the poorest water quality.

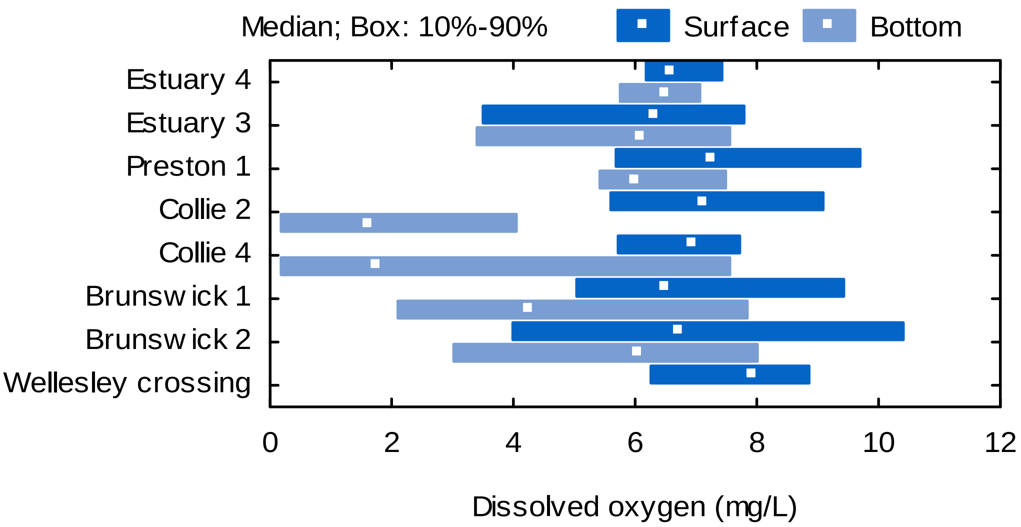


Figure 3-3: Median (point) and 80% of data for surface and bottom dissolved oxygen concentrations. Data collected from October to May (dry season) during 2006 to 2009.

Nutrients background information

Nutrients in estuaries are primarily derived from the catchment – from urban and agricultural runoff. Recycling processes within the estuary can also contribute to nutrient concentrations.

Nitrogen (N) and phosphorus (P) are two nutrients that are routinely monitored in estuaries due to their importance to plant growth. Each of these nutrients occurs in either a dissolved or particulate form and may be inorganic or organic in nature.

Total nitrogen (TN) and total phosphorus (TP) include all forms (inorganic and organic, dissolved and particulate) of N and P in the water column. Measures of inorganic nutrients include dissolved nutrients such as ammonium (NH4+), nitrate/nitrite (NO3+/ NO2+) and soluble phosphate or filterable/soluble reactive phosphorus (PO4-). These inorganic dissolved nutrients are readily available to plants and algae for growth. Dissolved organic nutrients are measured less frequently. Dissolved organic N and P are derived from decaying plant and animal matter. These nutrients are also available to plants and algae for growth, but are not as easily processed.

Nutrients

Surface nutrient concentrations in the estuary and estuarine reaches of the Brunswick, Collie and Preston rivers are shown in Figure 3-4 for the dry (October to May) and wet (June to September) periods. The data is for the period 1998 to 2003, as this is the only period for which data was collected year-round. Recent estuary sampling programs have only sampled during the dry season.

There is a clear difference in the data, in that concentrations of inorganic nutrients are much greater in winter than summer. This indicates that large amounts of inorganic nutrients are mobilised during the winter flow season and transported to the estuary.

In summer, the Collie and Brunswick sites have higher total nutrient concentrations than in winter, with a larger proportion being organic and particulate matter, whereas the Preston estuary site has lower summer concentrations. The greater organic and particulate concentrations in the Collie and Brunswick estuarine reaches in the dry season compared with the wet season may be due to remobilisation of nutrients from the sediments, especially under low oxygen conditions.

Summer inorganic nutrient concentrations are greater at the Brunswick and Collie 2 sites than at the Collie 4 and Preston sites. This is likely due to the irrigation return flows from the Wellesley and Brunswick catchments that impact on the lower Brunswick River sites and the Collie 2 site which are downstream of the confluence of the Brunswick and Collie rivers.

In summer Estuary 3 and Estuary 4 have lower nutrient concentrations than the other sites due to greater mixing with sea water. In winter the Estuary 4 site near The Cut in the lower estuary is affected by the high nutrient river flows, whereas the Estuary 3 site in the upper estuary has the lowest nutrient concentrations of all the sites.

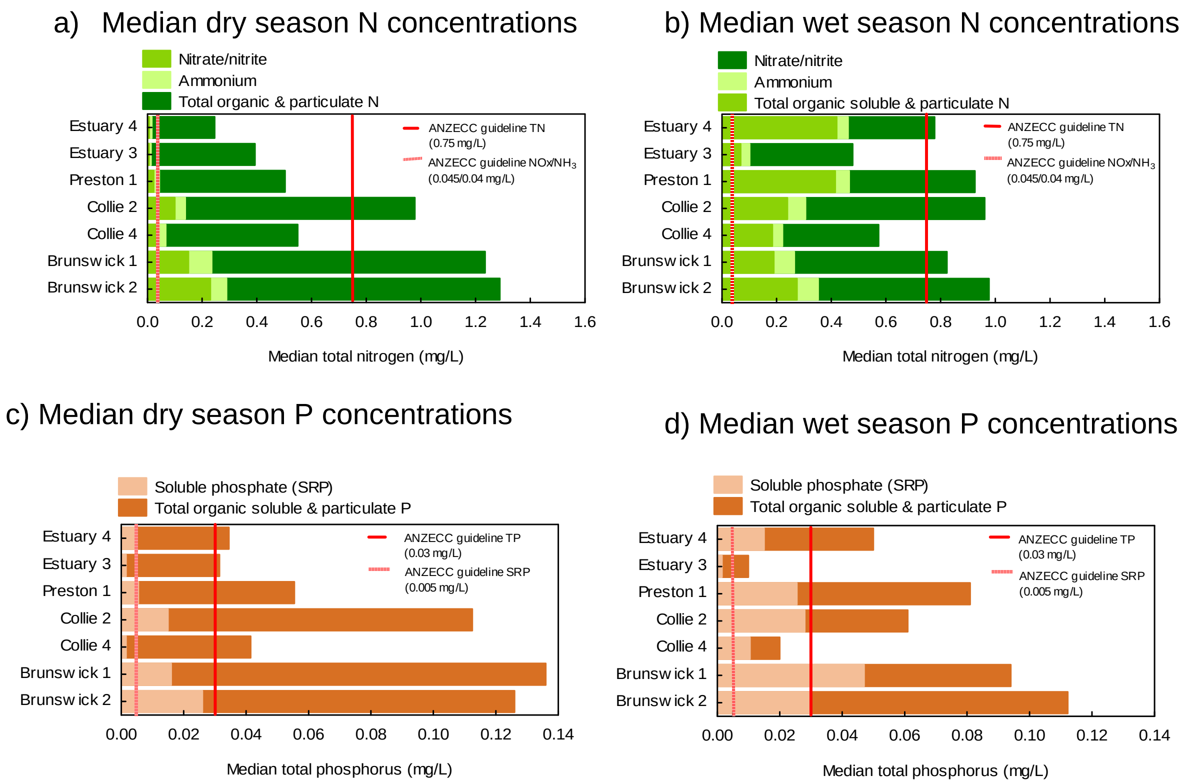


Figure 3-4: Median dry season (October to May between 1998 and 2003) and wet season (June to September between 1998 and 2003) nitrogen and phosphorus concentrations in the estuary and estuarine reaches of the Brunswick, Collie and Preston rivers. The stacked bar indicates the relative proportions of different nitrogen and phosphorus forms

The ANZECC guidelines for total nutrient concentrations are given as solid lines, and for inorganic nutrient concentrations as dotted lines in Figure 3-4. The TP ANZECC guideline value of 0.03 mg/L is exceeded at all sites in the dry season when most algal blooms occur, and at all sites except for Estuary 3 (upper estuary) and Collie 4 in the wet season. The inorganic phosphorus guideline (0.005 mg/L) is exceeded at most sites in both seasons. The pattern is similar for nitrogen, except the ANZECC TN guideline (0.75 mg/L) is exceeded at only three sites (Collie 2, Brunswick 1 and Brunswick 2) in summer, and it is in this portion of the estuary where the worst water quality problems occur.

The exceedence of ANZECC guidelines for inorganic (soluble) nitrogen and phosphorus at most of the monitored sites is of particular concern. Primary producers such as phytoplankton respond rapidly to the availability of soluble nutrients, especially in the warmer months when growth is not limited by light or temperature. Summer phytoplankton blooms are common in the lower Brunswick and Collie rivers with, in some instances, the presence of harmful algal species.

The drying and warming climate in south Western Australia will provide more periods favourable for algal growth in the estuary. The decreased river flows will have greater concentrations, as the relative contributions of low concentration flows from the upper catchment will be fewer compared with the high concentration flows from the coastal plain portion of the catchment. Increased summer rainfall also has the potential to mobilise large amounts of inorganic and organic material.

Comparisons between TN and TP concentrations in the Leschenault Estuary and other south-west estuaries are given in figures Figure 3-5 and Figure 3-6. The Leschenault values are the median of data from the sites Estuary 3, Estuary 4, Collie 2, Collie 4, Brunswick 1, Brunswick 2 and Preston 1 (Figure 3-1).

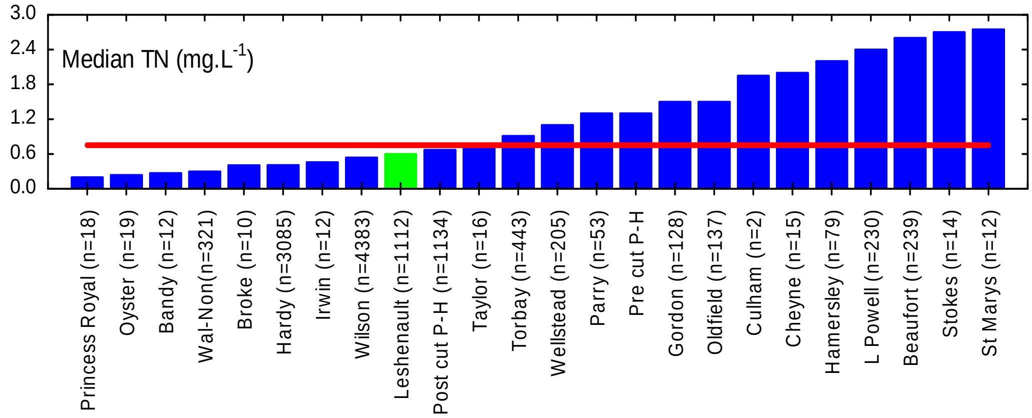


Figure 3-5: Median TN concentrations for south-west estuaries. Data includes sites in main estuary bodies and estuarine river reaches. Red line is the ANZECC TN guideline.

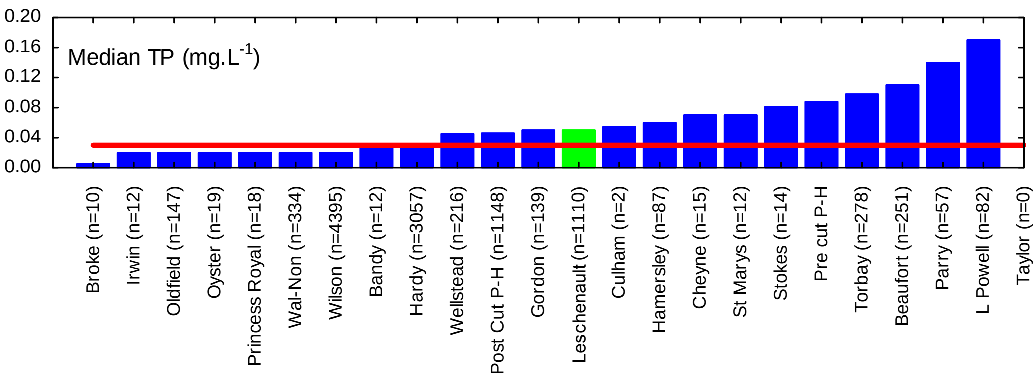


Figure 3-6: Median TP concentrations for south-west estuaries. Data includes sites in main estuary bodies and estuarine river reaches. Red line is the ANZECC TP guideline.

Algal activity

Appendix E discusses algal activity in the Leschenault Estuary. Measurements of total chlorophyll-a (Chl-a) concentration are used to assess algal activity (microalgae and cyanobacteria populations). The median Chl-a concentrations of all data for the monitored sites are listed in Table 3-4. At most of the estuarine sites in the lower rivers, the median values exceed the ANZECC guideline; whereas in the main estuary the median Chl-a concentrations are below the guideline values, due to the influence of sea water. The Chl-a seasonal concentrations for the main body of the estuary and the estuarine portions of the rivers are presented in Figure 3-8. Although the Preston River has relatively low Chl-a concentrations compared with the Collie and Brunswick rivers, its median summer concentration is above the ANZECC guideline.

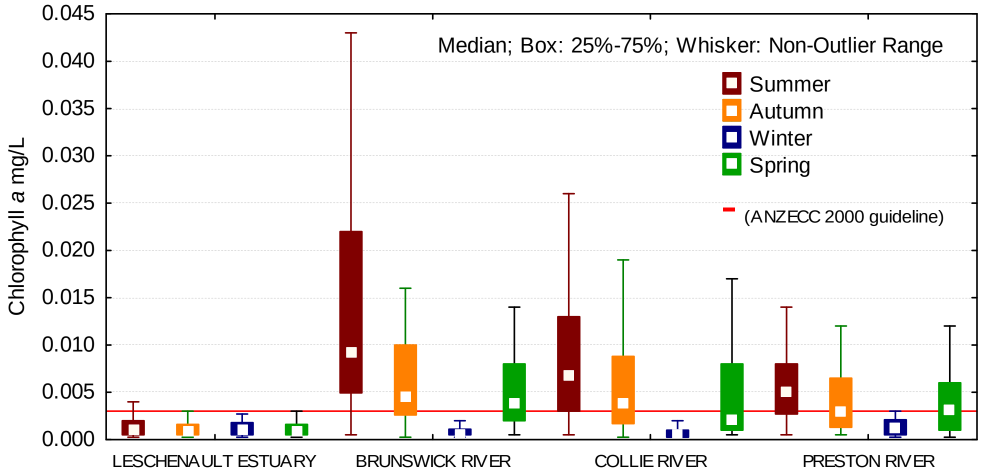


Figure 3-7: Median seasonal chlorophyll-a concentrations for the main estuary and the estuarine sections of the rivers for period 1997 to 2009

Phytoplankton assemblages in the Leschenault Estuary and the lower reaches of the Brunswick, Collie and Preston rivers consist of several groups including chlorophytes, chrysophytes, cryptophytes, diatoms and dinoflagellates. The phytoplankton assemblages follow typical patterns as shown for the Brunswick River in Figure 3-8. Assemblages of phytoplankton for the other areas of the estuary are given in Appendix E.

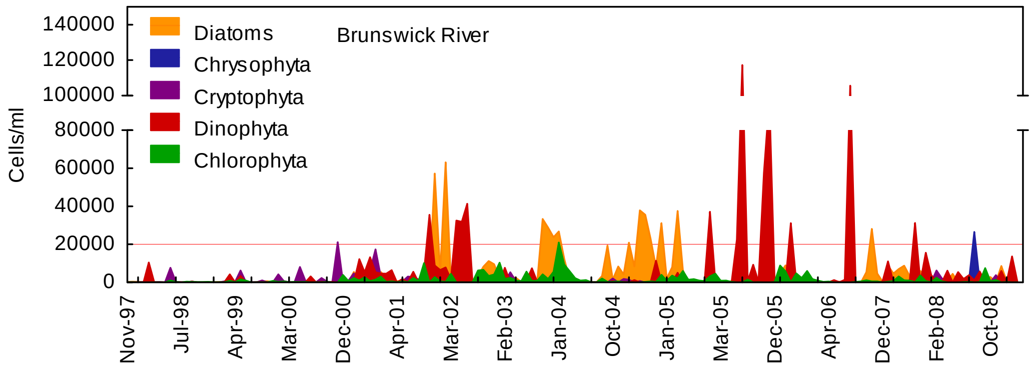


Figure 3-8: Cell densities of dominant phytoplankton groups in the Brunswick River (1997 to 2009)

Most of the algal species are not classified as harmful, although all algae cause oxygen depletion of the water column as blooms decay. However, a number of harmful algal species have been recorded in the estuary and rivers belonging to the groups known as dinoflagellates, raphidophytes, cyanophytes and prasiniophytes (Table 3-5). For these algae and cyanobacteria, densities from one to a few cells/ml depending on the species can be enough to trigger health warnings if detected in estuaries.

Table 3-5: Harmful algal species recorded in the Leschenault Estuary and its rivers.

Species	Significance	Estuary	Preston	Collie	Brunswick
	Dinoflagellates				
Dinophysis acumunata	Potential DSP (okadaic acid and derivatives, pectenotoxins) producer	Yes			
GKC-Gymnodinium/Karenia complex	Potential PSP(saxitoxins) producer				Yes
Karlodinium micrum	Potential fish-killing species. Potential NSP (brevetoxins and derivates) producer			Yes	Yes
Rhizosolenia	Potential NSP (brevetoxins and derivates) producer, developed an unpleasant bitter taste	Yes	Yes	Yes	Yes
Pfiesteria	Potential fish-killing species. Circumstantially linked to (temporary) human health problems such as skin irritation and cognitive impairment (Estuarine Associated Syndrome) through water or aerosol contact.				Yes
Prorocentrum cordatum	Forming red tide, fishy odour. Potential DSP (okadaic acid and derivates) producer.		Yes	Yes	Yes
	Raphidophyte				
Heterosigma sp.	Potential fish-killing species, brown water discolouration. Potential NSP producer	Yes	Yes	Yes	Yes
	Cyanophytes				
Oscillatoria	Potential for irritation when abundant	Yes			
Anabeana	Greenish-blue scum and odour forming at high density		Yes		
Coelosphaerum					Yes
Anabeanopsis	Microcystins. Greenish-blue scum and odour forming at high density				Yes
	Prasoinophyte				
Pyramimonas sp.			Yes		

Estuary sediment studies

Sediment background information

Estuaries are depositional environments in which sediments and nutrients accumulate. Sediments rich in organic material can contribute significantly to the availability of nutrients for plant and algal production. Organic matter consists of plant and animal material, including animal and human waste, and decomposes to release either available (nitrate, ammonium and phosphate) or less available nutrients (organic dissolved or particulate nutrients and nitrogen gas). These nutrients may either remain stored within the sediments ('nutrient sink'), be processed further or be released into the overlying water column ('nutrient source'). Nutrients such as ammonium and soluble phosphate which can be released from sediments (especially under low oxygen conditions) are readily used by primary producers such as phytoplankton.

Estuary 'health' is affected when there is an increase in organic loading and nutrient availability to the bottom sediments and overlying water column. This contributes to the process of eutrophication (nutrient enrichment) of estuaries.

Since The Cut was constructed, wave-dominated ocean processes have increased sedimentation of the lower estuary and modified the deltas to a series of channels and islands. River flow also brings sediments into the estuary. Coarser sediments are deposited around the entrance to the Collie and Preston rivers, forming tidal flats, while finer sediments are transported throughout the main basin. The Preston River delta has been modified by dredging. Bunbury Port is currently being developed and another realignment of the Preston River will begin soon.

Detailed sediment studies were conducted in the main body of the Leschenault Estuary by the Department of Water in collaboration with Geoscience Australia in 2009 (unpublished) to describe the characteristics of the sediments and the degree to which they act as sinks or sources for nutrients.

The sediment studies found sediments across most of the estuary to be organic-rich and contain large amounts of fine-grained mud (high porosity). Sediments nearer The Cut and along shallower sections of the eastern and western shorelines were lower in organic matter content and coarser in their grain-size characteristics (lower porosity). Sediment nutrient concentrations were surprisingly low, particularly given the composition of fine sediments and the high organic-matter content. Thus, sediments in the estuary do not appear to be a sink for nutrients. However, it should be noted that the study did not include the estuarine sections of the rivers, which appear to be accumulating sediment and releasing nutrients during summer when these areas are salinity stratified and suffer from low DO concentrations.

Nutrient flux studies using benthic chambers, at the sites shown in Figure 3-1, also found that the release of ammonium (NH_4), nitrate/nitrite (NO_X), phosphate (PO_3), and silica (SiO_4), carbon and oxygen from the sediments to the overlying water to be low to moderate compared with other Western Australian estuaries. The highest nutrient release rates measured were for NH_4 fluxes at the lower estuary sites. Previous studies using sediment incubations to monitor nutrient fluxes from Leschenault Estuary sediments also found nutrient release rates to be low, in particular for phosphate (McComb et al. 2001). The estuary sediments contain a substantial proportion of phosphorus bound in mineral form (apatite P), distinctly more than in the Peel-Harvey and Swan-Canning estuaries. McComb et al. (2001) suggested this contributed to the low rate of phosphorus sediment release in the Leschenault Estuary compared with the other estuaries.

The benthic chamber studies (2009) also investigated N_2 fluxes to indicate the amount of denitrification (nitrogen removal) and nitrogen fixation (additional source of nitrogen) occurring within the system. It was found that denitrification and nitrogen fixation both occur to varying degrees in the estuary, and that denitrification plays a significant role in the removal of nitrogen from the estuary.

Nitrogen fixation was mostly associated with seagrass habitats. Seagrasses like *Ruppia* have been shown to support nitrogen cycling in sediments as well as the conversion of N_2 gas to ammonium (an important plant nutrient). It is not unusual for denitrification to occur during the day and nitrogen fixation to occur at night. Many types of nitrogen-fixing bacteria are inhibited by the oxygen produced through photosynthesis, and thus restrict their nitrogen-fixing to the night time. Rates of denitrification suggest that almost all excess nitrogen in the upper estuary is being denitrified, that is, nitrogen is not accumulating in the sediments; whereas in the middle estuary sites, denitrification rates are lower and only 50% of the nitrogen is denitrified.

Plots of total CO_2 and NH_4 fluxes from the Geoscience Australia studies of south-west estuaries are shown in figures Figure 3-9 and Figure 3-10. On the continuum of estuaries from oligotrophic to eutrophic, the Leschenault Estuary is about half way. The estuary is moderately nutrient enriched (mesotrophic). However, the benthic chambers were located in the main body of the estuary and thus this data does not reflect the poor water quality and eutrophic condition of the estuarine sections of the rivers, particularly the Brunswick and Collie.

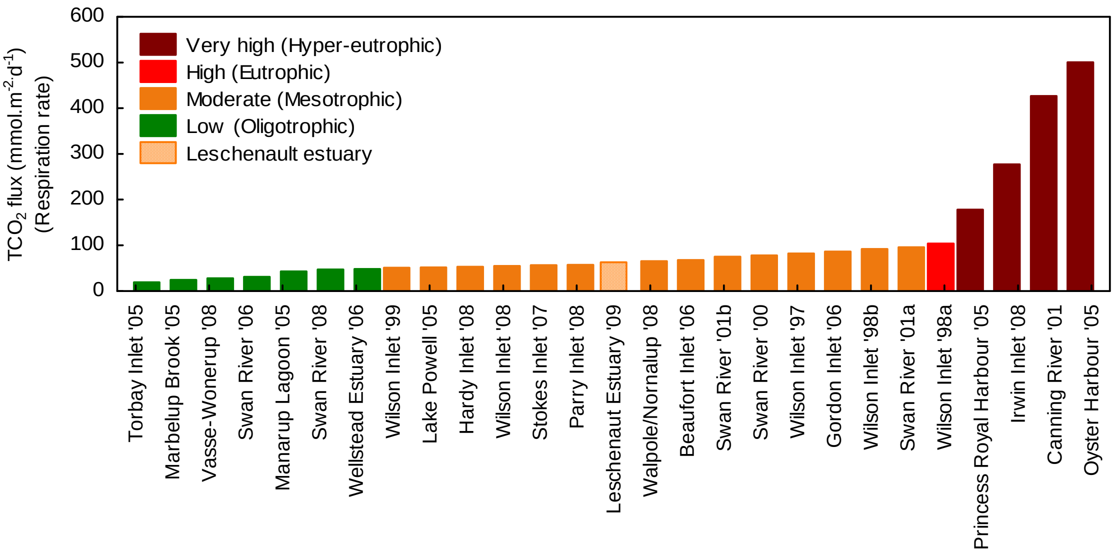


Figure 3-9: Average total CO_2 flux at the benthic chamber sites monitored by Geoscience Australia in south-west estuaries.

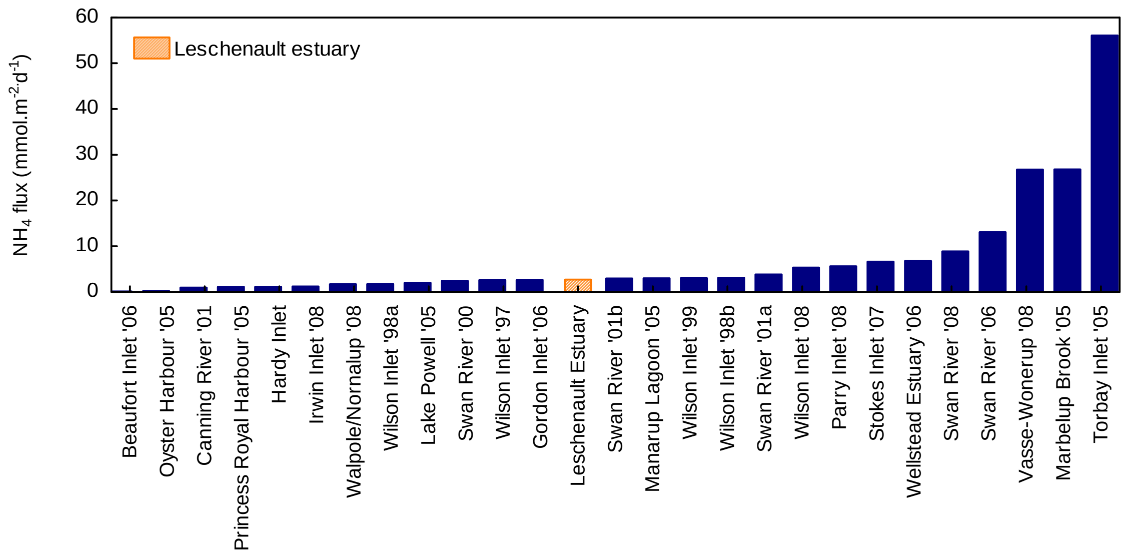


Figure 3-10: NH_4 flux at the benthic chamber sites monitored by Geoscience Australia in south-west estuaries

3.2.2 Catchment water quality

Status and trends

Water quality data collected from 42 sites within the Leschenault catchment was statistically analysed to determine current status, and identify trends in nutrient concentrations (Kelsey & Hall 2010). As a result, the current water quality status of all the Leschenault catchment's major waterways is well understood. The results of this analysis are given in Appendix F; for further information on the statistical analyses, see Kelsey and Hall (2010).

The classification scheme for TN and TP concentration status is given in Table 3-6

Sites with high and very high TN and TP classifications are extremely nutrient enriched. Site locations and nutrient status are shown in Figure 3-11. There are a few sites with changing concentrations – these are shown in the figure as a small arrow adjacent to the site (upward-pointing arrow indicates an increasing trend, downward-pointing arrow a decreasing trend). Note that trends in nutrient concentrations are difficult to detect in disturbed systems because their nutrient concentrations vary greatly depending on when samples are taken in relation to rainfall events, fertilisation application, stock movements, ploughing, harvesting and other activities.

Figure 3-11 highlights the poor water quality (nutrient enrichment) of the coastal plain streams, with most sites having high or very high status for TN and TP concentrations. This is a consequence of intensive land uses on poor nutrient-retaining soils. In contrast, on the Darling Plateau all sites have low or moderate status. However, sites with moderate status on the plateau are considered to have poor water quality because the concentrations are greater than the TN and TP ANZECC guidelines for upland rivers (Table 3-3).

Table 3-6: Classification used to assess the status of TN and TP concentrations in monitored waterways

TN	Status	TP
> 2.0 mg/L	Very high	> 0.2 mg/L
> 1.2 - 2.0 mg/L	High	> 0.08 - 0.2 mg/L
0.75 - 1.2 mg/L	Moderate	0.02 - 0.08 mg/L
< 0.75 mg/L	Low	< 0.02 mg/L

Current water quality in the Collie basin

The Wellesley subcatchment displayed high to very high TN and TP status at all sites monitored. Increasing trends in TN and TP are evident at the outlet of the subcatchment and at site 6121184 on Mangosteen Drain, indicating the water quality is deteriorating.

The lower reaches of the Brunswick and Collie rivers and their tributaries generally have moderate to high nutrient status for TN and TP. In addition, some tributaries to the main rivers have extremely high nutrient status: Elvira Gully in the Mid Brunswick subcatchment and Vindictive Drain in the Lower Collie subcatchment.

The upper reaches of the Brunswick and Collie rivers on the Darling Plateau had low concentrations of TN and TP.

Current water quality in the Preston basin

The upper Preston River on the Darling Plateau had low concentrations of TN and TP (low to moderate status). Median concentrations at most sites on the Swan Coastal Plain were moderate to very high. The high to very high status sites were on the lower Ferguson River and Crooked Brook. The lower reaches of the Preston River had moderate status for both TN and TP, due to dilution by low concentration flow from the upper catchment.

The Punch Bowl Canal site in the Coast subcatchment had very high TN status and moderate TP status.

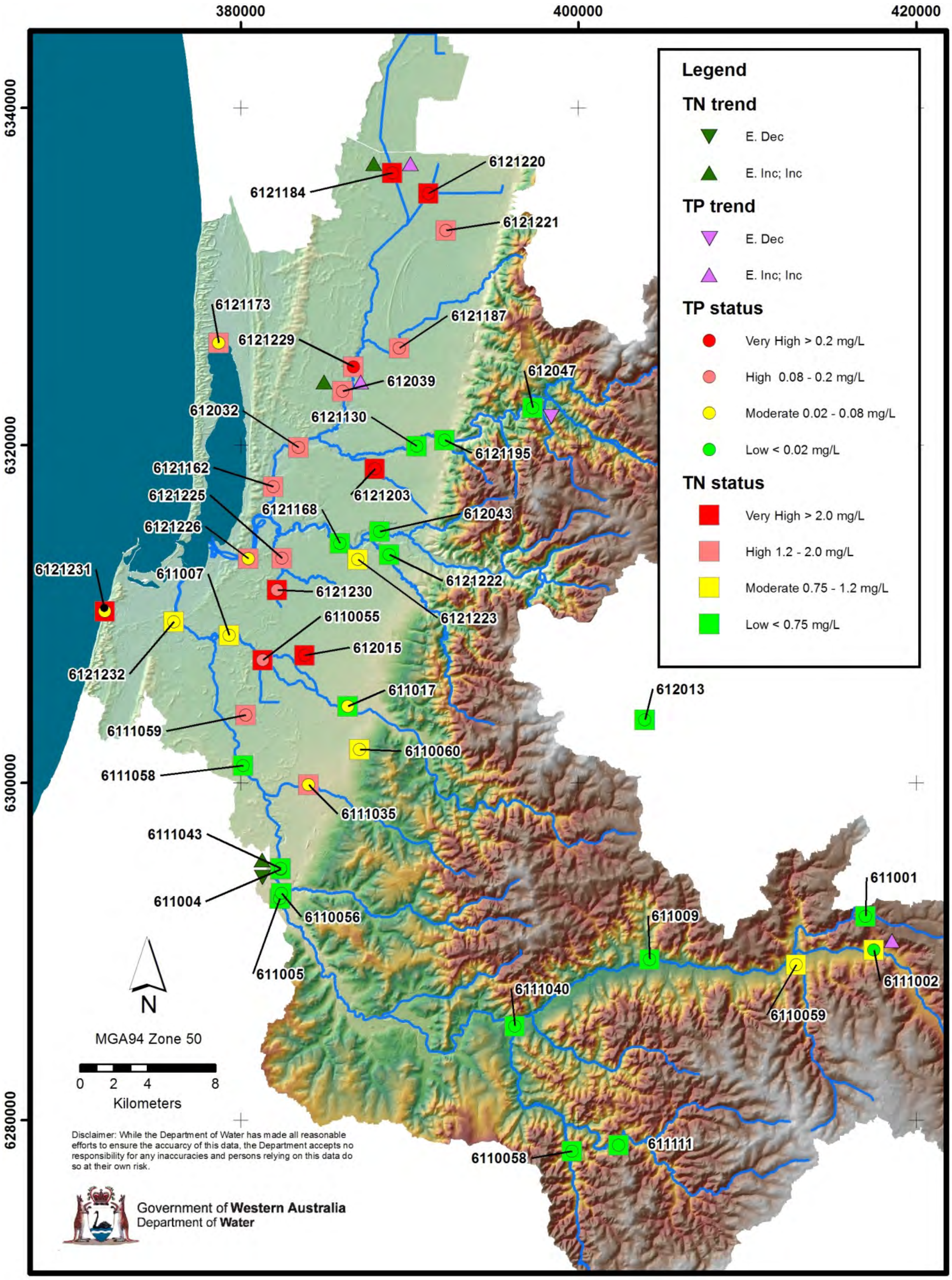


Figure 3-11: Nutrient status in the Leschenault catchment (2006–08), data sourced from Kelsey and Hall (2010). The nutrient status is assigned by using the median of nutrient concentrations over a three-year period to diminish the influence of natural variation among years. The years 2006, 2007 and 2008 were used.

3.2.3 Seasonality of nutrient concentrations

There is generally a strong correlation between nutrient concentration and flow, as shown in figures Figure 3-12 and Figure 3-13. Rainfall and flow events have the capacity to mobilise and transport sediment and contaminants, including particulate and dissolved forms of nitrogen and phosphorus. Nutrient concentrations are also generally greater at the start of the winter flow season ('first flush') than later in the year, as shown in Figure 3-14.

The time of year that nutrients are delivered to an estuary can be important in determining whether a bloom will occur. The physical conditions in winter – short days, low light and temperatures – generally inhibit algal growth. However, rainfall events in summer, for example ex-tropical cyclones, can result in nutrient- and organic-rich water discharging to the estuary at a time when physical conditions are optimum for phytoplankton growth.

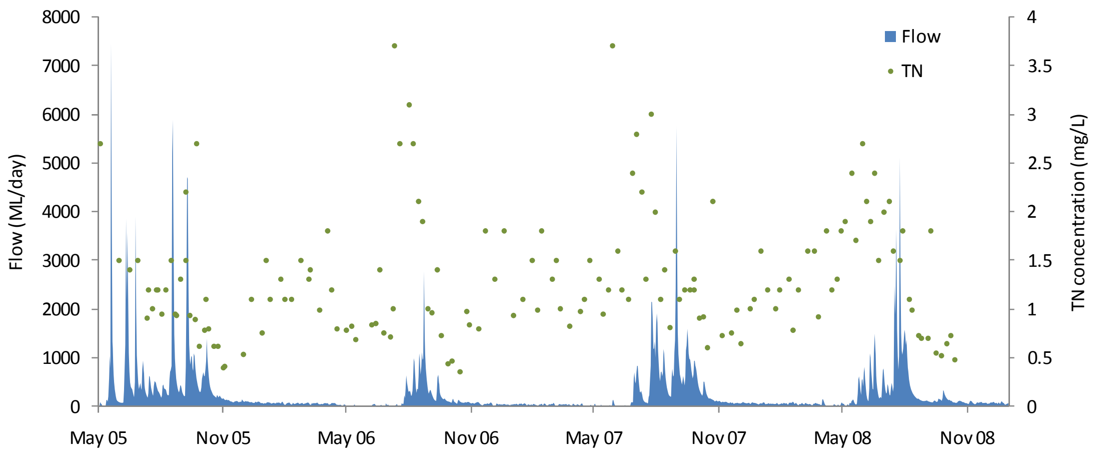


Figure 3-12: Brunswick River (612032) flow and TN concentration 2005 to 2008

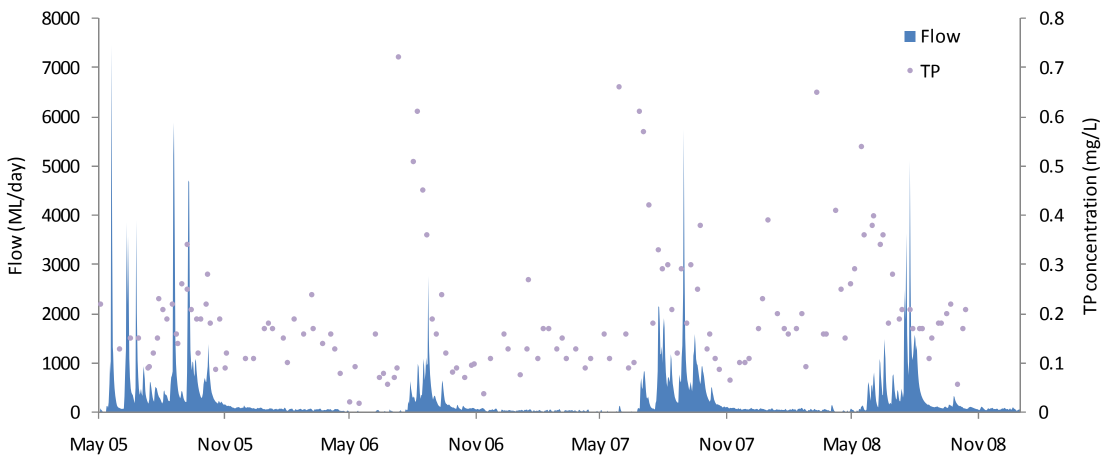


Figure 3-13: Brunswick River (612032) flow and TP concentration 2005 to 2008

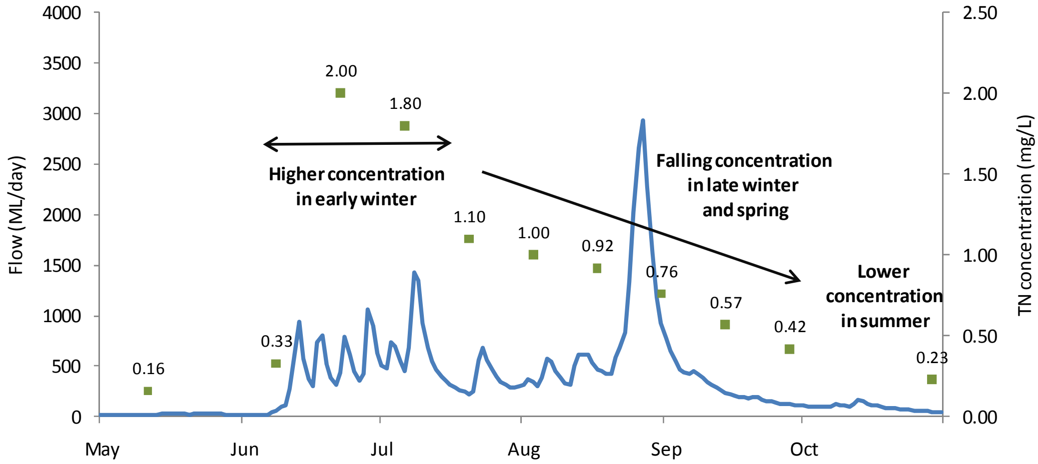


Figure 3-14: Preston River (611004) flow and TN concentration in 2004

3.2.4 Acid sulfate soil risk

Acid sulfate soil mapping

Acid sulfate soils, characterised by the presence of iron sulfides (e.g. pyrite), are formed naturally by bacterial sulfate-reduction under persistent anaerobic conditions where sulfate and degradable organic matter are present. These conditions most typically occur in low-lying, waterlogged or floodplain regions of the landscape. Currently, known acid sulfate soil distribution is confined to the Swan Coastal Plain, as shown in the acid sulfate soil risk map (Figure 3-15). Acid sulfate soil occurrences in inland areas of the catchment, to the east of the Darling Scarp, have not been fully investigated, however they are expected to be confined to permanent wetlands, lakes, pools and groundwater-discharge zones.

Acid sulfate soils do not pose an environmental risk while undisturbed within the landscape (in this state they are called potential acid sulfate soils). However, acidity is generated when the sulfide-containing soils are disturbed sufficiently to oxide the sulfide minerals (creating actual acid sulfate soils). This disturbance may be through dredging, dewatering, excavation or other processes (natural or anthropogenic) that lower the groundwater table. Predicted decreases in watertables arising from decreasing annual rainfall (CSIRO 2009a) represent a major threat to the stability of potential acid sulfate soils.

The acidity released by oxidation of the soil may also mobilise metals adsorbed on soil minerals and/or lead to the dissolution of clays, mobilising the metals therein.

Within the Leschenault catchment, a total of 117 shallow and deep soil cores were analysed for acid sulfate soils during a 2004–05 project to develop the current acid sulfate soils risk maps (Degens 2006) (Figure 3-15). Of these, 88 contained potential acid sulfate soils within 3 m of the land surface, with eight being actual acid sulfate soils. An estimated 55 900 ha of the Leschenault catchment is likely to contain potential acid sulfate soils. Of this, there is approximately 8700 ha of mostly low-lying landscape near the estuary where the soils are likely to be within 3 m of the soil surface.

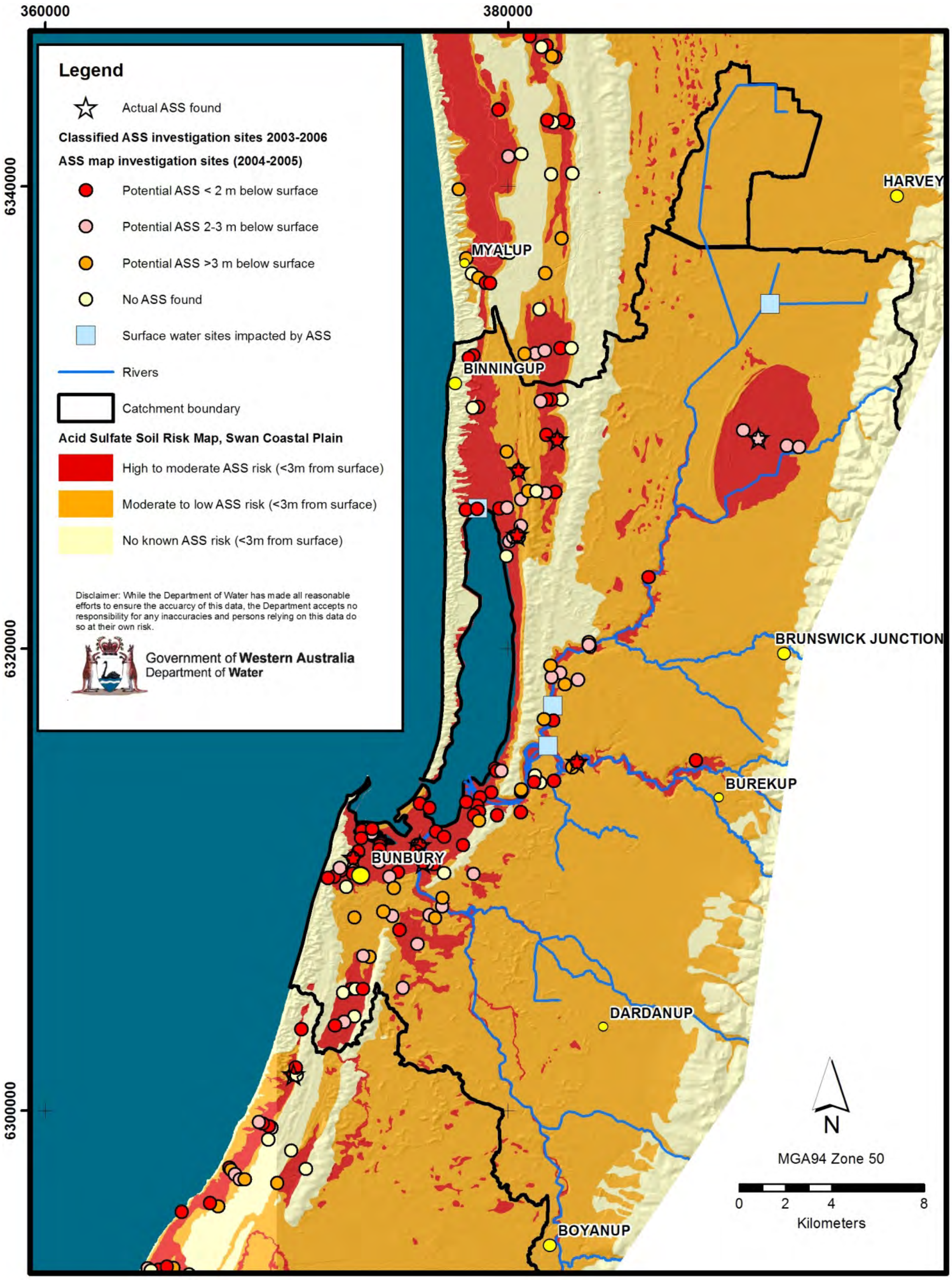


Figure 3-15: Map of the Leschenault catchment showing acid risk, locations of sampled soil, occurrences of actual acid sulfate soil and occurrences of water influenced by acid sulfate soil

Effect of acid sulfate soils on water quality

Acid sulfate soil impacts on water quality in the Leschenault Estuary and catchment tributaries were observed in a 2007 study assessing the influence of acid sulfate soils on water quality in south Western Australian catchments and estuaries (Kilminster et al. 2011). For the Leschenault region this included sampling of 10 estuarine sites and 16 catchment sites. During this study a new indicator for acid sulfate soils was developed (Kilminster & Cartwright 2011). For the Leschenault region three estuary samples and one catchment sample were identified by this indicator as being impacted by acid sulfate soils (locations of these sites are shown in Figure 3-15). Samples identified as being influenced by acid sulfate soils had higher median concentrations of many metals (Al, Co, Cr, Cu, Fe, Mn, Ni, V, Zn) than those water samples that were not.

Consequence of acid sulfate soil disturbance

Acid sulfate soil disturbance may have a range of impacts. These depend on the timing and magnitude of the acid release, and the capacity of the soil matrix to buffer this acidity. These impacts may include:

- concrete infrastructure damage
- vegetation scalds
- loss of agricultural productivity
- enhanced phosphorus leaching
- stress of terrestrial plants by metal exposure
- death of plants irrigated with affected water
- smothering of benthic aquatic animals by iron precipitates
- metal bioaccumulation in aquatic plants and animals.

A significant area around the Leschenault Estuary is underlain by acid sulfate soils. There is evidence that in some locations disturbance of these has already taken place, acidifying the soil and affecting water quality. Little is currently understood about the capacity of the Leschenault Estuary ecosystem to withstand the pressures from disturbed acid sulfate soils.

Acid sulfate soil management is a necessity due to increasing pressures on water resources, decreasing rainfall and development in areas with shallow watertables where potential acid sulfate soils are found near the surface. Poor acid sulfate soil management could have grave environmental consequences in the Leschenault Estuary and catchment tributaries.

3.2.5 Summary

Estuary

DO per cent saturation is less than the ANZECC guidelines at most sites, indicating that biogeochemical processes are consuming oxygen.

The exceedence of ANZECC guidelines for inorganic (soluble) nitrogen and phosphorus at most of the monitored sites is of particular concern. Primary producers such as phytoplankton respond rapidly to the availability of soluble nutrients, especially in the warmer months when growth is not limited by light or temperature.

Based on nutrient and DO concentrations, and algal and plant growth, the main estuary is considered moderately eutrophic and the riverine portions of the estuary are considered highly eutrophic.

The main body of the Leschenault Estuary, which is moderately nutrient enriched, has infrequent algal blooms which are diatom dominated.

The estuarine reaches of the Collie and Brunswick rivers, which are highly nutrient enriched, have frequent algal blooms in summer and autumn in response to nutrient inputs from summer river flows and release from the sediments. The Preston River estuary is less nutrient enriched but still has excess algal activity in summer.

The presence of harmful algal species in all reaches of the estuary system indicates it is under stress or at risk.

Catchment tributaries

Most tributaries on the Swan Coastal Plain have high and very high TN and TP concentrations. Some of the main rivers have lower concentrations due to relatively clean inflows from their upper catchments on the Darling Plateau.

The Wellesley subcatchment has high to very high TN and TP concentrations at all sites monitored. Increasing trends in TN and TP are evident at the outlet of the subcatchment and at site 6121184 on Mangosteen Drain, indicating the water quality is deteriorating.

Acid sulfate soils

A significant area around the Leschenault Estuary is underlain by acid sulfate soils, with evidence that some of these may be oxidising. Poor acid sulfate soil management could have grave environmental consequences in the Leschenault Estuary and catchment tributaries.

The estuarine reaches of the Collie and Brunswick rivers have for many years exhibited the symptoms of nutrient pollution and excess organic matter such as low oxygen, algal blooms (including toxic species) and fish kills. In low-flow conditions much of the nutrient and organic matter delivered from the catchment will accumulate in these areas and exacerbate the current poor water quality.

The estuary itself shows reasonable water quality with respect to nutrients, however excess nutrients in estuaries may be expressed as algal growth. Considerable biomass of drifting macroalgae is seen in the northern poorly-mixed part of the estuary and seagrass loss has already been documented. The estuary is thus showing symptoms of increasing degradation.

Given the current condition as described above and planned developments in the Greater Bunbury region, it is likely the estuary’s condition will further deteriorate with the consequent loss of ecological function and amenity if actions described in this WQIP are not implemented.

4 Water quality objectives

4.1 Environmental values, issues and objectives

The environmental values and beneficial uses of the Leschenault waterways are interrelated. Recreational activities that depend on ecosystem health include fishing and crabbing, water-based sports such as swimming, wind- and kite-surfing, canoeing, kayaking and boating, and other uses such as picnicking, walking and sightseeing. The cultural and spiritual values of the waterways are of importance to both Indigenous and non-Indigenous communities.

Most of the recreational activities and supporting commercial operations are likely to affect the ecosystem health of the waterways, yet also depend on good water quality for their appeal and/or viability. Meeting the water quality objectives for ecosystem health will protect these beneficial uses. Table 4-1 summarises the waterway's environmental values and assesses whether they are being met.

4.1 Specification of water quality objectives

In action plans of this sort a number of seemingly similar terms are used – water quality objectives, targets, guidelines and indicators – so it is important to understand the purpose of each.

Water quality objectives (WQOs) are defined in the *Framework for marine and estuarine water quality protection* (DEWHA 2002) as:

> A numerical concentration limit or narrative statement that has been established to support and protect the designated uses of water at a specified site. It is based on scientific criteria or water quality guidelines but may be modified by other inputs such as social or political constraints.

In many cases the WQO is simply left as a narrative statement such as *all waterways will be free of nuisance algal blooms.* The objective measures of a waterway's condition such as nutrients, DO and so on are called indicators if they are sensitive to changes in condition. A target is simply an indicator that is feasible to measure and that when reached will either indicate the WQO has been achieved or that progress is being made towards achieving the WQO. The indicators selected for targets should be robust, sensitive to change and related to the WQO. This WQIP aims to improve water quality through the reduction of algal growth. In the estuary the indicators of change are algal concentrations and species and DO, and in the catchment the concentration of nutrients is directly related to the growth of algae. Since we are targeting nutrient reduction, then measures of nutrient concentration are directly related to the success or otherwise of nutrient reduction actions.

In selecting WQOs for waterways, a common debate is whether to use nutrient concentrations or nutrient loads. The former measures the concentration of a particular nutrient in the waterway at any one time, while the latter measures the total weight (load) of a particular nutrient delivered to or by a waterway over a given time period (usually an annual average over a number of years) and is a function of both concentration and flow. Concentration has to be measured either way. Both have particular advantages and applications and in fact we use and report on both.

Total nutrient loads are important when considering both open and closed estuarine systems that can accumulate nutrients (in the sediments), which can later be released back into the water. To use load information we need to understand the fate and effects of the delivered load. This is relevant to the Leschenault Estuary and the estuarine portions of the Brunswick, Collie and Preston rivers. The major rivers within the Leschenault catchment discharge to the estuary’s southern end, close to The Cut. As such, it is likely that much of the nutrient load from these rivers is transported into the marine environment during high flows, and is not deposited in the estuary itself. During low flows much of the load may be delivered into the estuarine parts of the rivers. However, this is difficult to quantify without hydrodynamic and sediment modelling of the estuary.

Where control of algal growth is the management goal, the nutrient concentrations are very important because given suitable physical conditions, algal growth depends on ambient nutrient concentrations. Nutrient concentrations are simpler to measure than loads and are also associated with less error. It is for these reasons that the Department of Water uses WQOs that are primarily based on nitrogen and phosphorus *concentrations*. Nitrogen and phosphorus are generally the limiting nutrients for algal growth in marine and freshwater environments. Other nutrients, such as carbon and silicon, are usually in plentiful natural supply.

To assess changes to nutrient inflows to the Leschenault Estuary, the WQOs were expressed in terms of TN and TP concentrations in the streams and tributaries. So the overall WQO is to *reduce the concentrations of nitrogen and phosphorus in rivers and streams entering the estuary*. The selection of concentration targets that reflect this outcome is discussed in the next section. By using long-term datasets on nutrient concentrations and flow we can also establish the relationship between concentrations and loads which allows the setting of load reduction targets for each catchment. In this case the load reduction required in tonnes or per cent helps communicate the overall work to be done.

Guidelines are set as indicative numbers of what one could expect in a regional waterbody. In most cases we refer to the ANZECC guidelines established under the National Water Quality Management Scheme. The values for south-west Western Australia were derived from Western Australian data on a range of rivers and streams and reflect the nutrient concentrations one could expect in unaffected streams. ANZECC guideline values are quoted for both lowland (the Swan Coastal Plain) and upland tributaries (those flowing from the Darling Scarp: these values are used for comparison only to indicate departure from the natural condition).

Table 4-1: Environmental values and water quality issues for Leschenault waterways

<table>
<tr><th>Environmental values</th><th>Are values being presently achieved?</th><th>Water quality issues</th></tr>
<tr><th colspan="3">Leschenault Estuary</th></tr>
<tr><td>Ecosystem health:
• seagrass distribution and ecological functions
• fish nursery habitat and blue swimmer (manna) crab population
• bird population
• dolphin population
• invertebrate population</td><td>No</td><td rowspan="7">• Nutrient enrichment
• Macroalgal blooms occurring on the estuary mudflats
• Seasonal odour from decaying algae around Australind and north-east shore
• Macroalgal blooms possibly increasing and persistent
• Loss of seagrass beds that are important nurseries for fish and decline of macroinvertebrate abundance
• Dolphin deaths in 2009
• Swan deaths in 2010 near Cathedral Avenue</td></tr>
<tr><td>Harvesting of molluscs for human consumption</td><td>Not consistently</td></tr>
<tr><td>Recreational fishing and crabbing</td><td>Yes</td></tr>
<tr><td>Recreational water-based sports (wind- and kite-surfing, canoeing, kayaking, boating)</td><td>Not consistently</td></tr>
<tr><td>Land value</td><td>Under threat</td></tr>
<tr><td>Aesthetic values</td><td>Not consistently</td></tr>
<tr><td>Cultural and spiritual values</td><td>No</td></tr>
<tr><th colspan="3">Estuarine section of the Collie River</th></tr>
<tr><td>Ecosystem health:
• fish habitat
• food sources for birds, fish and dolphins
• invertebrate population</td><td>No</td><td rowspan="7">• Limited bathing in the river compared with historical use due to low summer flows, and large amounts of silt and mud in the water column
• Reduced water depths
• Nutrient concentrations are high in summer and autumn
• Algal blooms increasing in frequency
• Fish kills
• Sedimentation limits boating activity in the river channel
• Black bream fishing competition – fish kills (2002, 2003, 2004) have prevented the competition from being held annually
• Phytoplankton blooms (inclusive of toxic species)
• Anoxic conditions</td></tr>
<tr><td>Recreational contact sports (bathing, triathlon, kayaking)</td><td>Not consistently</td></tr>
<tr><td>Passive recreation (boating, picnicking, walking)</td><td>Not consistently</td></tr>
<tr><td>Recreational fishing and crabbing</td><td>Yes</td></tr>
<tr><td>Harvesting of molluscs</td><td>Not consistently</td></tr>
<tr><td>Aesthetic values</td><td>Not consistently</td></tr>
<tr><td>Cultural and spiritual values</td><td>No</td></tr>
</table>

Estuarine section of the Brunswick River		
Ecosystem health: • fish habitat • food sources for birds, fish and dolphins • invertebrate population	No	• Reduced water depths • Nutrient concentrations are high in summer and autumn • Algal blooms increasing in frequency • Fish kills • Sedimentation limits boating activity in the river channel • Phytoplankton blooms (inclusive of toxic species) • Anoxic conditions • Low oxygen concentrations in summer and autumn
Passive recreation (picnicking, walking)	Not consistently	
Recreational fishing	Yes	
Harvesting of molluscs	Not consistently	
Aesthetic values	Not consistently	
Estuarine section of the Preston River		
Ecosystem health: • fish habitat • food sources for birds, fish and dolphins • invertebrate population	No	• High nutrient concentrations • Algal blooms • Sedimentation • Historical records of Dieldrin in the 1980s resulting from horticulture practices
Passive recreation (picnicking, walking)	Not consistently	
Aesthetic values	Not consistently	
Recreational fishing and crabbing	Not consistently	
Protection subcatchments		
Brunswick Upper 2		
Ecosystem health	Yes	None to report
Recreational fishing	Yes	
Aesthetic values	Yes	
Drinking water supply for animals	Yes	
Intervention subcatchments		
Parkfield Drain *Brunswick Upper 1* *Mid Preston*	*Upper Preston* *Collie Lower 2* *Thomson Brook*	*Upper Ferguson* *Preston-Donnybrook*
Ecosystem health	Not consistently	• High nitrogen concentrations • Instance of high faecal count and other contaminants entering drinking water supply in Donnybrook town • Reduced flows due to water abstraction for farming and dams • High sedimentation rates: pool infilling due to sediment and riverbank erosion • Many river foreshores degraded and eroded
Recreational fishing	Yes	
Aesthetic values	Not consistently	
Drinking water supply for animals	Yes	
Recreational contact (swimming, kayaking)	Not consistently	
Cultural and spiritual	Not consistently	

<table>
<tr><th colspan="3">Recovery subcatchments</th></tr>
<tr><td>Wellesley
Collie Lower 1
Mid Brunswick</td><td>Lower Preston
Estuary Foreshore
Lower Ferguson</td><td>Coast</td></tr>
<tr><td>Ecosystem health:
• fish habitat
• food sources for birds, fish and dolphins
• invertebrate population</td><td>Not consistently</td><td rowspan="6">• Loss of native fish habitat (infilling of pools), decreasing water quality (nutrients and salinity)
• Water releases from Wellington Dam consist of saline ‘scour’ water from the bottom of the dam, not the fresh water required to maintain good riverine ecology. Water release is not consistent and restricted, resulting in a lack of good flushing of the river to remove sediments and nutrients
• Many river foreshores degraded and eroded
• Sedimentation
• Nutrient enrichment
• Anoxic conditions and salt wedge
• Algal blooms (toxic species occurring) and fish kills
• Black bream fishing competition cancelled in some years due to fill kills on the lower Collie River between ‘the Elbow’ and the river mouth</td></tr>
<tr><td>Harvesting of molluscs for human consumption</td><td>Not consistently</td></tr>
<tr><td>Recreational contact sport (bathing, triathlon, kayaking, canoeing)</td><td>Not consistently</td></tr>
<tr><td>Passive recreation (boating, picnicking, walking)</td><td>Not consistently</td></tr>
<tr><td>Recreational fishing and crabbing</td><td>Not consistently</td></tr>
<tr><td>Aesthetic values</td><td>Not consistently</td></tr>
</table>

4.2 Selection of concentration targets

This WQIP, similar to those for the Swan-Canning, Peel-Harvey and Vasse-Wonnerup/Geographe Bay, provides TN and TP concentration targets for the tributary inflows to the estuary, against which changes in stream concentrations can be assessed. The underlying assumption is that decreased nutrient concentrations in the tributary inflows will improve the estuary’s health.

The winter TN concentration at subcatchment outlets (modelled data discussed in Section 0), the ANZECC guideline for upland and lowland rivers, and the TN concentration target used in other WQIPs are shown in Figure 4-1. Similar data for TP are in Figure 4-2. In the Leschenault subcatchments a clear difference in nutrient concentration is found between the upland and lowland tributaries, indicating that different concentration targets are required. In the other catchments for which WQIPs have been written, all the subcatchments debouch onto the coastal plain or are wholly located on the coastal plain and the differences in nutrient concentrations due to the natural setting of the subcatchments are small.

The estimated TN concentrations at all subcatchment outlets except Brunswick Upper 2 are greater than the ANZECC TN guideline concentrations. For TP the pattern is different: all tributaries on the coastal plain have TP concentrations greater than the ANZECC guideline and all tributaries on the Darling Plateau have concentrations less than the guideline. This is typical of other locations in south Western Australia. The high phosphorus-retaining soils of the Darling Plateau inhibit phosphorus leaching, while the environment on the coastal plain –

low PRI soils, high watertables, artificial drainage and intensive land uses – leads to high nutrient concentrations (especially TP) in receiving waterways.

Donohue et al. (2002 unpublished) set water quality targets in terms of TN and TP concentrations applicable to the tributaries of the Swan Coastal Plain, which were subsequently used for the Swan and Canning rivers as part of the Swan Canning Cleanup Program (SCCP) (SRT 1999) – now the Healthy Rivers Action Plan (HRAP) (SRT 2007). The SCCP management goal was to reduce nutrient inputs to the estuary. Compliance testing against the SCCP targets is supported by a rigorous sampling regime and specified statistical data analyses. Compliance with the targets (long-term targets of TN 1 mg/L and TP 0.1 mg/L) would simply indicate that TN and TP concentrations in the Swan-Canning tributaries had declined. Their achievement would not necessarily mean phytoplankton blooms in the estuary would cease, since there is a long lag time for a response due to storage of nutrients in the estuary.

The Swan-Canning, Peel-Harvey and Vasse-Wonnerup/Geographe Bay WQIPs (SRT 2009; EPA 2008; White 2010) used the Swan Coastal Plain TN and TP concentration targets. However, for the Swan-Canning WQIP, Kelsey et al. (2010a) examined the hydrology of Perth's urban areas and modified the targets to account for increased flows in highly urbanised catchments. Thus the Peel-Harvey and Vasse-Wonnerup/Geographe Bay WQIPs used the same targets as the SCCP/HRAP TN target of 1 mg/L and TP target of 0.1 mg/L, while the Swan-Canning WQIP used the modified targets to account for catchment imperviousness and water yield.

The selected TN and TP targets for the Leschenault catchment's lowland tributaries are the same as those for the other WQIPs, while for the upland tributaries the ANZECC guideline values are used – as shown in tables Table 4-2 and Table 4-3 – taking into account the better water quality of these streams.

Once set the nutrient concentration targets are used in a number of different ways to:

- establish the nutrient status of the catchment (Section 4.3)
- provide the target concentration in the model to be reached by implementing management actions (Section 5.4)
- establish the concentration value against which progress can be measured (Section 10.3).

Table 4-2: Water quality objectives (expressed as TN and TP concentration target) for upland and lowland tributaries of the Leschenault Estuary

Guideline	TN (mg/L)	TP (mg/L)
Upland tributaries – ANZECC guidelines targets for upland rivers	0.45	0.02
Lowland tributaries – Swan Coastal Plain targets	1.00	0.10

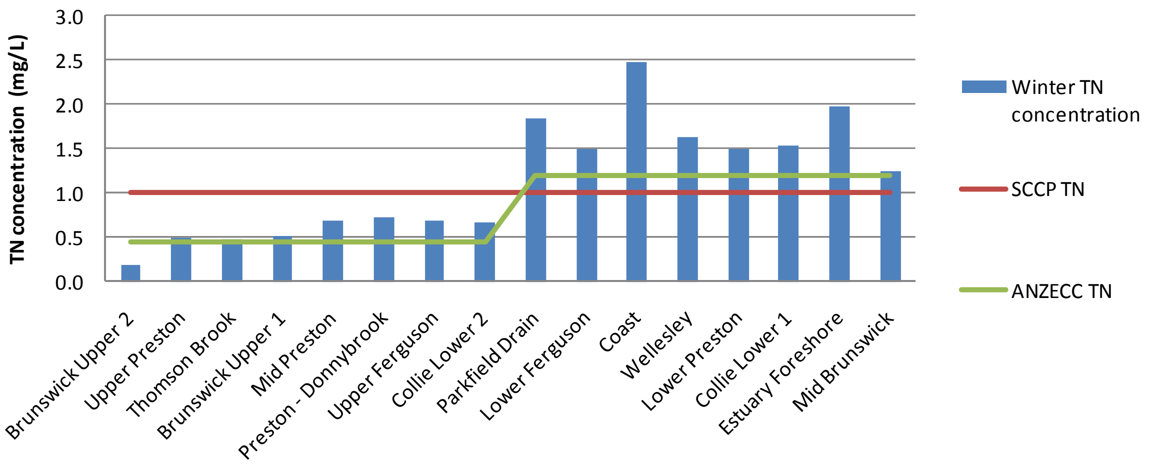


Figure 4-1: TN concentrations at subcatchment outlets (modelled data – see Section 0), ANZECC guideline values and TN concentration target

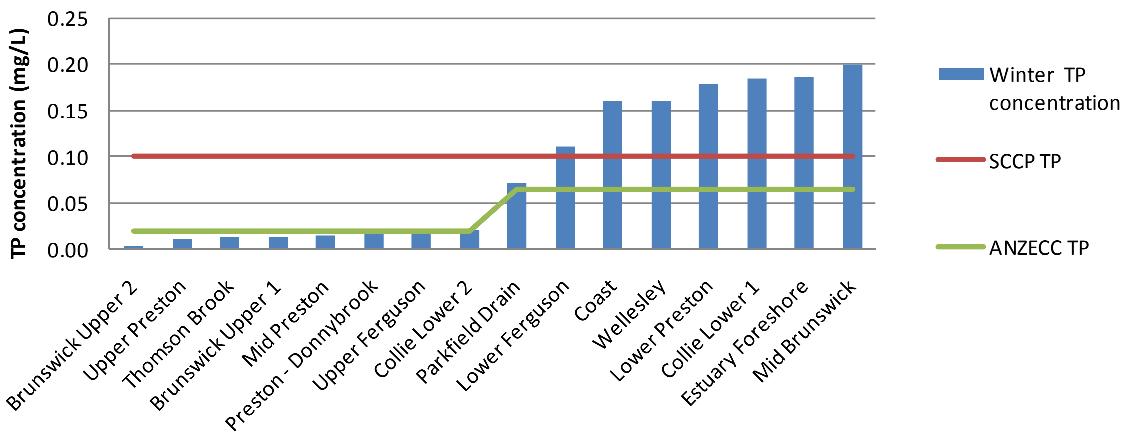


Figure 4-2: TP concentrations at subcatchment outlets (modelled data – see Section 0), ANZECC guideline values and TP concentration target

4.3 Water quality objective process and framework

The reporting subcatchments were classified by comparing the estimated nutrient concentration in runoff against the water quality targets for TN and TP.

The classification is as follows:

- *protection* – for all reporting subcatchments currently meeting both the nitrogen and phosphorus targets
- *intervention* – for all reporting subcatchments that meet the phosphorus, but not the nitrogen target

- *recovery* – for all reporting subcatchments meeting neither the nitrogen nor the phosphorus target.

Classified reporting subcatchments are listed in Table 4-3 and shown in Figure 4-3.

The chosen WQOs and the classification scheme for reporting subcatchments provide a framework for water quality management in the Leschenault catchment that does the following:

- sets nutrient concentration targets for the Leschenault Estuary tributaries that take into account subcatchment character
- recognises the importance of preventing a shift from acceptable water quality to poor water quality, as well as achieving improvements in areas that have already declined
- aims to improve the ecological health of the waterway reaches associated with each reporting subcatchment
- places a high value on protecting water quality of inflows to the Leschenault Estuary.

Only one catchment falls into the ‘protection’ category – Brunswick Upper 2. All the other upland subcatchments are in the ‘intervention’ category, while all the reporting subcatchments on the Swan Coastal Plain fall into the ‘recovery’ category with the exception of Parkfield Drain, which is in the ‘intervention’ category. Note that water quality within the reporting subcatchments can be quite variable, depending on local physiography, hydrology and land use. WQOs for each category are given in Table 4-4.

Table 4-3: TN and TP concentration targets for catchment tributaries

Name	Type	Winter TN concentration	TN target	Winter TP concentration	TP target	Classification
Brunswick Upper 2	Upland	0.19	0.45	0.004	0.02	Protection
Upper Preston	Upland	0.49	0.45	0.011	0.02	Intervention
Thomson Brook	Upland	0.48	0.45	0.012	0.02	Intervention
Brunswick Upper 1	Upland	0.52	0.45	0.013	0.02	Intervention
Mid Preston	Upland	0.68	0.45	0.015	0.02	Intervention
Preston - Donnybrook	Upland	0.73	0.45	0.017	0.02	Intervention
Upper Ferguson	Upland	0.68	0.45	0.019	0.02	Intervention
Collie Lower 2	Upland	0.66	0.45	0.020	0.02	Intervention
Parkfield Drain	Lowland	1.8	1.0	0.072	0.1	Intervention
Lower Ferguson	Lowland	1.5	1.0	0.11	0.1	Recovery
Coast	Lowland	2.5	1.0	0.16	0.1	Recovery
Wellesley	Lowland	1.6	1.0	0.16	0.1	Recovery
Lower Preston	Lowland	1.5	1.0	0.18	0.1	Recovery
Collie Lower 1	Lowland	1.5	1.0	0.18	0.1	Recovery
Estuary Foreshore	Lowland	2.0	1.0	0.19	0.1	Recovery
Mid Brunswick	Lowland	1.2	1.0	0.20	0.1	Recovery

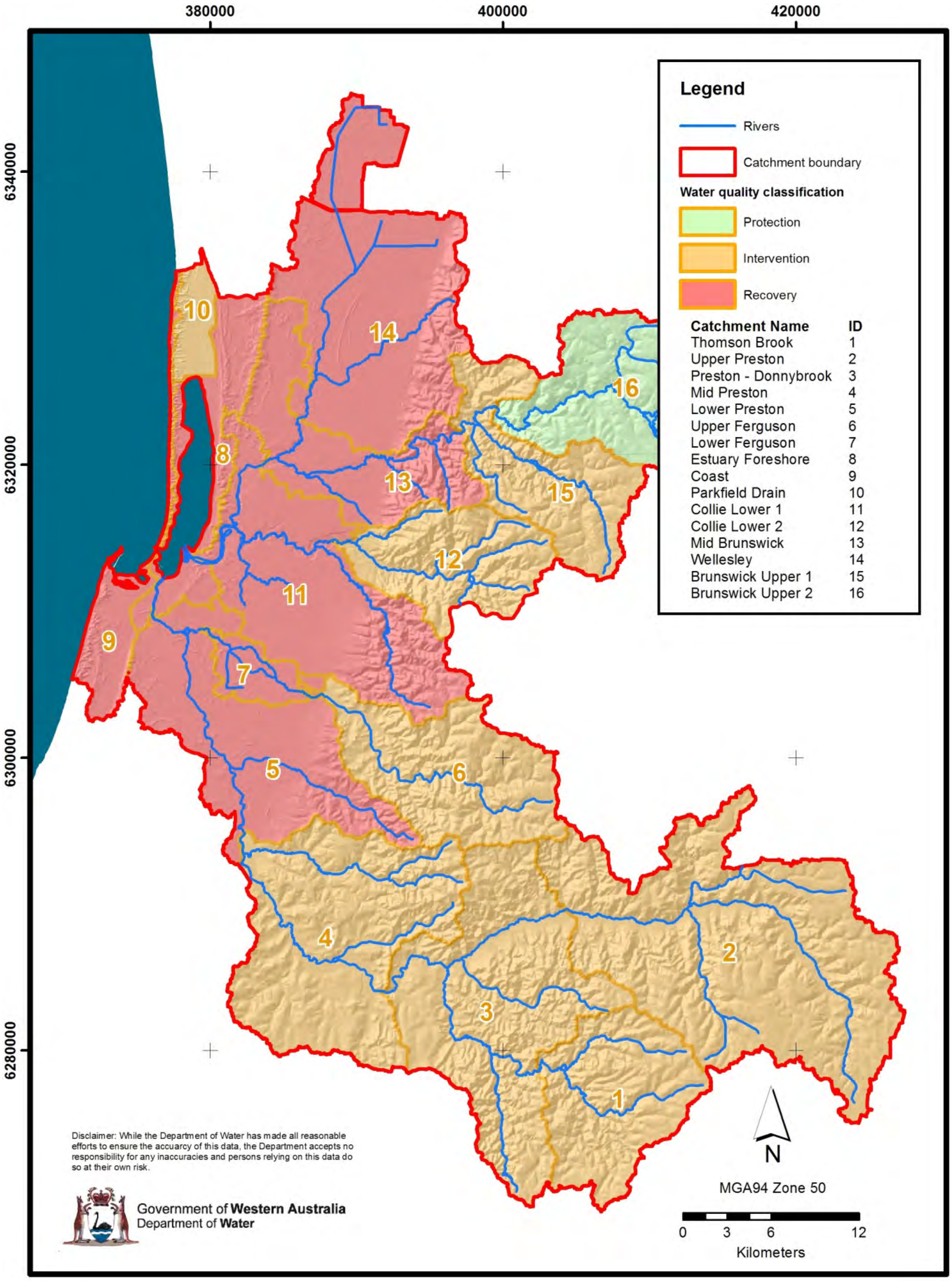


Figure 4-3: Classification of reporting subcatchments according to water quality objectives

Table 4-4: Water quality objectives for the Leschenault reporting subcatchments

	Protection	**Intervention**	**Recovery**
Reporting subcatchments discharging to the estuary	Brunswick Upper 2	Collie Lower 2 Mid Preston Preston-Donnybrook Thomson Brook Upper Ferguson Brunswick Upper 1 Upper Preston Parkfield Drain	Wellesley Mid Brunswick Lower Preston Lower Ferguson Estuary Foreshore Collie Lower1
Reporting subcatchments discharging to the ocean			Coast
Assessment against water quality target	Meets both TN and TP	Fails TN Passes TP	Fails both TN and TP
Water quality objectives	Prevent further increases from current median winter concentrations	Decreases median winter TN concentrations to 0.45 mg/L in upland streams and 1.0 mg/L in lowland streams Decreasing trends in TN concentrations Prevent TP concentrations from increasing	Decreases median winter TN concentrations to 0.45 mg/L in upland streams and 1.0 mg/L in lowland streams Decreasing trends in TN concentrations Decreases median winter TP concentrations to 0.02 mg/L in upland streams and 0.1 mg/L in lowland streams Decreasing trends in TP concentrations

5 WaterCAST modelling

5.1 Background to the modelling

Much of the data presented in this report is based on water quality modelling by the Department of Water. The Water and Contaminant Analysis and Simulation Tool (WaterCAST) (Argent et al. 2008) was selected as the modelling tool for this project. WaterCAST, which is now known as eWater Source, is a simple, semi-distributed conceptual model. The hydrology of the model is dynamic, although the nutrient component is partially steady-state – in that nutrient load varies with flow conditions but concentration does not. The model provided estimates of monthly flows, flow-weighted nutrient concentrations and loads at the subcatchment scale.

The input requirements for WaterCAST included:

- land use mapping (2005)
- annual nutrient input rates – provided by DAFWA's rural surveys and the Department of Water's urban nutrient survey project
- point source nutrient load contributions – provided by DEC
- WWTP nutrient load contributions – provided by the Water Corporation
- soil characteristics – provided by DAFWA
- monthly rainfall and evaporation
- monthly irrigation supply time-series – provided by Harvey Water and the Preston Valley Irrigation Cooperative
- dam releases – provided by the Water Corporation
- high-quality spatial data depicting the drainage network and topography for delineation of subcatchments.

Output data was summarised for each reporting subcatchment to provide the following information:

- the monthly flow
- monthly nitrogen and phosphorus loads (and flow-weighted concentrations)
- average annual loads
- average annual acceptable loads
- average annual load reduction targets
- nutrient sources
- catchment nutrient-export hotspots
- the impact of land use changes on flow, nutrient concentration and load.

The model was calibrated using flow data from gauging stations and nutrient concentration data from regular sampling within the Leschenault catchment. The nutrient calibration matched modelled winter flow concentrations to observed nutrient data. A detailed description of the modelling is provided in the report *WaterCAST nutrient modelling of the Leschenault catchment* (Marillier 2010). Several improvements have been made to the model since this publication, and these are discussed in Appendix G.

The Leschenault WaterCAST model estimates flows and loads at a monthly timestep for the period modelled (1998–2007), which allows examination of monthly, seasonal and annual values. The monthly concentrations are deduced by dividing the monthly loads by the monthly flows; as such, these are monthly flow-weighted concentrations (generally called modelled monthly concentrations in this report). Median modelled monthly TN and TP concentrations were compared with the concentration targets outlined in Section 4.

Note that the reported flows, loads and concentrations at the outlets of the subcatchments represent contributions from the subcatchment alone. They do not include contributions from upstream subcatchments, and are thus are not directly comparable with observed and/or calculated flows, loads and concentrations in the stream at the subcatchment outlet. The main aim of the modelling was to determine nutrient load reduction targets for quantifying the management interventions required in each subcatchment, as discussed in Section 6.

This modelling enables us to identify which subcatchments have the greatest nutrient loads, as well as which land uses make the greatest nutrient contributions both to the estuary overall and within each subcatchment.

In the next section, the nitrogen and phosphorus load contributions per land use are described for the whole catchment. Data for each subcatchment are in Appendix H. This information will help identify the BMPs and drive the cost/benefit analysis.

The accuracy of modelling outputs is largely determined by the data used to drive the model. The land use mapping used in this project was done at the cadastral scale. The estimated nutrient inputs – in terms of fertiliser, stockfeed and nitrogen fixation in agricultural areas and fertiliser and pet waste in urban areas – were derived from a survey of landholders (Ovens et al. 2008; Kelsey et al. 2010) and applied at the cadastral scale. As such, there is high confidence in the input data and thus in the estimated monthly and annual loads and concentrations from the model.

However, not all subcatchments had flow and water quality data for model calibration, and these subcatchments will have greater errors in model outputs than the subcatchments with comprehensive calibration data. A simple method that scores the availability of flow and nutrient calibration data was used to give confidence measures for the modelling results. Table 5.1 contains the scoring for each subcatchment for the flow and nutrient modelling, and Table 5-2 interprets the scores.

Gaps in monitoring data and the future data required to assess the impacts of the management changes proposed in this WQIP are discussed in Section 8.

Table 5-1: Assessment of model confidence

	Brunswick Upper 2	Mid Brunswick	Brunswick Upper 1	Lower Ferguson	Collie Lower 1	Mid Preston	Upper Ferguson	Lower Preston	Upper Preston	Preston - Donnybrook	Thomson Brook	Collie Lower 2	Estuary Foreshore	Coast	Parkfield Drain	Punchbowl Canal	Wellesley
Flow criteria																	
Flow gauging station on catchment	✓	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	✗	✗	✗	✗	✓
Flow gauging station on nearby catchment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Catchment hydrology is understood and documented	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Flow has been estimated in other documents / models	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Hydrological calibration > 0.8 Nash Sutcliffe	✗	✓	✗	✗	✗	✓	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓
Total water	3	4	3	2	1	3	3	1	3	3	2	2	1	1	1	1	3
Nitrogen criteria																	
Nutrient sampling on catchment	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓
Nutrient sampling at flow gauging station	✗	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	✗	✗	✗	✗	✓
Sampling record > 3 years	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓
Modelled TN concentration within 5% of observed	✗	✓	✓	✓	✗	✗	✓	✗	✓	✗	✓	✓	✗	✗	✗	✗	✓
Confidence score for flow estimations ≥ 3	✓	✓	✓	✗	✗	✓	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓
Total nitrogen	1	5	5	4	2	4	5	2	5	4	4	4	0	0	1	1	5
Phosphorus criteria																	
Nutrient sampling on catchment	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓
Nutrient sampling at flow gauging station	✗	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	✗	✗	✗	✗	✓
Sampling record > 3 years	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓
Modelled TP concentration within 5% of observed	✗	✓	✗	✗	✗	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✓
Confidence score for flow estimations ≥ 3	✓	✓	✓	✗	✗	✓	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓
Total phosphorus	1	5	4	3	2	5	5	2	5	4	3	3	0	0	1	1	5

**Secondary gauges and WQ sites were not used in calibration*

Table 5-2: Model confidence values and descriptions

Flow value	Confidence in results
4 - 5	High confidence that actual flows are well represented by modelled flows for the output of the catchments, on a monthly and annual basis.
2 - 3	Modelled flows are likely to represent actual flows, but cross-checks with documented flow studies are required. If flow is not calibrated to gauging data, annual flow quantities will still have a relatively high degree of confidence.
1	Annual flows will be likely to have some error associated with them (plus or minus 30%), which will be compounded in annual nutrient-load estimations. Cross-checks with other flow data is essential.
0	Flow quantities are likely to be associated with large errors , and priority in these catchments will be to improve the estimation and understanding of the flow, and to reassess the flow and subsequent load targets.
Nutrient value	**Confidence in results**
4 - 5	High confidence (small error) in modelled monthly, seasonal and annual loads.
2 - 3	Modelled annual loads are likely to be associated with a high level of confidence for the period over which the sampling has occurred. Past and future loads have lower confidence due to the length of the sampling record.
1	Annual loads will be likely to have some error associated with them (up to plus or minus 50%).
0	Low confidence associated with the nutrient loads and concentration values in these catchments, and high errors in annual loads are likely (could be > 50% in some cases). Priority is to begin a sampling regime in these catchments before remedial activities are conducted.

5.2 Modelling results

5.2.1 Sources of nitrogen and phosphorus with respect to land uses

The WaterCAST modelling estimated average annual nitrogen loads of 312 tonnes to the estuary and 14 tonnes directly to the ocean (and Leschenault Inlet) from the Coast subcatchment. The estimated average annual phosphorus loads were 28 tonnes to the estuary and 1 tonne to the ocean from the Coast subcatchment.

Identifying the sources of nutrients within the Leschenault catchment is a critical first step in prioritising management actions to reduce nutrient loading to the estuary. Figure 5-1 shows current land uses and nutrient point sources. The modelling has provided information on the sources of nutrients to the estuary (Table 5-3 and Figure 5-2) and to the ocean from the Coast subcatchment (Table 5-4 and Figure 5-3)

Individual sources for each reporting subcatchment are discussed with management actions in the accompanying report, Implementing the Leschenault Estuary water quality improvement plan (DoW 2012).

Pie charts showing the nutrient sources in each subcatchment are given in Appendix H.

Agricultural contribution

Diffuse sources

Two main industries are clearly identified as sources of nutrients to the Leschenault Estuary (Figure 5-2). Beef and dairy grazing represent large diffuse sources of pollution that dominate both nitrogen and phosphorus loads (beef: 49% of nitrogen and 43% of phosphorus; dairy: 20% of nitrogen and 25% of phosphorus). These industries also cover the greatest portion of the cleared area of the catchment (beef: 33%; dairy: 5%). Diffuse sources of nutrients from beef and dairy farming represent a management challenge in the Leschenault catchment due to the scale of the problem, the lack of regulations to address the problem and limited options for management changes from the industry to resolve the issue.

Horticulture (annual and perennial), viticulture, and horse and lifestyle blocks make up the rest of the diffuse agricultural nutrient load in the catchment. The influence of these land uses on water quality is more noticeable in some subcatchments. For example, in the Parkfield Drain subcatchment, half of the nitrogen and phosphorus loads come from horticulture (predominantly from the vegetable-growing sector) (see Appendix H). In the Lower Ferguson, poor water quality is associated with a canal on the Boyanup–Picton Road (monitoring site 6110055) draining an area of horse and lifestyle blocks, which make up 10% of the nitrogen and phosphorus load for the subcatchment.

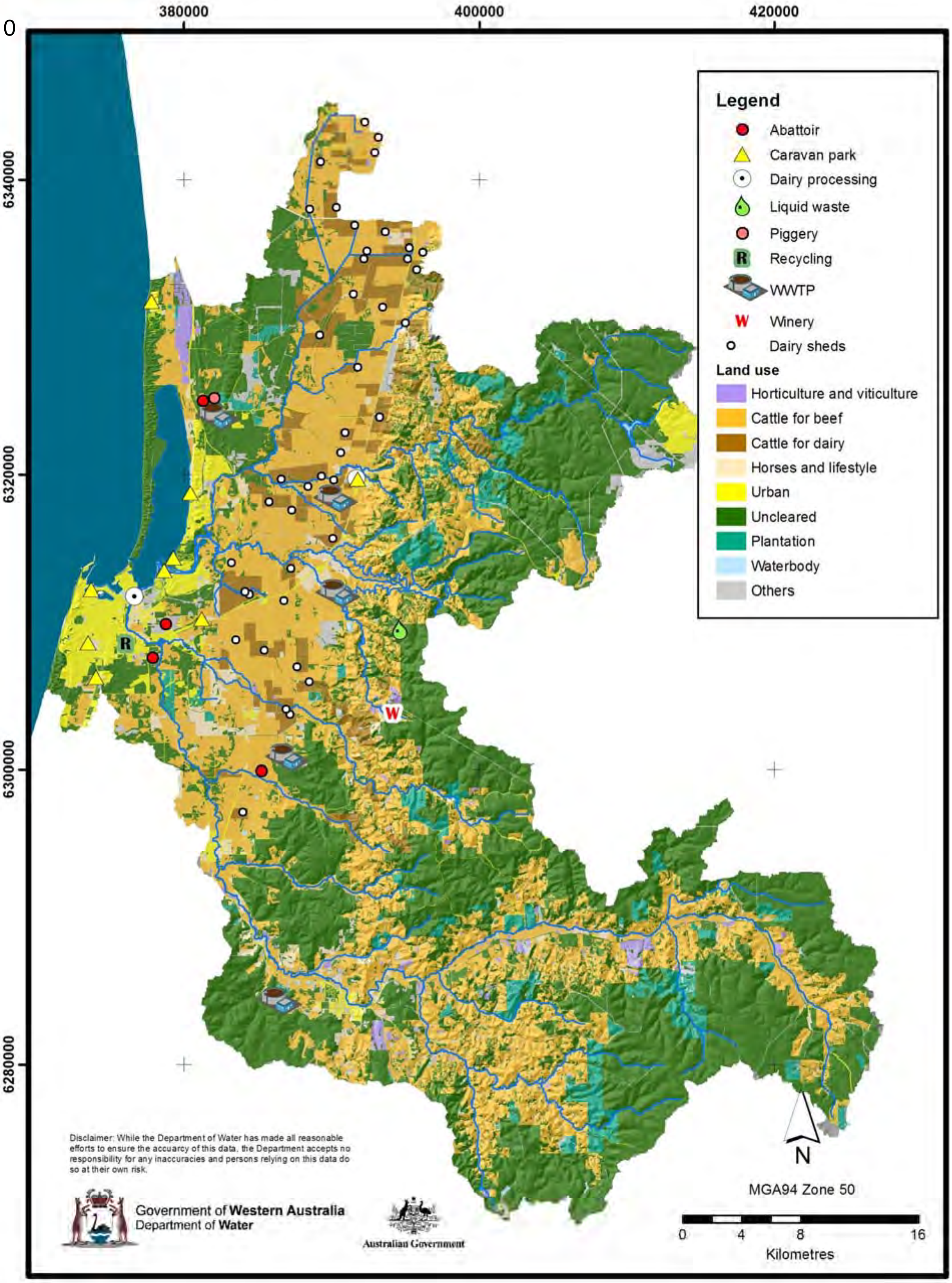


Figure 5-1: Land uses and nutrient point sources in the Leschenault catchment

Point sources

Point source pollution from dairy sheds contributes a substantial portion of nutrient loading to the estuary (3% of the nitrogen and 6% of the phosphorus). Dairy sheds have a high density in the Leschenault catchment's north and are often located adjacent to drains. Their impact is clear – the Wellesley and Mid Brunswick subcatchments have the worst water quality of the entire Leschenault catchment.

The dairy industry has a significant nutrient footprint in terms of load contribution to the estuary – diffuse and point source (dairy sheds) pollution from dairy farms contribute 23% of the nitrogen and 31% of the phosphorus loads, although dairy farms occupy only 5% of the total catchment area.

Urban contribution

As urban land use covers only a small portion of the catchment, it contributes little nutrient load relative to beef and dairy grazing. However, some subcatchments have large urban areas and so the influence of urbanisation is more obvious; for example, in the Coast subcatchment as shown in Figure 5-3. Urban land uses are associated with poor water quality throughout the Swan Coastal Plain.

Septic tanks, which are distributed widely throughout the catchment, export a substantial load of nitrogen and phosphorus (6% and 7% respectively) to the Leschenault Estuary. There are a large number concentrated around Australind in the Estuary Foreshore subcatchment.

Licensed point sources

The estimated contributions to the estuary from DEC-licensed point sources, including WWTPs, are 5% of the nitrogen and 3% of the phosphorus loads. In the Lower Preston subcatchment, however, the four DEC-licensed industries contribute 29% of the nitrogen and 13% of the phosphorus loads. Other subcatchments such as Estuary Foreshore and Mid Brunswick have substantial loads from WWTPs (see Appendix H).

Others

Because about half the Leschenault catchment is covered by either uncleared native vegetation or plantation, 8% of the nitrogen and 5% of the phosphorus loads are attributed to these land use categories. However, it is important to note the nutrient concentrations in runoff from these land uses are very low – in the case of native vegetation, less than 0.3 mg/L for TN and less than 0.006 mg/L for TP (see the Mumballup Road site, 611001, as an example).

Table 5-3: Sources of nutrients delivered to the Leschenault Estuary (excludes the Coast subcatchment which drains into the inlet and ocean)

Reporting land use	Area (ha)	%	Nitrogen load (kg)	%	Phosphorus load (kg)	%
Misc point sources	0	0	14 424	5	767	3
WWTP	0	0	5 400	2	821	3
Septics	73	0	20 328	7	1 867	7
Urban	6 380	3	11 153	4	1 492	5
Beef	62 486	33	152 618	49	12 083	43
Dairy	8 791	5	62 557	20	6 861	25
Horticulture & viticulture	1 717	1	3 805	1	211	1
Uncleared	91 153	48	22 077	7	762	3
Plantation	7 496	4	3 232	1	697	3
Horses & lifestyle	3 653	2	7 456	2	521	2
Dairy sheds	0	0	8 817	3	1 756	6
Others	7 122	4	0	0	0	0
Total	188 874	100	311 866	100	27 839	100

Table 5-4: Sources of nutrients delivered to the Leschenault Inlet and ocean from the Coast subcatchment

Reporting land use	Area (ha)	%	Nitrogen load (kg)	%	Phosphorus load (kg)	%
Misc point sources	0	0	0	0	0	0
WWTP	0	0	0	0	0	0
Septics	26	0	6 028	44	221	20
Urban	1 891	53	6 180	45	598	55
Beef	228	6	731	5	184	17
Dairy	0	0	0	0	0	0
Horticulture & viticulture	0	0	0	0	0	0
Uncleared	1 308	35	518	4	16	1
Plantation	0	0	0	0	0	0
Horses & lifestyle	112	3	297	2	65	6
Dairy sheds	0	0	0	0	0	0
Others	99	3	0	0	0	0
Total	3 664	100	13 755	100	1 084	100

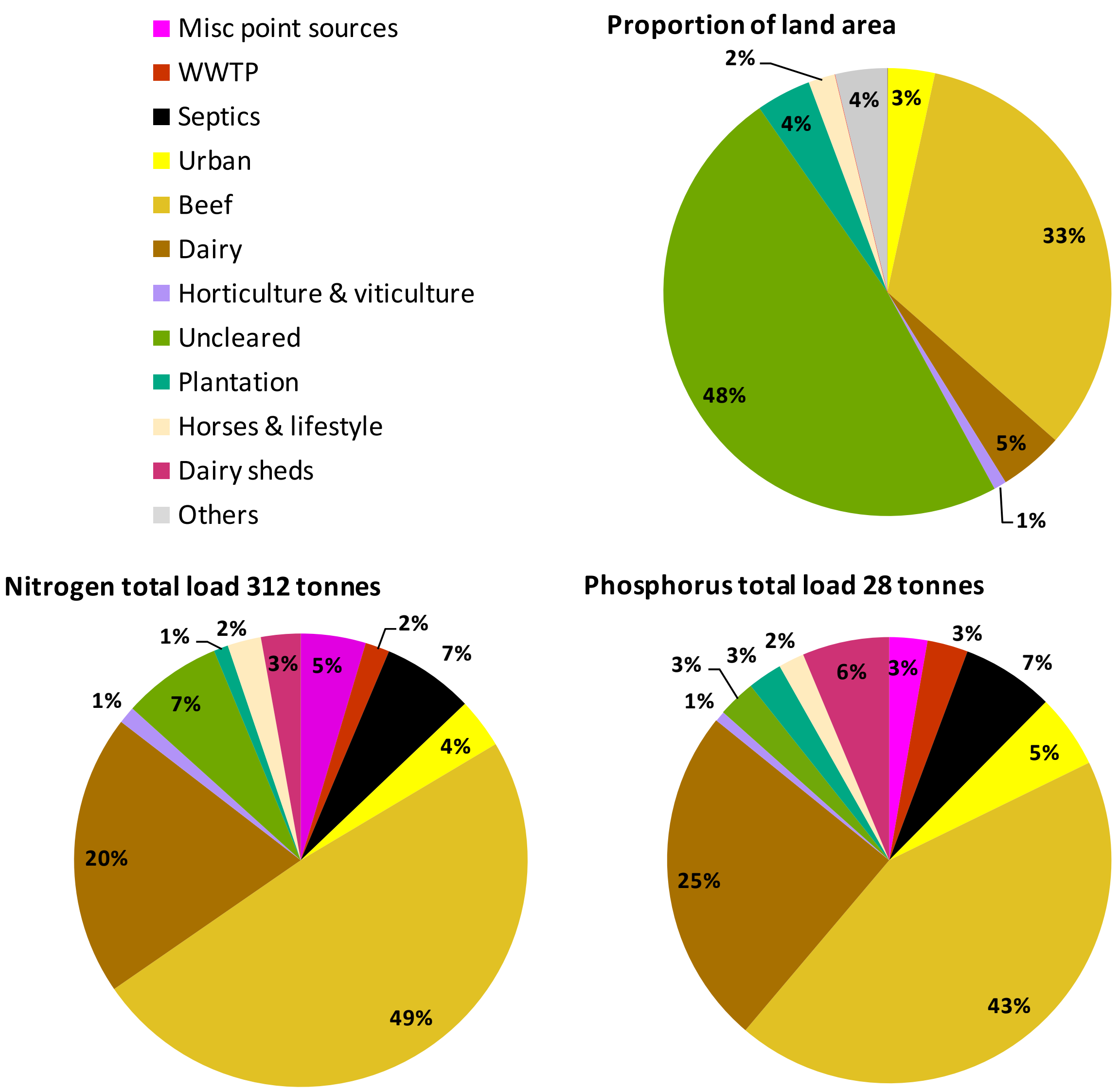


Figure 5-2: Sources of nutrients delivered to the Leschenault Estuary (excludes the Coast subcatchment which drains into the inlet and ocean)

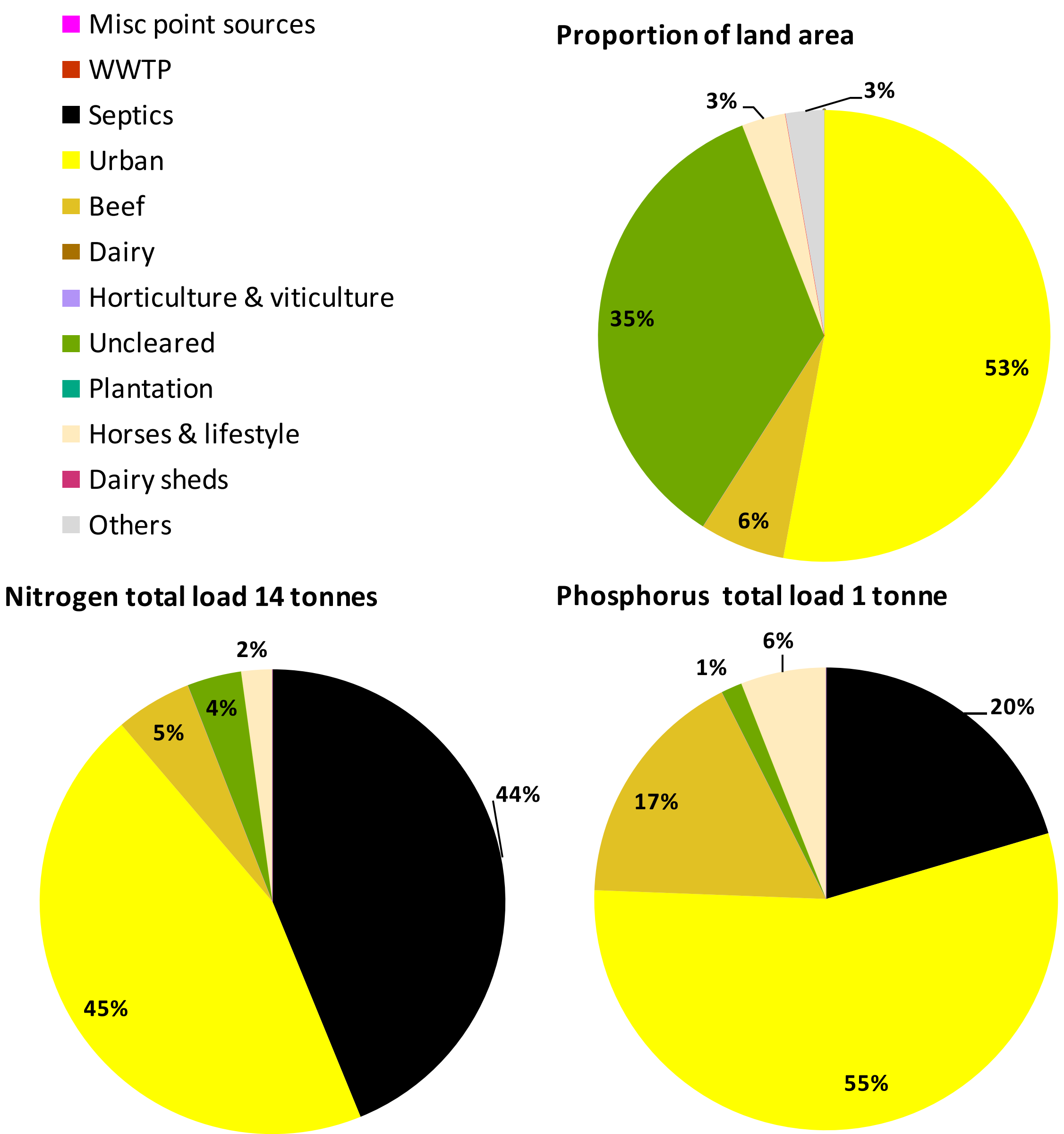


Figure 5-3: Sources of nutrients delivered to the Leschenault Inlet and ocean from the Coast subcatchment

5.2.2 Current nutrient loads in waterways

The average annual loads of nitrogen and phosphorus were estimated for each of the Leschenault reporting subcatchments. Using these loads it is possible to identify the relative contribution of nutrients to the Leschenault Estuary from the different rivers within the catchment, as shown inTable *5-5* and Figure 5-4. The Collie (22% of nitrogen and 25% of phosphorus), Wellesley (24% of nitrogen and 27% of phosphorus) and Preston (30% of nitrogen and 26% of phosphorus) rivers contribute the greatest loads to the estuary (however load is a function of the size of the river basin).

The Wellesley River contributes a disproportionate nutrient load for the size of its catchment, and is the stand-out problem area of the catchment. The Preston River, on the other hand, drains around half the Leschenault catchment, but contributes only one third of the nitrogen load and one quarter of the phosphorus load entering the estuary.

Table 5-5*: Contribution of nutrient loads to the Leschenault Estuary from the rivers in the Leschenault catchment*

River	Area		Nitrogen load		Phosphorus load	
	(ha)	%	(kg)	%	(kg)	%
Brunswick	30 803	16	29 013	9	3 454	12
Collie	24 608	13	68 768	22	6 886	25
Estuary	7 713	4	25 510	8	2 095	8
Ferguson	13 778	7	17 679	6	888	3
Preston	91 846	49	95 024	30	7 125	26
Wellesley	20 127	11	75 872	24	7 390	27
Total	188 874	100	311 866	100	27 839	100

Table 5-6 and Figure 5-5 shows the relative contribution of nutrient load by reporting subcatchment. The larger subcatchments on the Swan Coastal Plain all contribute substantial loads to the estuary: these include the Wellesley, Collie Lower 1, Lower Preston, and Mid Brunswick. The Estuary Foreshore subcatchment contributes 6% of both the nitrogen and phosphorus loads despite being a relatively small subcatchment.

Nitrogen export loads are more evenly distributed among the reporting subcatchments than phosphorus loads. This is because:

- the difference in nitrogen concentrations between agricultural and uncleared subcatchments is relatively less than for phosphorus concentrations
- phosphorus loads depend on the soil PRI of the catchment – those with high soil PRI have relatively low phosphorus loads for their size.

Nutrient hotspot maps of nitrogen and phosphorus load exported per unit area are shown in figures Figure 5-6 and Figure 5-7. These illustrate the spatial distribution of nutrient export, and highlight problem areas of the catchment.

Table 5-6: Nutrient loads to the Leschenault Estuary and ocean from reporting subcatchments

Name	Area		Nitrogen load		Phosphorus load	
	(ha)	%	(kg)	%	(kg)	%
Brunswick Upper 1	9 278	5	4 907	2	123	0
Brunswick Upper 2	11 665	6	3 498	1	75	0
Coast	3 664	2	13 755	4	1 084	4
Collie Lower 1	16 377	9	55 825	17	6 497	22
Collie Lower 2	8 231	4	12 943	4	389	1
Estuary Foreshore	5 710	3	18 090	6	1 799	6
Lower Ferguson	2 339	1	9 053	3	649	2
Lower Preston	14 593	8	48 119	15	6 034	21
Mid Brunswick	9 860	5	20 609	6	3 256	11
Mid Preston	18 579	10	14 560	4	332	1
Parkfield Drain	2 003	1	7 420	2	296	1
Preston - Donnybrook	19 558	10	17 011	5	399	1
Thomson Brook	10 237	5	4 340	1	108	0
Upper Ferguson	11 439	6	8 626	3	239	1
Upper Preston	28 879	15	10 994	3	252	1
Wellesley	20 127	10	75 872	23	7 390	26
Totals	192 538	100	325 621	100	28 923	100

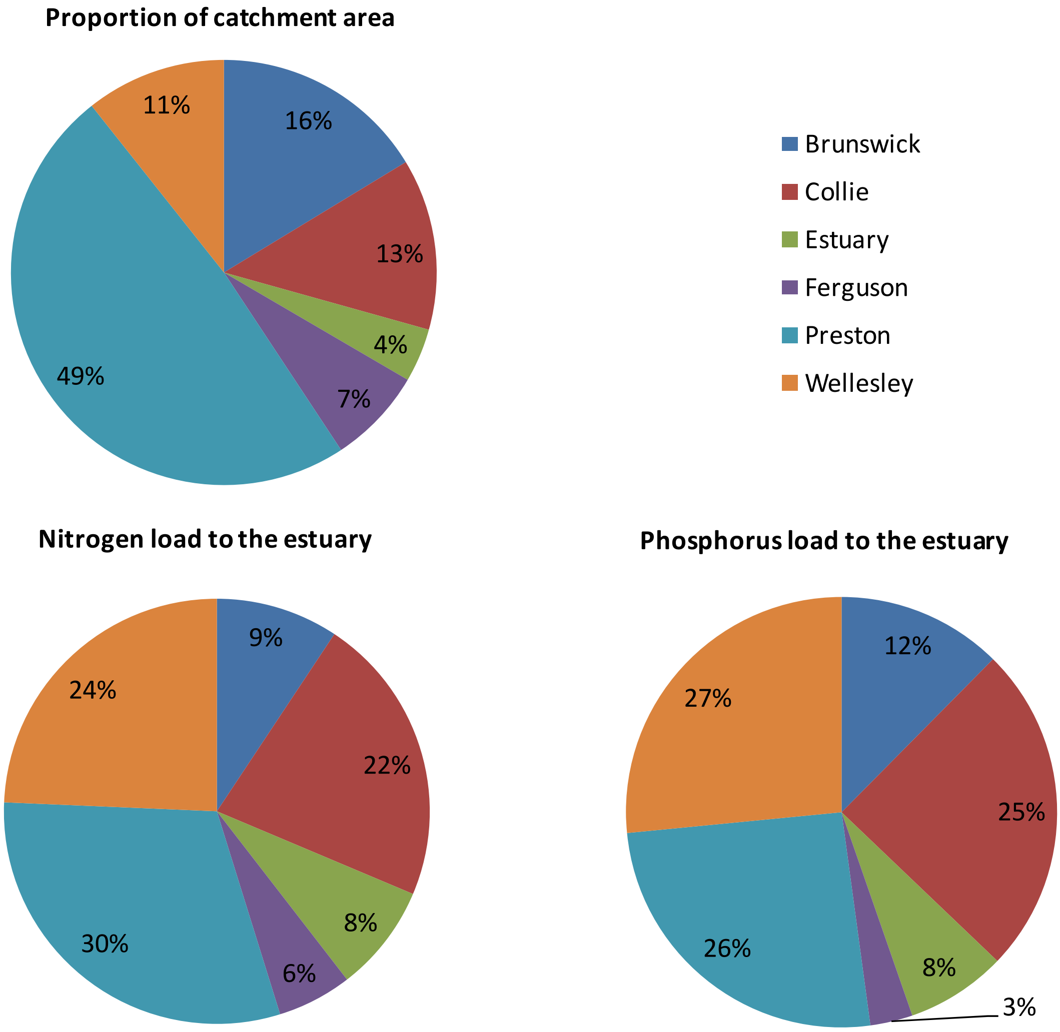


Figure 5-4: Relative contribution of nutrient loads to the Leschenault Estuary from rivers in the Leschenault catchment

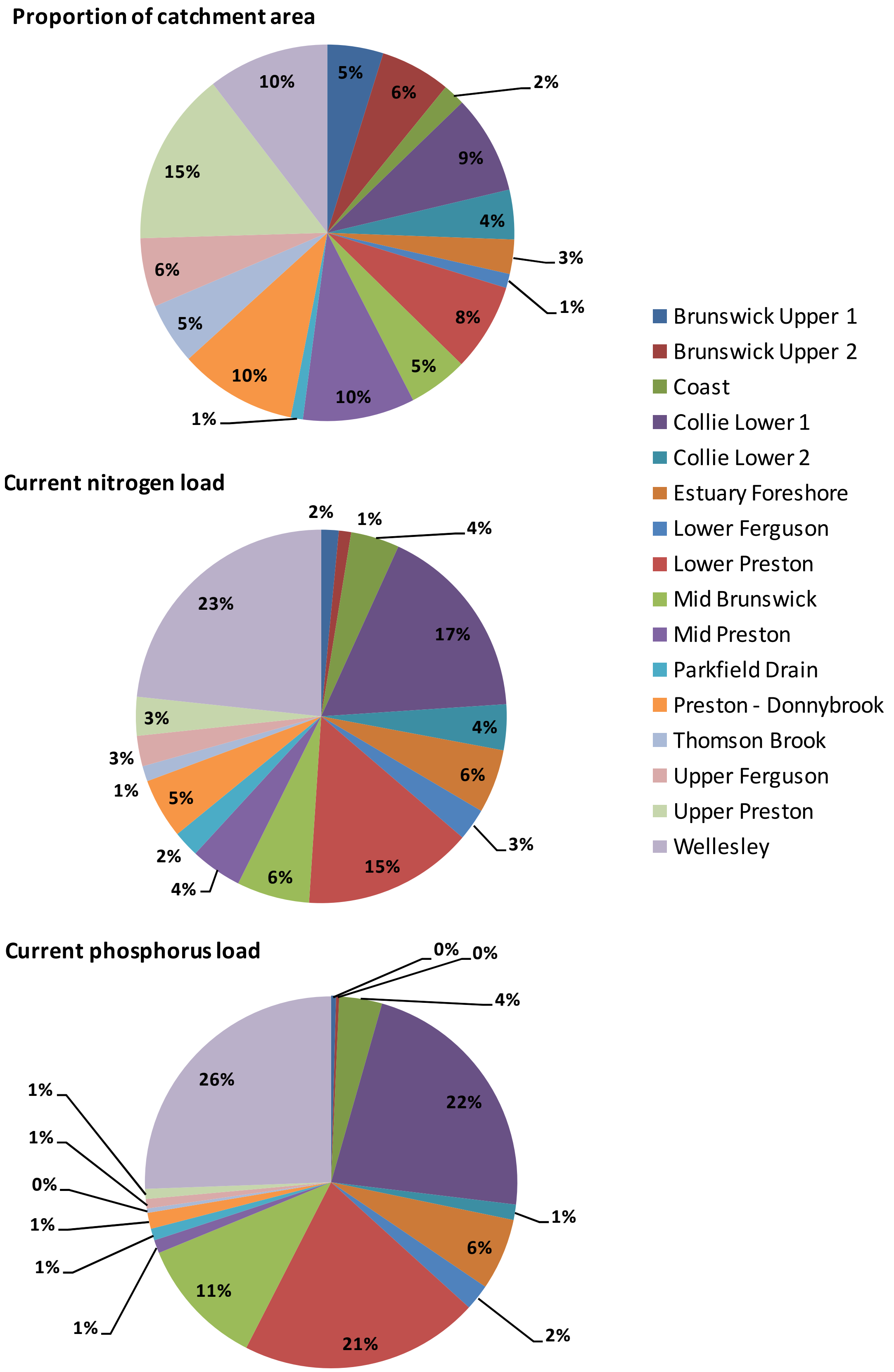


Figure 5-5: Relative contribution of nutrient loads to the Leschenault Estuary and ocean from reporting subcatchments

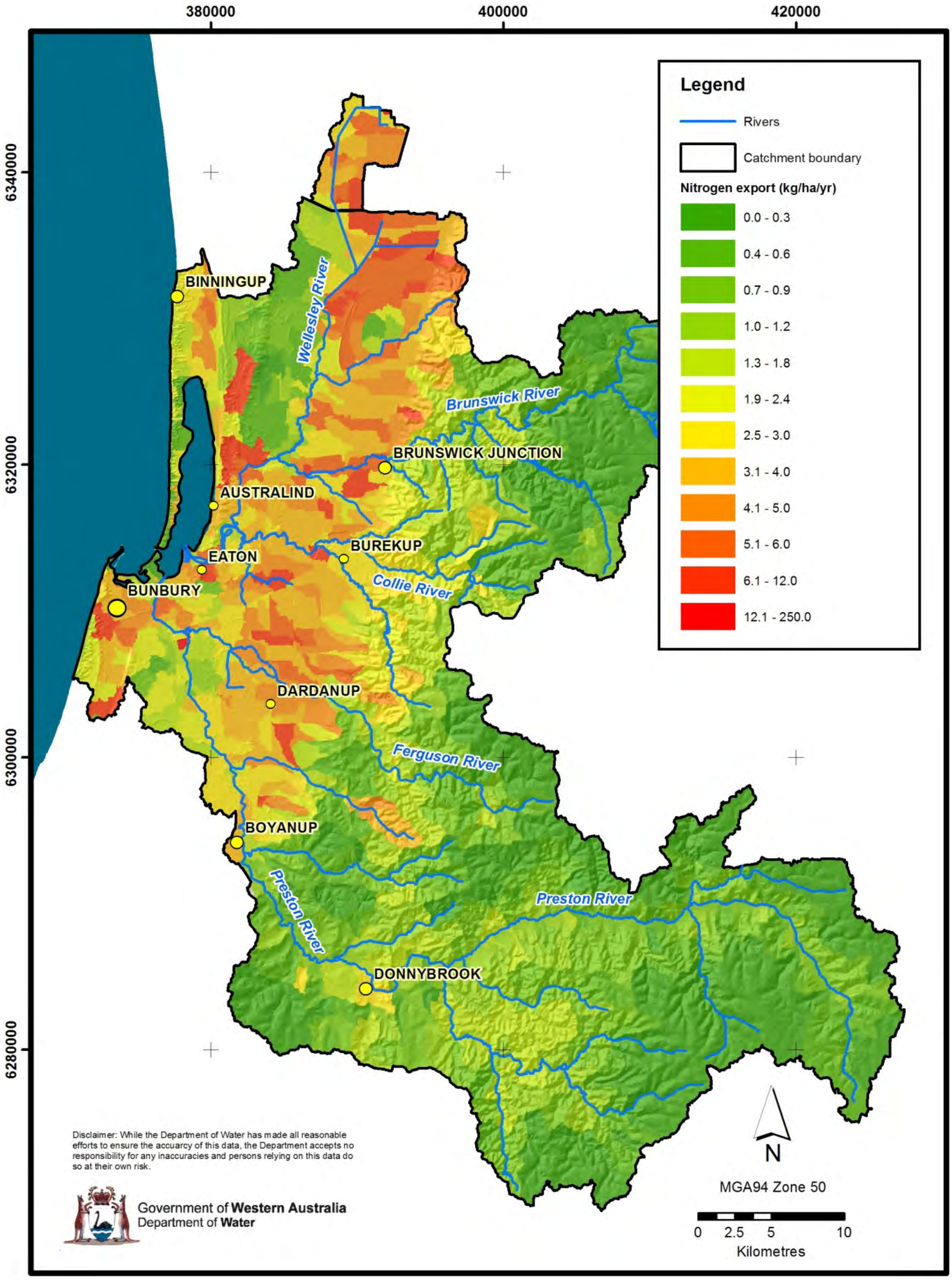


Figure 5-6: Nitrogen export hotspots in the Leschenault catchment

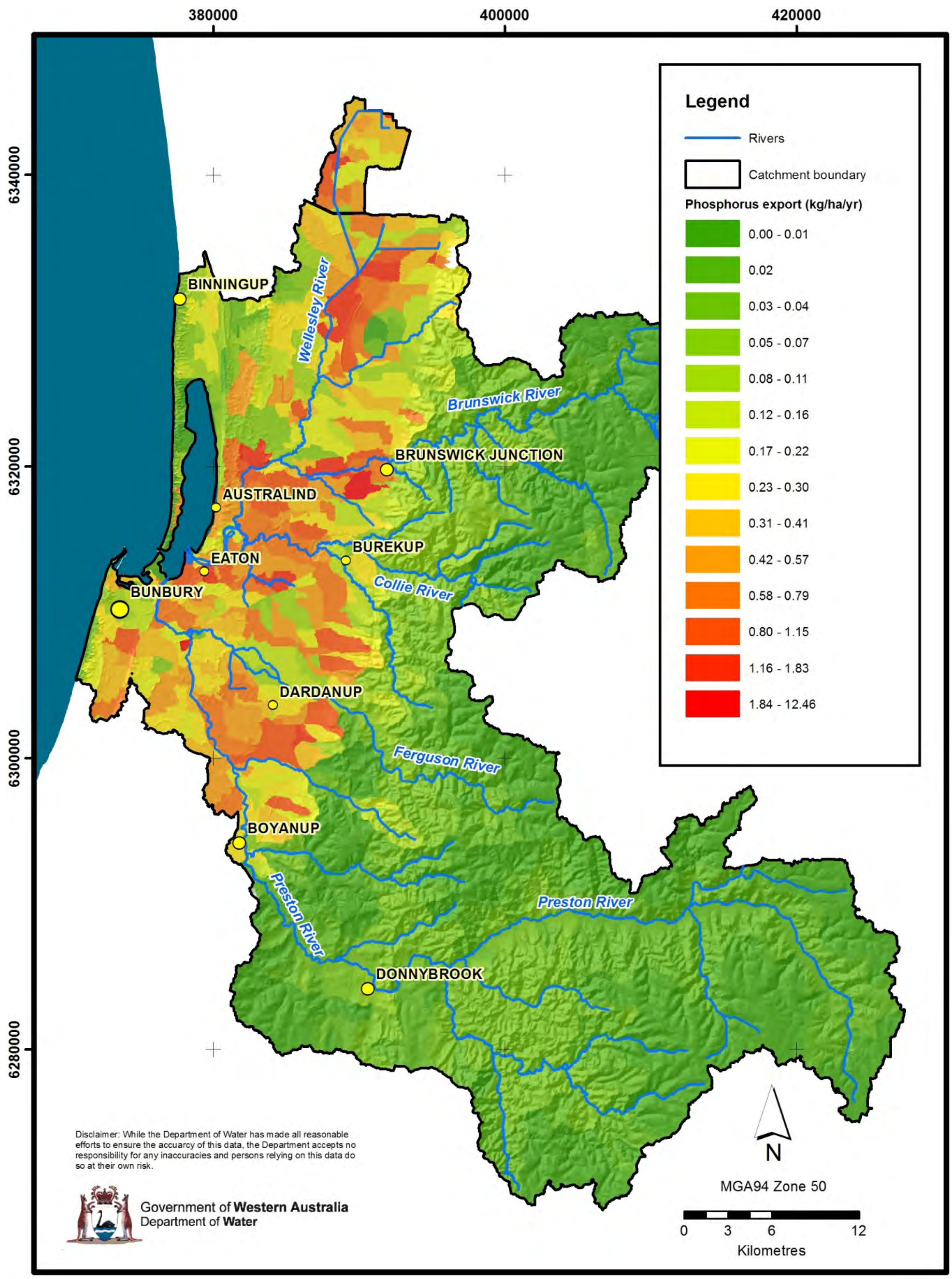


Figure 5-7: Phosphorus export hotspots in the Leschenault catchment

5.3 Additional future loads from proposed GBRS urban expansion

The WaterCAST model was used to estimate the increases in nutrient loads to the Leschenault Estuary and ocean associated with the larger urban area proposed in the GBRS. The inputs to the WaterCAST model were modified to include the potential increases in urban land use area and the estimated increases in WWTP loads.

The GBRS predicts an increase in urban area from 4.3% of the catchment in 2005, to 5.2% of the catchment at completion of the development. Most new urban areas are located close to the coast and estuary near Bunbury, Australind and Eaton.

Future loads from the Kemerton, Dardanup and Donnybrook WWTPs were estimated by assuming the annual load increases are in proportion to the forecast increases in annual discharge, based on Water Corporation estimates for the year 2030. That is, it was assumed that the effluent quality (except for Kemerton) does not change. Output loads from the WWTPs are shown in Table 5-7. The modelling assumed that septic tank numbers did not change.

Table 5-7: Estimated current and future output loads from the WWTPs

WWTP	Median TN concentration 2000 to 2008 (mg/L)[c]	Median TP concentration 2000 to 2008 (mg/L)[c]	Average annual flow 1998 to 2007 (ML/yr)[a]	Future 2030 annual flow (ML/yr)[a]	Estimated nitrogen load 1998 to 2007 (kg/yr)[c]	Estimated phosphorus load 1998 to 2007 (kg/yr)[c]	Estimated future nitrogen load 2030 (kg/yr)[bd]	Estimated future phosphorus load 2030 (kg/yr)[d]
Kemerton	8.7[b]	1.3	769	3 285	10 155	1 641	14 290	4 271
Donnybrook	36.0	11.0	35	237	1 305	391	8 541	2 610
Dardanup	17.5	12.0	30	52	548	380	913	626

[a] *2030 flow estimates based on IPB 2007 projected flow based on 540 litres per service (kl/day) supplied by Water Corporation*
[b] *Water Corporation expects TN concentration in discharge to halve after upgrades to Kemerton*
[c] *Calculated monthly timeseries of flow and concentration*
[d] *Estimated flow in 2030 multiplied by median concentration from 2000 to 2008*

In reality, as the WWTPs are upgraded as treatment volumes increase, loads will not necessarily increase in the linear way assumed here. For example, the Water Corporation is planning to upgrade Kemerton WWTP to include an oxidation ditch to further denitrify wastewater. The expected halving of TN concentration in discharges was taken into consideration for estimated future nitrogen loads. There is also a proposal to pipe wastewater from Kemerton to ocean outfall using the Verve pipeline. The Water Corporation plans to direct wastewater to the pipeline when irrigation of the woodlot is undesirable. It is estimated this would decrease the current loading by 50% (Van Wyck, pers. comm. 20 May 2010). No major upgrades are planned for the other plants.

The Water Corporation has further advised (Scott Moorhead, pers. comm. April 2012) that the Eaton sewer catchment will be diverted in 2014 from Kemerton to the Bunbury WWTP, thus reducing flows to the Kemerton WWTP from an estimated 3600 m^3/day to 1800 m^3/day (50% reduction). The Kemerton WWTP would then only receive flows from the Australind sewer catchment.

Data on projected growth for the Burekup and Brunswick WWTPs were not provided and thus future loads could not be estimated.

The current average annual loads and the estimated future loads following the GBRS expansion are listed in Table 5.8 and plotted in Figure 5-9. The total nitrogen and phosphorus loads to the estuary and ocean are estimated to increase from 326 to 338 tonnes and 29 to 31 tonnes respectively. Nutrient loads from urban areas (including those draining to the coast) are expected to increase from 17 to 29 tonnes for nitrogen, and from 2.1 to 4.0 tonnes for phosphorus. WWTP annual loads were estimated to increase from 5 to 11 tonnes for nitrogen and 0.8 to 1.6 tonnes for phosphorus. The load increases include new connections, and infill sewerage in existing areas.

Table 5-8: Current and future (following GBRS full development) nitrogen and phosphorus loads to receiving waterways from urban areas, septic tanks, WWTPs and other sources

	Current load		Future load	
Nutrient source	**Nitrogen (tonnes)**	**Phosphorus (tonnes)**	**Nitrogen (tonnes)**	**Phosphorus (tonnes)**
WWTP	5	0.8	11	1.6
Septics	26	2.1	26	2.1
Urban	17	2.1	29	4.0
Others	277	23.9	272	22.9
Total	326	28.9	338	30.6

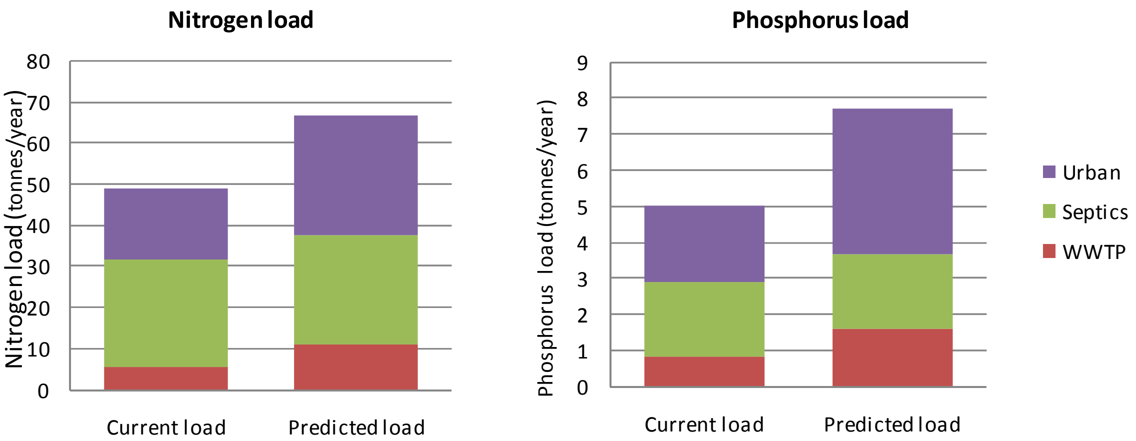


Figure 5-8: Estimated urban, septic tank and WWTP nitrogen and phosphorus loads in receiving waterways currently, and following full development of the GBRS

5.4 Load reduction targets

The water quality modelling has provided four sets of data on nutrient loads that may be compared for each reporting subcatchment as follows:

- the current average annual loads of phosphorus and nitrogen for the years 1998 to 2007

- the estimated future loads of phosphorus and nitrogen that will be delivered by the waterways once the predicted land use changes (based on the GBRS urban expansion) over the next 20 years have occurred
- the ‘acceptable’ loads of phosphorus and nitrogen which assume the WQOs – TN: 0.45 mg/L for upland streams and 1.0 mg/L for lowland streams; TP: 0.02 mg/L for upland streams and 0.1 mg/L for lowland streams – are achieved in the intervention and recovery catchments (‘acceptable’ loads in the protection subcatchment are the current loads)
- ‘load reduction targets’ calculated as the difference between the ‘current’ load and the ‘acceptable’ load of phosphorus and nitrogen.

Load reduction targets

Current, future and acceptable nitrogen and phosphorus loads for the Leschenault subcatchments are shown in Table 5-9 and Figure 5-9. The totals for the estuary and the Coast subcatchment are shown in Table 5-10.

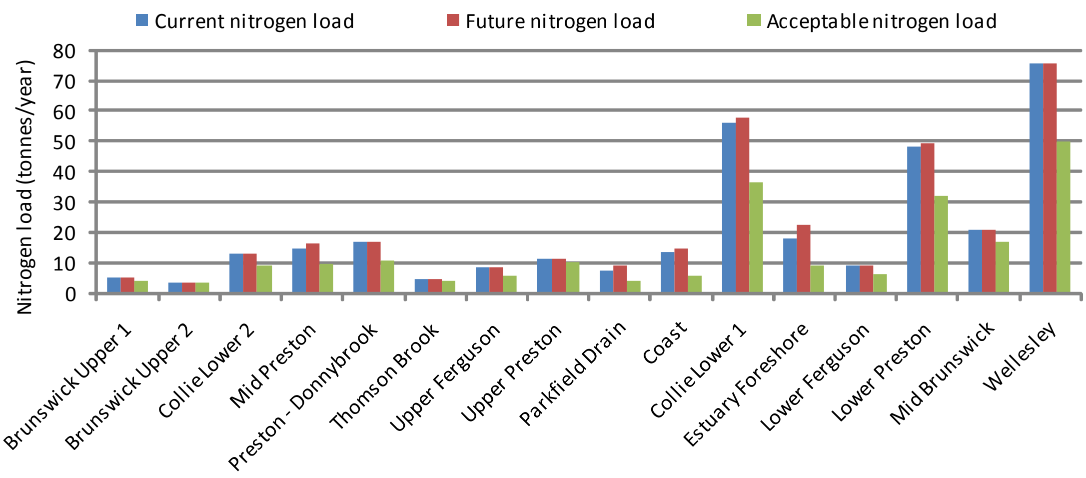
Several subcatchments stand out as requiring dramatic reductions in both nitrogen and phosphorus loads, including the Wellesley, Lower Preston, Collie Lower 1 and Mid Brunswick. Of particular concern is the Wellesley subcatchment, which needs to reduce phosphorus export by almost two thirds to meet water quality objectives . All of the subcatchments located on the Swan Coastal Plain require some nitrogen load reduction.

The load reduction target for the estuary is shown in Table 5-10. This target will contribute to protecting and maintaining the ecological values and services afforded by the estuary. It is based on the cumulative load reduction targets that need to be achieved within each subcatchment so that the TN and TP concentration targets are met.

Table 5-9: Estimated current, future (after full development of the GBRS) and acceptable loads and load reduction targets. The load reduction targets are relative to the current loads.

Name	Current nitrogen load (tonnes/year)	Future nitrogen load (tonnes/year)	Acceptable nitrogen load (tonnes/year)	Nitrogen load reduction target (tonnes/year)	Nitrogen load reduction target (%)
			Protection		
Brunswick Upper 2	3.5	3.5	3.5	0.0	0%
			Intervention		
Brunswick Upper 1	4.9	4.9	4.2	0.7	13%
Collie Lower 2	12.9	13.1	8.8	4.2	32%
Mid Preston	14.6	16.2	9.6	4.9	34%
Preston - Donnybrook	17.0	17.0	10.4	6.6	39%
Thomson Brook	4.3	4.3	4.1	0.3	6%
Upper Ferguson	8.6	8.6	5.7	2.9	34%
Upper Preston	11.0	11.0	10.0	1.0	9%
Parkfield Drain	7.4	9.0	4.0	3.4	46%
			Recovery		
Coast	13.8	14.8	5.7	8.0	58%
Collie Lower 1	55.8	57.9	36.5	19.3	35%
Estuary Foreshore	18.1	22.7	9.2	8.9	49%
Lower Ferguson	9.1	9.1	6.0	3.0	33%
Lower Preston	48.1	49.5	32.0	16.1	33%
Mid Brunswick	20.6	20.7	16.7	3.9	19%
Wellesley	75.9	75.9	50.0	25.9	34%
Total	325.6	338.3	216.5	109.1	34%

Name	Current phosphorus load (tonnes/year)	Future phosphorus load (tonnes/year)	Acceptable phosphorus load (tonnes/year)	Phosphorus load reduction target (tonnes/year)	Phosphorus load reduction target (%)
			Protection		
Brunswick Upper 2	0.08	0.08	0.08	0.0	0%
			Intervention		
Parkfield Drain	0.30	0.36	0.27	0.0	0%
Brunswick Upper 1	0.12	0.12	0.12	0.0	0%
Collie Lower 2	0.39	0.44	0.39	0.0	0%
Mid Preston	0.33	0.35	0.33	0.0	0%
Preston - Donnybrook	0.40	0.40	0.40	0.0	0%
Thomson Brook	0.11	0.11	0.11	0.0	0%
Upper Ferguson	0.24	0.24	0.24	0.0	0%
Upper Preston	0.25	0.25	0.25	0.0	0%
			Recovery		
Coast	1.08	1.2	0.6	0.5	43%
Collie Lower 1	6.50	6.9	3.5	3.0	46%
Estuary Foreshore	1.80	2.6	1.0	0.8	46%
Lower Ferguson	0.65	0.7	0.6	0.1	9%
Lower Preston	6.03	6.3	3.4	2.7	44%
Mid Brunswick	3.26	3.2	1.6	1.6	50%
Wellesley	7.39	7.4	4.9	2.5	34%
Total	28.92	30.6	17.8	11.2	39%



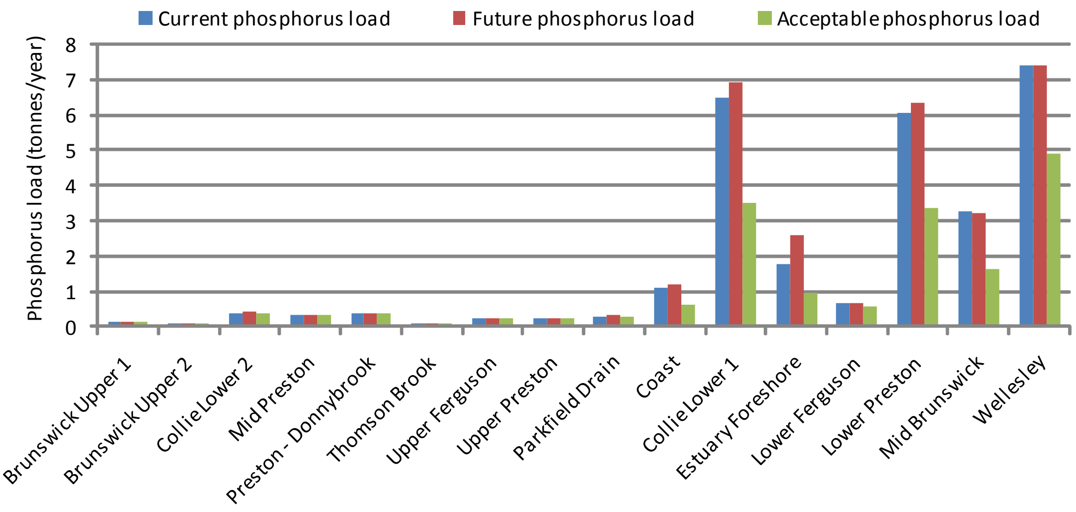


Figure 5-9: Current, future and acceptable nitrogen and phosphorus loads to the Leschenault Estuary and ocean (from the Coast subcatchment)

Table 5-10: Leschenault Estuary and Coast current future (after full development of the GBRS) and acceptable loads and load reduction targets. The load reduction targets are relative to the current loads.

	Current nitrogen load (tonnes/year)	Future nitrogen load (tonnes/year)	Acceptable nitrogen load (tonnes/year)	Nitrogen load reduction target (tonnes/year)	Nitrogen load reduction target (%)
Leschenault Estuary	312	323	211	101	32%
Coast	13.8	14.8	5.7	8.0	58%
	Current phosphorus load (tonnes/year)	**Future phosphorus load (tonnes/year)**	**Acceptable phosphorus load (tonnes/year)**	**Phosphorus load reduction target (tonnes/year)**	**Phosphorus load reduction target (%)**
Leschenault Estuary	27.8	29.4	17.1	10.7	38%
Coast	1.08	1.2	0.6	0.5	43%

5.5 How does the Leschenault Estuary compare with other estuaries?

The TN and TP concentrations in the water column and the CO_2 and NH_4 sediment fluxes in the Leschenault Estuary were compared with those of other south-west estuaries in Section 0. This section compares the flows and nutrient loads to the Leschenault Estuary with those to the Swan-Canning, Peel-Harvey and Vasse-Wonnerup estuaries.

The water and nutrient inflows to the estuaries are listed in Table 5-11. The estuary surface area and nutrient inputs per surface area are also listed. If surface area is used as a de facto for estuary size and thus its ability to absorb and process nutrients, then in terms of phosphorus the estuaries have approximately the same relative loadings, but for nitrogen the Swan-Canning and the Leschenault have much larger loadings than the other estuaries. The Swan-Canning has large nitrogen inputs from the Avon catchment (predominantly wheat/sheep farming) and the Leschenault from the large areas of dairy and beef farming in its catchment.

Table 5-11: Water and nutrient inflows to the south-west estuaries

Estuary	Estuary area (km^2)	Flow (GL)	Nitrogen load (tonnes)	Phosphorus load (tonnes)	Flow per area (GL/km^2)	Nitrogen load per area (t/km^2)†	Phosphorus load per area (t/km^2)†
Swan-Canning	40	443	826	46	11	21	1.1
Peel- Harvey	133	684	1022	140	5	8	1.1
Leschenault	27	358	312	28	13	12	1.0
Vasse-Wonnerup	18	61	134	16	3	7	0.9

† tonnes/km²

The ability of an estuary to flush and process nutrients depends on its physical characteristics – shape, size, connection to the ocean, sediment type, and amount of inflow. The Leschenault Estuary has relatively larger inflows than the other estuaries on a per surface area basis (Table 5-11). This and the natural setting of the waterways flowing near The Cut, as well as the estuary's good marine exchange and well-oxygenated waters, are helping to maintain its health. The high calcium content of the sediments may also be contributing to low TP concentrations.

The other estuaries generally have river inputs far from the ocean outlet and all exhibit greater consequences from eutrophication than the Leschenault. In fact, eutrophication of the Peel-Harvey estuary was such a problem that the Dawesville Channel was constructed to increase flushing from the estuary and improve marine exchange. The Vasse-Wonnerup estuary has experienced extreme eutrophication due to low flushing and barrages that stop marine inflows.

Catchment characteristics

Figure 5-10 shows the nitrogen and phosphorus loads to the Swan-Canning, Peel-Harvey, Leschenault and Vasse-Wonnerup estuaries from their catchments. The flows to the estuaries and the flow-weighted concentrations (average annual load/average annual flow) are shown in figures Figure 5-11 and Figure 5-12.

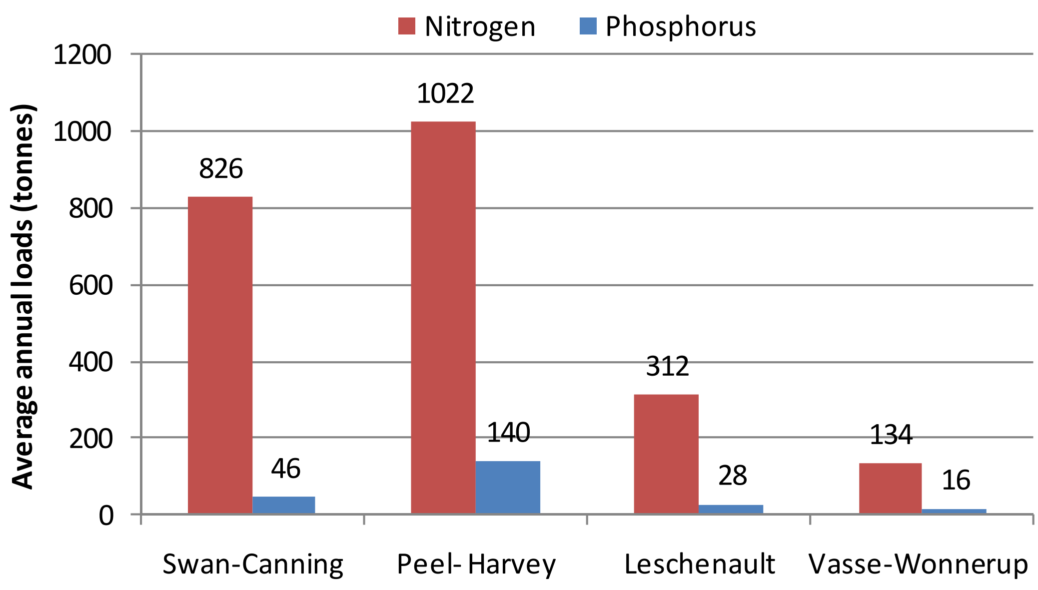


Figure 5-10: Average annual nitrogen and phosphorus loads to south-west estuaries

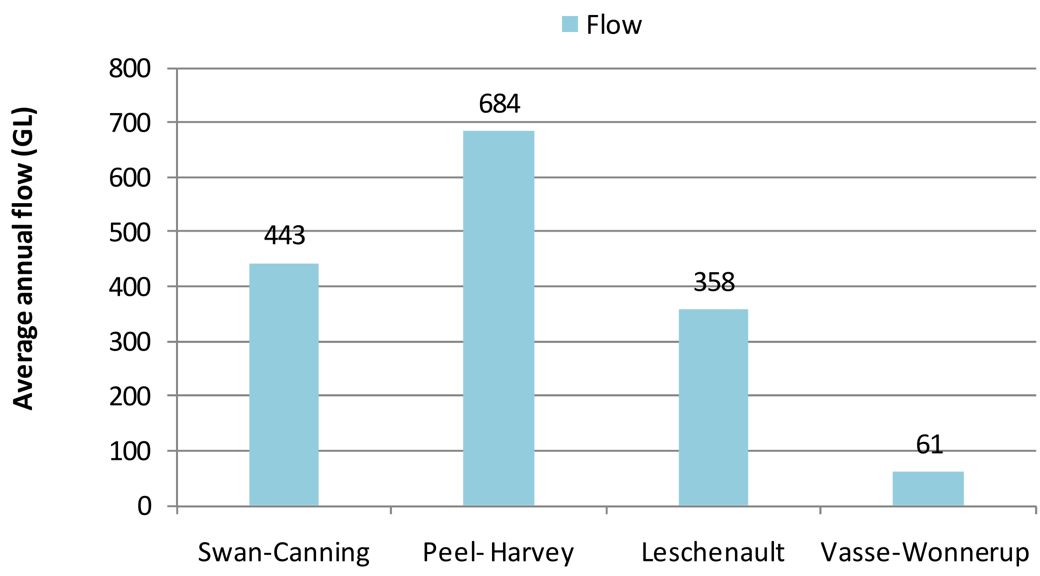


Figure 5-11: Average annual flow for south-west estuaries

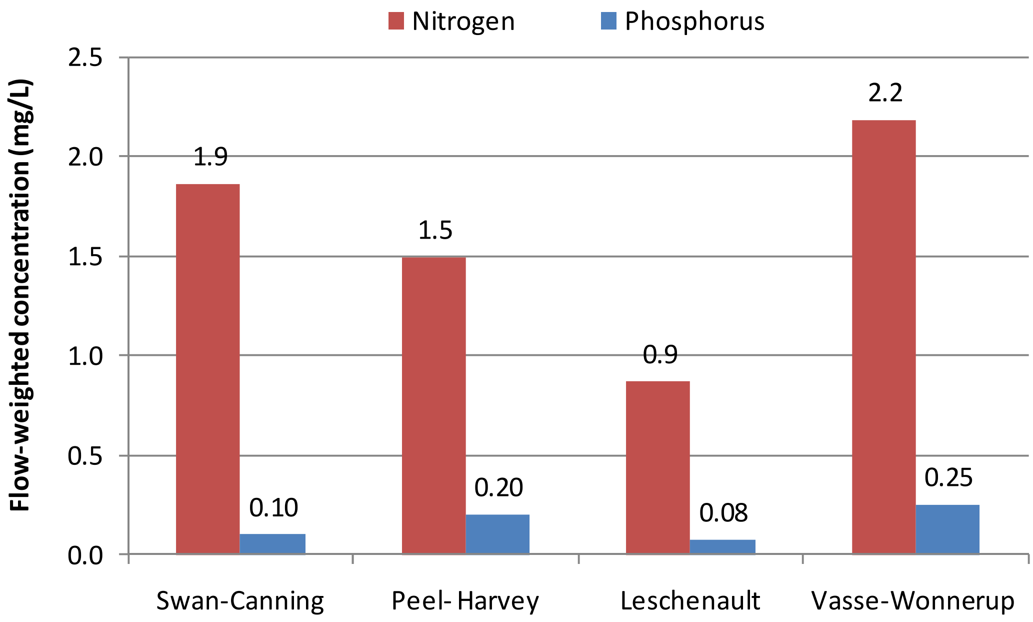


Figure 5-12: Flow-weighted concentrations of inflows to the south-west estuaries

The Leschenault Estuary has the lowest flow-weighted nitrogen and phosphorus concentrations. The Vasse-Wonnerup estuary, which has most of its contributing area on the Swan Coastal Plain, has the highest flow-weighted nutrient concentrations. The low concentrations in the Leschenault Estuary inflows are due to it having the smallest percentage of cleared area (48% compared with approximately 60% for most of the other catchments), relatively good soils and relatively large flow volumes.

However, the intensity of land use on the coastal plain portion of the Leschenault catchment is similar to that of the other catchments, as seen in the estimated nutrient loads per cleared catchment area shown in Figure 5-13. The coastal plain portions of the catchments contribute most of the nutrient loads (especially phosphorus) due to the poor nutrient-retaining soils, high watertable and intensive land uses compared with areas on the Darling Plateau.

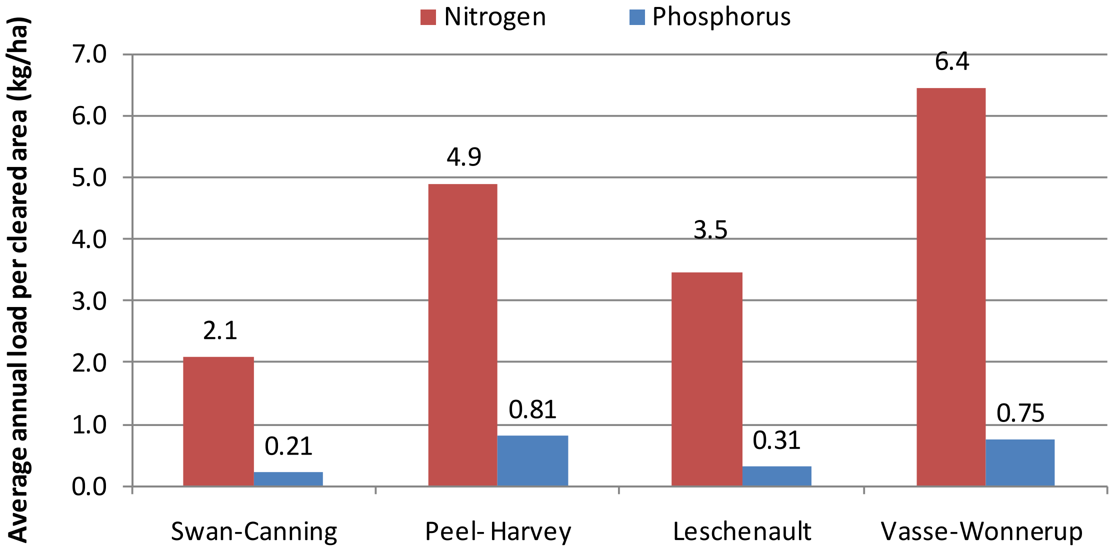


Figure 5-13: Average annual nitrogen and phosphorus loads per cleared area for the catchments of the south-west estuaries. Avon catchment (upstream of 616011) is not included in the Swan-Canning data and the area upstream of Baden Powell Water Spout (614006) is not included in the Peel-Harvey data.

Conclusions

Despite having relatively large flow volumes with low nutrient concentrations, at present the Leschenault Estuary is moderately disturbed. It suffers from severe water quality problems in the summer months. The natural setting of the waterways flowing near The Cut and the good marine exchange are helping to maintain the health of the main body of the estuary. However, it has catchment land uses of similar intensity to the other south-west estuaries and is becoming increasing eutrophied. Unless measures are put in place to decrease nutrient inflows, the estuary will suffer further ecosystem degradation, including more frequent algal blooms and fish deaths. The drying climate will exacerbate the situation as decreased flow volumes will have higher nutrient concentrations. In a drier climate, the estuary will also be more saline and thus cause other ecosystem stresses including:

- increased hypersalinity in the northern part of the estuary
- greater extent and duration of salinity stratification in the estuarine portions of the rivers
- changed biota composition towards more salt-tolerant species.

6 Implementation of management measures to address nutrient pollution

As outlined in previous sections, the identification of management solutions has been based on a logical progression:

- identifying problems in terms of declining water quality and loss of amenity due to nutrient and organic discharges from the catchment
- establishing sources of nutrients
- identifying potential solutions
- determining the cost and benefit of identified solutions where data exist
- applying the solutions to the subcatchments so the required load reductions are achieved using the catchment models
- assessing the aggregated cost/benefit.

6.1 Management directions arising from water quality modelling

The Departments of Water's monitoring and modelling of nutrient pollution in the Leschenault catchment provides key messages to guide nutrient management. These are:

Agricultural sources

At present, diffuse agricultural land uses are the main source of nutrients entering the Leschenault Estuary. The largest contributors are beef and dairy farming, which together contribute approximately 70% of both the nitrogen and phosphorus loads. The dairy industry on 5% of the land area contributes 20% of the nitrogen load and 25% of the phosphorus load.

Dairy sheds, of which there are an estimated 42 within the catchment, also have significant load contributions totalling 3% of the nitrogen and 6% of the phosphorus loads.

Urban sources

Urban settlements and industries contribute 20% of both nitrogen and phosphorus loads, but only represent 3% of the catchment's cleared area. Urban development is concentrated in the lower part the Leschenault catchment, generally abutting the estuary, inlet and waterways where algal blooms tend to occur. Although not the focus of this report, it should be noted that urban and industrial land uses are also associated with non-nutrient contaminants such as heavy metals, hydrocarbons and endocrine-disrupting chemicals.

Urban residential and recreational areas contribute a moderate load of nutrients (5% of nitrogen and 7% of phosphorus). Further urbanisation of the Leschenault catchment would contribute to increased loads.

Septic tanks are a source of considerable nutrient loads to the estuary (8% of the nitrogen and 7% of the phosphorus) and most are located near the estuary or the coast. In some subcatchments, septics contribute a large percentage of the nutrient load; for example, 44% of the nitrogen and 20% of the phosphorus load in the Coast subcatchment, and 33% of the nitrogen and 34% of the phosphorus load in the Estuary Foreshore subcatchment.

DEC-licensed point sources contribute 5% of the nitrogen and 3% of the phosphorus load. Yet in the Lower Preston subcatchment, point sources contribute 29% of the nitrogen and 13% of the phosphorus load. At this scale the local impact cannot be ignored.

WWTP contributions also need attention. The Kemerton WWTP contributes 20% of the nitrogen and 12% of the phosphorus load from the Estuary Foreshore subcatchment, while the Brunswick WWTP contributes 6% of the nitrogen and 16% of the phosphorus load from the Mid Brunswick subcatchment. Further urbanisation of the Leschenault catchment will contribute to increased WWTP loads, for which the Water Corporation undertakes long-term planning to reflect the lead times required for major works such as WWTP upgrades. Current plans are firstly to limit and then reduce flow-through at the Kemerton WWTP. Based on the GBRS, which identifies regions for future growth, the Water Corporation is undertaking long-term strategic planning for wastewater services and identifying opportunities for re-use in the Greater Bunbury region.

The Water Corporation is also looking to reduce the nutrients discharging into Elvira Gully from Brunswick WWTP: options being evaluated include improving treatment of wastewater and transferring it to another WWTP for treatment and management.

Point sources

Some DEC-licensed point sources were identified as contributing significant amounts of nitrogen and/or phosphorus to land or water. Effort should be directed to reducing these discharges through implementation of industry best practice and improved treatment of effluent before discharge.

6.2 Best-management practices

The BMPs discussed in this section are based on the work completed for the Vasse-Wonnerup/Geographe Bay WQIP by White (2010). The assumptions behind the effectiveness of the agricultural BMPs were reviewed by DAFWA staff for the purpose of this project in July 2010, with some changes reflecting applications to the Leschenault catchment. The urban BMPs were also reviewed to reflect the Leschenault catchment’s situation. The BMPs are listed in Table 6-1 and a detailed description of each BMP including background information, definition, benefits, current uptake and barriers to adoption, advice for implementation and implications of investment is included in Appendix I. The BMPs have principally been chosen to address nutrients, but in some instances also to help address other contaminants.

6.2.1 The treatment train approach

To achieve the WQOs effectively and efficiently, management practices have to be implemented concurrently (in parallel) or sequentially (one after another) across the whole catchment. This is done using a ‘treatment train’, which retains or treats the nutrient at its source, as it travels beyond the farm paddock or urban development to the receiving waterbody, and in the receiving waterbody itself

Table 6-1: Best-management practices (BMPs)

Addressing pollutant sources	BMP description
Managing diffuse pollution from agriculture	– Improve fertiliser management throughout the catchment – Use of slow-release phosphorus fertilisers – Use of approved soil amendments – Using subtropical perennial pastures for broadacre dryland grazing – Implementation of annual horticulture BMPs† – Implementing riparian zone management – Improving irrigation efficiencies
Managing point source pollution from agriculture	– Improving effluent management of dairy sheds
Managing diffuse nutrients and other contaminants (heavy metals, hydrocarbons, sediments etc.) from the urban landscape	– Reducing nutrient use and export risk in urban areas (includes improved fertiliser management) – Use of slow-release phosphorus fertilisers – Use of approved soil amendments – Ensuring new urban developments incorporate water sensitive urban design (WSUD); for example, biofiltration systems, raingardens, swales, nutrient stripping of subsurface drainage – Undertaking strategic retrofitting of WSUD in existing urban areas
Managing urban point sources	– No release of WWTP effluent to catchment waterways and ensure no adverse impacts from WWTP effluent re-use on woodlots, golf courses or other recreational grounds – Removal of DEC-licensed point sources, or more stringent licence conditions that prohibit pollutant release to the environment (air, land water) – Replace septic systems with fully-contained treatment units (no nutrient release to the environment) or reticulated deep-sewerage system

†Not modelled

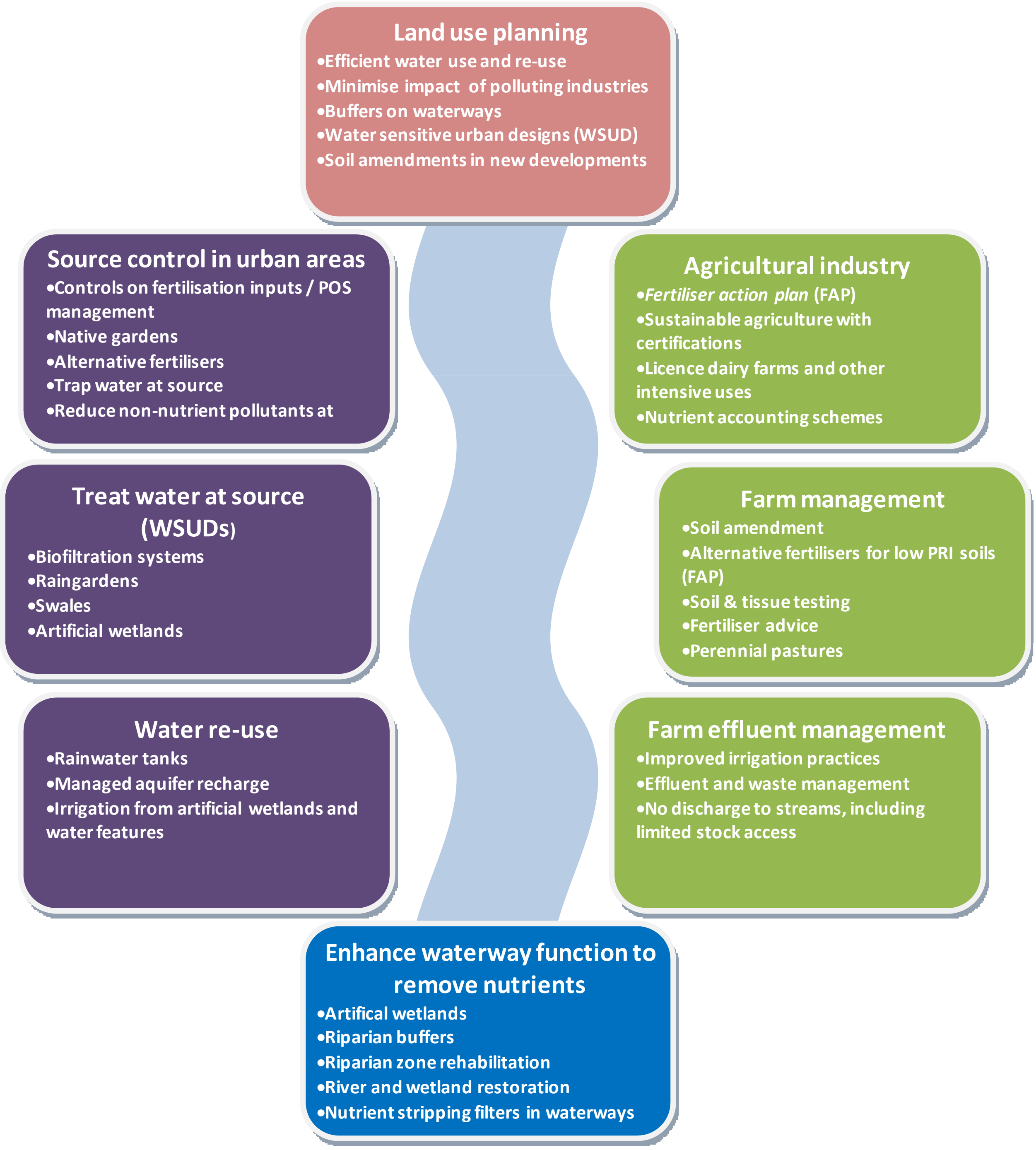


Figure 6-1: Best-management practice treatment train

6.3 BMP selection and implementation

Cost/benefit analyses that considered the cost of BMPs implemented and benefit in terms of nitrogen and phosphorus load reductions were undertaken to deduce the most cost-effective combination of BMPs. However, nitrogen and phosphorus load reductions that meet the load reduction targets given in Section 5.4 could only be achieved in some subcatchments if unrealistic adoption rates for many BMPs were assumed. Thus, the BMPs selected for implementation (Scenario 5b) are a compromise between realistic adoption rates that could be achieved in a 10-year timeframe and water quality improvement.

BMP capital and ongoing annual costs were based on SPNND modelling done for the Vasse-Wonnerup/Geographe Bay WQIP (Ecotones & Associates 2008; Neville 2008b, c) and updated for this project in consultation with DAFWA and the Department of Water. The capital costs do not include salaries/wages and project-related on-costs associated with delivery of these activities.

Table 6-2 lists capital costs, ongoing annual costs and returns, and potential load reductions (effectiveness) for the BMPs for which data were available.

BMP implementation is described for each subcatchment in *Implementing the Leschenault Estuary water quality improvement plan* (DoW 2012). The implementation assumptions are listed below. The number of sites, length of riparian zone or areas of land use treated for each BMP in each respective subcatchment are shown in Table *6-3*

Not all the BMPs discussed could be run in the cost/benefit analysis due to a lack of information: either on their effectiveness in reducing nitrogen and phosphorus loads or costs associated with their implementation. The BMPs that could not be included should, however, still be considered in the respective subcatchments where they would apply.

Implementation assumptions

BMP #1 Effluent management in dairy sheds:

- As it was assumed that approximately 10% of farmers already have effluent management systems, 37 of the 42 known dairy sheds were assumed to have new effluent management systems installed during the 10-year timeframe.

BMP #2 DEC-licensed point source mitigation:

- Assumed no emissions from all DEC-licensed point sources (note: some sites have minimal discharges).

BMP #3 Septic tanks removal (broken into three components):

- *Unsewered septic tanks urban*: urban areas with septic tanks where infill sewerage is not presently available assumed to be connected to infill sewerage
- *Unsewered septic tanks rural/commercial*: rural and commercial areas where deep-sewerage is not an option were assumed to install alternative systems (most likely ATUs) which have low nutrient emissions
- Unconnected septics in in-filled areas: homes in urban areas where deep-sewerage is available, but that are not connected, were assumed to connect to the deep-sewerage system.

Table 6-2: Effectiveness as a percentage of load reduction, capital cost and ongoing annual costs of BMPs implemented in the Leschenault catchment. Not all BMPs could be costed.

BMP	Units	N reduction effectiveness	P reduction effectiveness	Capital cost per unit	Annual return per unit	Annual cost per unit	Annual net per unit
Dairy effluent management	#	60%	60%	$35 750	$33 634	$9988	-$23 646.00
Septics							
Unsewered septic tanks urban	#	100%	100%	$14 000	$ -	$ -	$ -
Unsewered septic tanks rural/comm (ATU)	#	100%	100%	$13 889	$ -	$1000	$ 1000.00
Unconnected septics in infill areas	#	100%	100%	$1144	$ -	$ -	$ -
Fertiliser management	ha	5%	7.5%	$11	$28	$4	-$23.65
Perennials							
Beef grazing	ha	40%	5%	$330	$72	$33	-$38.50
Horses & lifestyle	ha	40%	5%	$330	$ -	$33	$33.00
Irrigation management	ha	25%	25%	$1375	$110	$34	-$75.90
Soil amendment							
NUA 5T/ha [Lesch]	ha	5%	30%	$84	$44	$8	-$35.59
NUA 10T/ha [Lesch]	ha	5%	50%	$168	$60	$17	-$43.19
NUA 20T/ha [Lesch]	ha	5%	60%	$336	$80	$34	-$46.38
Riparian management							
Hills							
Riparian management High 1st	km	50%	30%	$34 420	-$110	$110	$220.00
Riparian management Moderate 1st	km	40%	15%	$25 420	-$220	$55	$275.00
Riparian management Low 1st	km	25%	7.5%	$10 000	-$220	$55	$275.00
Coastal plain							
Riparian management High 1st	km	15%	5%	$34 420	-$110	$110	$220.00
Riparian management Moderate 1st	km	12%	2.5%	$25 420	-$220	$55	$275.00
Riparian management Low 1st	km	7.5%	1.3%	$10 000	-$220	$55	$275.00

BMP	Units	N reduction effectiveness	P reduction effectiveness	Capital cost per unit	Annual return per unit	Annual cost per unit	Annual net per unit
Hills							
Riparian management High 2nd	km	50%	30%	$34 420	$-	$110	$110.00
Riparian management Moderate 2nd	km	40%	15%	$25 420	-$165	$55	$220.00
Riparian management Low 2nd	km	25%	7.5%	$10 000	-$110	$55	$165.00
Coastal plain							
Riparian management High 2nd	km	15%	5%	$34 420	$-	$110	$110.00
Riparian management Moderate 2nd	km	12%	2.5%	$25 420	-$165	$55	$220.00
Riparian management Low 2nd	km	7.5%	1.3%	$10 000	-$110	$55	$165.00
Hills							
Riparian management High 3rd	km	50%	30%	$34 420	$110	$110	$ -
Riparian management Moderate 3rd	km	40%	15%	$25 420	-$110	$55	$165.00
Riparian management Low 3rd	km	25%	7.5%	$10 000	$-	$55	$55.00
Coastal plain							
Riparian management High 3rd	km	15%	5%	$34 420	$110	$110	$ -
Riparian management Moderate 3rd	km	12%	3%	$25 420	-$110	$55	$165.00
Riparian management Low 3rd	km	7.5%	1.3%	$10 000	$-	$55	$55.00

Table 6-3: BMPs implemented in cost/benefit analysis for each subcatchment

Subcatchment	Effluent manage-ment	Remove DEC-licensed point sources	Septics removal	WWTP upgrade	Better fertiliser manage-ment	Slow-release fertiliser for P	Perennial grasses uptake	Irrigation efficiency uptake	Apply soil amend-ments (e.g. NUA)	WSUD retrofit	Restore riparian zone[1]
	# dairy sheds	# point sources	#	#	Area managed (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Stream length (km)
Wellesley	20				9 225	3 552	982	355	1 105		44
Brunswick Upper 1					1 174	540	216				3
Brunswick Upper 2					132						4
Mid Brunswick	5	2	10	1	2 502	1 245	388	49	594		14
Collie Lower 1	9		1 005		5 000	2 561	830	184	1 513	73	33
Collie Lower 2					1 527	763	303		41		8
Estuary Foreshore			2 098	1	405	270	51		99	112	14
Parkfield Drain			474		885	205	76		21		7
Upper Preston					3 565	1 782	713				10
Thomson Brook					1 230	615	246				8
Preston-Donnybrook					4 393	2 183	873				25
Mid Preston			848		2 359	1 170	468		48	32	23
Upper Ferguson					1 866	933	316		22		8
Lower Ferguson			135		758	573	118	27	128		3
Lower Preston	3	4	414		3 378	1 708	621		2 147	35	21
Total for estuary	**37**	**6**	**4 984**		**38 397**	**18 098**	**6 202**	**616**	**5 718**	**253**	**225**
Coast			2832		173	173			8	160	3
Total for catchment	**37**	**6**	**7 816**		**38 570**	**18 271**	**6 202**	**616**	**5 726**	**413**	**228**

[1] Different effectiveness and cost depending on stream order and location

The cost of connection in the cost/benefit table is based on cost per household of a recent infill program in Eaton: approximately $14 000 per lot. The Water Corporation also provided an estimated cost for the installation of infill deep-sewerage in some other areas (Australind, Australind East and West) (see Appendix L). Due to the large block sizes (up to 5 ha) and the presence of shallow groundwater, the cost per household in those areas is much higher than the densely urbanised area of Eaton. Although the infill cost for Eaton was used, it should be noted that this may underestimate the cost of infill in the Estuary Foreshore and Lower Collie subcatchments.

BMP #4 WWTP upgrades:

- Kemerton WWTP – 50% reduction in nitrogen and phosphorus loads assumed, which is meant to reflect the planned upgrade and diversion of excess loads into the Verve Pipeline to the ocean.
- Brunswick WWTP – 50% reduction in phosphorus load only assumed.

BMP #5 Fertiliser management:

Implementation depends on subcatchment, with a maximum of 50% uptake in ‘beef’, ‘dairy’ and ‘horse and lifestyle blocks’; and 10% in ‘urban’ land uses.

BMP #6 Slow-release phosphorus fertiliser:

- The modelling of this BMP was undertaken with effectiveness rates and costs based on a product called ‘redcoat’ for which effectiveness rates were available. For low PRI (<5) soils, potential reductions in nutrient leaching were assumed to be 30% for phosphorus and 5% for nitrogen; and for high PRI soils, potential reductions were assumed to be 10% for phosphorus and nil for nitrogen.
- It is assumed a maximum of 25% uptake in ‘beef’ and ‘dairy’ (depending on subcatchment) and 10% uptake in ‘urban’ land uses would occur. Low uptake in rural areas reflects the fact that no slow-release phosphorus fertilisers are currently available for broadacre agriculture. The 10% uptake in urban areas recognises the changes recently introduced for bagged fertilisers in urban areas as part of the *Fertiliser accord*.

BMP #7 Perennial pasture:

- It is assumed a maximum of 10% uptake in ‘beef’ would occur. The low uptake rate reflects past difficulties in implementing perennial pastures in Western Australia.

BMP #8 Irrigation efficiency and management:

- Flood irrigation is a common practice in the irrigated districts of the Leschenault catchment. Water for irrigation from the HWIA is supplied by several dams, which can only supply enough water to irrigate one third of each property (Harvey Water 2009). For example, a 90 ha property would have enough water for about 30 ha with a 9.2 ML total water entitlement (TWE). Therefore, most farms have only invested in the development of one-third of their properties for irrigation, such as laser levelling.
- This BMP assumes that dairy farms in the HWIA area have 25% uptake of converting their current flood-irrigated fields to pivot irrigation. The low uptake is due to capital cost, the poor water quality (too salty) in the Collie irrigation district and low water pressure.

BMP #9 Use of soil amendment:

- There are a range of soil amendments. But for the purpose of this plan, it was decided to run the scenario with NUA amendment and thus the cost and efficiencies of this BMP are based on available data provided by DAFWA (Table 6-4) and revised transport costs from its closest source, the Iluka plant in Capel. The highest application rate (20 tonnes/ha) was chosen for the purpose of the scenario modelling, to maximise phosphorus load reductions. It was assumed that in a 10-year timeframe, there would be a maximum of 50% uptake (depending on subcatchment) in ‘beef’ and ‘dairy’ at a rate of 20 tonnes/ha on low PRI soils and 10% uptake in the urban areas of recovery catchments.

Table 6-4: NUA application rates and related nitrogen and phosphorus percentage runoff reduction

Application rate	Units	Land use impacted	Nitrogen load reduction	Phosphorus load reduction
5 t/ha	ha	Low PRI soils	5%	30%
10 t/ha	ha	Low PRI soils	5%	50%
20 t/ha	ha	Low PRI soils	5%	60%

BMP #10 Water sensitive urban design (WSUD) retrofit:

- It was assumed that a maximum of 15% of urban residential areas and public open space retrofit would be carried out in recovery and intervention subcatchments, as well as the Preston-Donnybrook subcatchment. The assumptions are explained in detail in *Implementing the Leschenault Estuary water quality improvement plan* (DoW 2012).

BMP #11 Riparian restoration and management

- Based on the uncertainty about the effectiveness of riparian buffers on the Swan Coastal Plain, two categories were established with different effectiveness rates: the ‘hills’ and the ‘coastal plain’ (Table 6.5). The modelling could only allow the running of scenarios within each subcatchment with either ‘hills’ or ‘coastal plain’ effectiveness rates. Hence, the category chosen in each subcatchment was based on which category was the most abundant. The uptake of riparian zone rehabilitation varied greatly across the catchment and depended on location and stream order. Priority was given to third- and higher-order streams, which assumed between 50 to 80% uptake. First- and second-order streams had 0 to 30% uptake. Parkfield Drain and some urban areas had high rates of adoption on first- and second-order streams.
- Note that riparian restoration can also reinstate riverine ecological integrity, which provides benefits beyond the nutrient reductions achieved by the riparian buffers (Figure 6-2).

Table 6-5: Riparian restoration BMP effectiveness rates for different topography

		Hills		*Coastal plain*	
Category	**Definition**	**% Nitrogen load reduction**	**% Phosphorus load reduction**	**% Nitrogen load reduction**	**% Phosphorus load reduction**
High	fencing, stock crossing, and dense riparian restoration	50%	30%	15%	5%
Medium	fencing and lower revegetation density	40%	15%	12%	2.5%
Low	fencing only and grass	25%	7.5%	7.5%	1.3%

Figure 6-2: Section of the Preston River requiring fencing to prevent stock access to reduce bank erosion and reinstate riverine ecological integrity (photo: Cathy Derrington, Department of Water)

6.4 Results of scenario modelling

This section discusses the effectiveness of the various BMPs to reduce nitrogen and phosphorus loads at catchment and subcatchment scales. A detailed discussion is included in *Implementing the Leschenault Estuary water quality improvement plan* (DoW 2012). The loads presented are the average annual loads that would eventuate once the full impact of the BMP implementation is apparent. Note that the lag time between BMP implementation and measurable water quality improvement can be years – particularly for diffuse pollution.

6.4.1 Load reductions at catchment and subcatchment scale

The sum of the loads from all subcatchments draining to the Leschenault Estuary, and the Coastal subcatchment which drains to the Leschenault Inlet and the ocean, are shown in Table 6-6 and Figure 6-3.

Table 6-6: Estimated nutrient loads to the estuary and ocean following BMP implementation (Scenario 5b)

	Average annual nitrogen load				Average annual phosphorus load			
	Current load (tonnes)	Load after BMP adoption (tonnes)	Load reduction (%)	Target load (tonnes)	Current load (tonnes)	Load after BMP adoption (tonnes)	Load reduction (%)	Target load (tonnes)
Estuary	312	217	31%	211	28	18	37%	17
Inlet and ocean	13.8	7.1	49%	5.7	1.08	0.77	29%	0.60

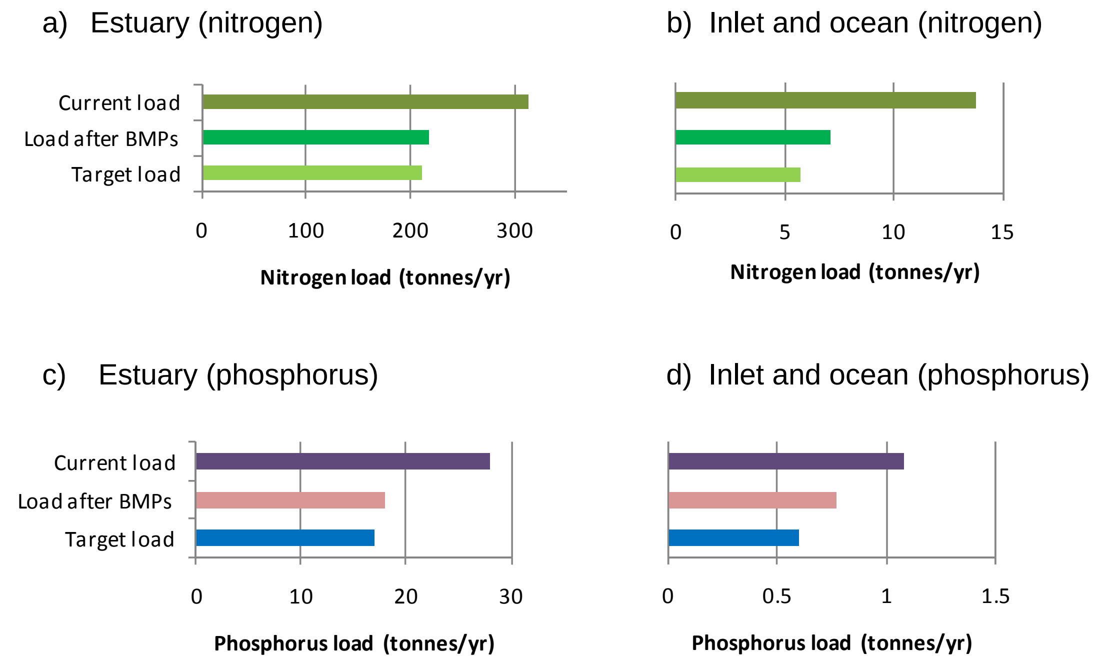


Figure 6-3: Estimated loads to the estuary and ocean following BMP implementation Scenario 5b)

The estimated nutrient loads following BMP implementation (Scenario 5b), in each subcatchment, are listed inTable 6-7. The key results are:

- all subcatchments are predicted to have nutrient load reductions which contribute to the overall load reductions for the estuary
- the total nitrogen load from all subcatchments to the estuary (217 tonnes) is a 31% reduction and almost achieves the total acceptable load to the estuary (211 tonnes)
- the total phosphorus load to the estuary (18 tonnes) is a 37% reduction and almost achieves the acceptable load (17 tonnes).

The load reductions to the inlet and ocean are approximately 50% for nitrogen and 30% for phosphorus. To further reduce loads from areas that drain to the inlet and ocean, extensive WSUD retrofit and urban drainage interventions would be necessary.

Currently nine of the 16 reporting subcatchments meet their water quality objectives for phosphorus and one for nitrogen. Following BMP implementation it is predicted that 12 subcatchments would achieve their phosphorus targets (see Table 6-8):

- Mid Brunswick (R)
- Estuary Foreshore (R)
- Lower Preston (R)
- Parkfield Drain (I)
- Brunswick Upper 1 (I)
- Lower Collie 2 (I)
- Upper Preston (I)
- Thomson Brook (I)
- Mid Preston (I)
- Preston-Donnybrook (I)
- Upper Ferguson (I)
- Brunswick Upper 2 (P)

and nine their nitrogen targets:

- Mid Brunswick (R)
- Lower Preston (R)
- Brunswick Upper 1 (I)
- Lower Collie 2 (I)
- Upper Preston (I)
- Thomson Brook (I)
- Mid Preston (I)
- Preston-Donnybrook (I)
- Brunswick Upper 2 (P)

Nine subcatchments improve their classification (see Table 6-8).

Table 6-7: Predicted subcatchment annual average loads following BMP implementation (Scenario 5b)

Subcatchment	Annual nitrogen load				Annual phosphorus load			
	Current load	Load after BMP adoption		Target load	Current load	Load after BMP adoption		Target load
	(tonnes)	(tonnes)	(% reduction of current load)	(tonnes)	(tonnes)	(tonnes)	(% reduction of current load)	(tonnes)
Protection subcatchment								
Brunswick Upper 2	3.5	2.6	25%	3.5	0.08	0.07	8%	0.08
Intervention subcatchments								
Brunswick Upper 1	4.9	1.4	71%	4.2	0.12	0.07	43%	0.1
Collie Lower 2	12.9	5.6	57%	8.8	0.39	0.23	40%	0.4
Mid Preston	14.6	6.9	53%	9.6	0.33	0.20	39%	0.3
Preston - Donnybrook	17.0	10.4	39%	10.4	0.40	0.31	23%	0.4
Thomson Brook	4.3	3.8	12%	4.1	0.11	0.10	7%	0.1
Upper Ferguson	8.6	7.1	18%	5.7	0.24	0.21	13%	0.2
Upper Preston	11.0	10.0	9%	10.0	0.25	0.24	6%	0.3
Parkfield Drain	7.4	5.0	33%	4.0	0.30	0.21	28%	0.3
Recovery subcatchments								
Wellesley	75.9	60.4	20%	50.0	7.39	4.71	36%	4.9
Mid Brunswick	20.6	15.8	23%	16.7	3.26	2.10	35%	1.6
Collie Lower 1	55.8	42.4	24%	36.5	6.50	4.25	35%	3.5
Estuary Foreshore	18.1	9.6	47%	9.2	1.80	1.04	42%	1.0
Lower Ferguson	9.1	7.8	14%	6.0	0.65	0.49	25%	0.6
Lower Preston	48.1	27.6	43%	32.0	6.03	3.36	44%	3.4
Estuary subtotal	312	216	31%	211	28	18	37%	17.1
Coast	13.8	7.1	49%	5.7	1.08	0.77	29%	0.62
Total	**326**	**224**	**31%**	**217**	**28.9**	**18.4**	**37%**	**17.8**

Table 6-8: Subcatchment status following BMP implementation (Scenario 5b)

Reporting subcatchment	Present classification	Classification with BMPs
Wellesley	Recovery	Recovery
Mid Brunswick	Recovery	Protection
Collie Lower 1	Recovery	Recovery
Estuary Foreshore	Recovery	Intervention
Lower Ferguson	Recovery	Recovery
Lower Preston	Recovery	Protection
Coast	Recovery	Recovery
Parkfield Drain	Intervention	Intervention
Brunswick Upper 1	Intervention	Protection
Lower Collie 2	Intervention	Protection
Upper Preston	Intervention	Protection
Thomson Brook	Intervention	Protection
Mid Preston	Intervention	Protection
Preston-Donnybrook	Intervention	Protection
Upper Ferguson	Intervention	Intervention
Brunswick Upper 2	Protection	Protection

For the subcatchments draining to the estuary the most effective BMPs (Scenario 5b) in decreasing order of effectiveness for **nitrogen** are:

BMP	Per cent of estimated load reduction
Riparian zone restoration and creation of buffer:	53%
Removal of DEC-licensed point sources:	15%
Septics removal (connect to infill or replace by ATUs):	9.5%
Better fertiliser management:	6.8%
Perennial pastures:	6.3%
Effluent management of dairy sheds:	5.0%
WWTP upgrades:	1.9%
Irrigation efficiency of flooded dairy:	1.2%
Soil amendment	1.1%
Slow-release phosphorus fertiliser (‘redcoat’ super):	0.7%
WSUD retrofit:	0.6%

Slow-release fertilisers and soil amendments were estimated only to reduce nitrogen export by 0.7% and 1.1% respectively. However, this is an expected result because these BMPs target phosphorus pollution. WWTPs only contribute 2% of total nitrogen load so decreases are small on a catchment-wide scale, but are significant in the Estuary Foreshore and Mid Brunswick subcatchments. Similarly WSUD retrofit is only relevant in subcatchments with large urban areas. However, WWTP and urban sources are generally located closer to the estuary than other sources and their impacts may be underestimated. Due to the small area of adoption, irrigation efficiencies on flooded dairy farms also have little impact on nitrogen export on a catchment-wide scale. All other management interventions made significant contributions towards reducing total loads to the estuary. Although the effectiveness of riparian zone rehabilitation is estimated to be only 7.5 to 15% of the nitrogen load on the coastal plain and 1.3 to 5% on the Darling Plateau, it contributes greatly to nitrogen load reduction because it treats all nitrogen from the catchment to the receiving waterways, not just the contributions from single land uses.

For **phosphorus** reduction, the most effective BMPs (Scenario 5b) in the estuary subcatchments in decreasing order of effectiveness are:

BMP	Per cent of estimated load reduction
Soil amendments:	38%
Slow-release phosphorus fertiliser (‘redcoat’ super):	12%
Riparian zone restoration and creation of buffer:	9.7%
Effluent management of dairy sheds:	9.3%
Better fertiliser management	8.5%
Removal of DEC-licensed point sources:	7.5%
Septic removal (connect to infill or replace by ATUs):	6.6%
WWTP upgrades	3.7%
Irrigation efficiency of flooded dairy:	2.9%
WSUD retrofit	1.3%
Perennial pastures:	0.5%

All BMPs apart from WSUD retrofit and perennial grasses contribute significantly to reducing phosphorus loads on a catchment-wide scale. While soil amendment and slow-release phosphorus fertiliser are the most effective BMPs which account for 50% of the phosphorus load reductions predicted, these products are not yet commercially available or approved. Therefore, without them (in a 10-year implementation plan), catchment phosphorus load reductions will be the much less. The optimistic outcome, if the other management measures suggested here are adopted, is an 18% reduction in the current phosphorus load to the estuary, which is less than half of the required load reduction. It is thus imperative to accelerate the commercialisation of soil amendments and slow-release phosphorus fertilisers (testing and approval process) to ensure they are made available – particularly for beef and dairy farms on low PRI soils, and for new urban developments. This is reinforced by the statement made in the *Fertiliser action plan* (Joint Government and Fertiliser Industry Working Party 2007):

> …costs associated with phasing out high water soluble phosphorus fertiliser are very much lower than almost all other preventative phosphorus reduction strategies especially when applied over the whole south west. It is the single most cost effective management action that can be taken to reduce phosphorus losses to waterways of the coastal plain.

The results, especially for phosphorus, highlight that to achieve the load reduction targets for the Leschenault Estuary, water quality management is a multi-pronged approach that requires the adoption of many BMPs by a range of stakeholders and land managers. Furthermore, implementing water quality improvement is not solely the agricultural sector’s responsibility; solutions also need to be found in urban areas.

Other management actions not included in this cost/benefit analysis, due to lack of data on implementation, effectiveness or cost, also have a role in reducing nutrient loads to receiving waterways. These include effluent management of intensive animal industries, artificial wetlands, acid sulfate soil management, horticultural BMPs and WSUD in new urban developments.

6.4.2 Effectiveness of the individual BMPs in different subcatchments

Estimated average annual nitrogen and phosphorus load reductions for each BMP in each subcatchment are given in tables and respectively, and represented in graphs in figures Figure 6-4 and Figure 6-5. (See Table 6-3 for the amount of BMP uptake in each subcatchment.)

All catchments except for Brunswick Upper 2, Upper Preston and Thomson Brook have significant nitrogen load reductions. There are eight subcatchments with nitrogen load reductions greater than 5 tonnes per year – Lower Preston (20 tonnes), Wellesley (15 tonnes), Lower Collie 1 (13 tonnes), Estuary Foreshore (8 tonnes), Mid Preston (8 tonnes), Lower Collie 2 (7 tonnes), Preston-Donnybrook (7 tonnes) and Coast (7 tonnes).

For phosphorus, as Figure 6-5 shows, the subcatchments where implementation of the selected BMPs would have the largest phosphorus load reductions are the Lower Preston, Wellesley, Lower Collie 1, Mid Brunswick and Estuary Foreshore. The other subcatchments have small phosphorus load reductions, less than 0.16 tonnes individually, yet cumulatively achieving a reduction of 0.73 tonnes (not including the Coast subcatchment).

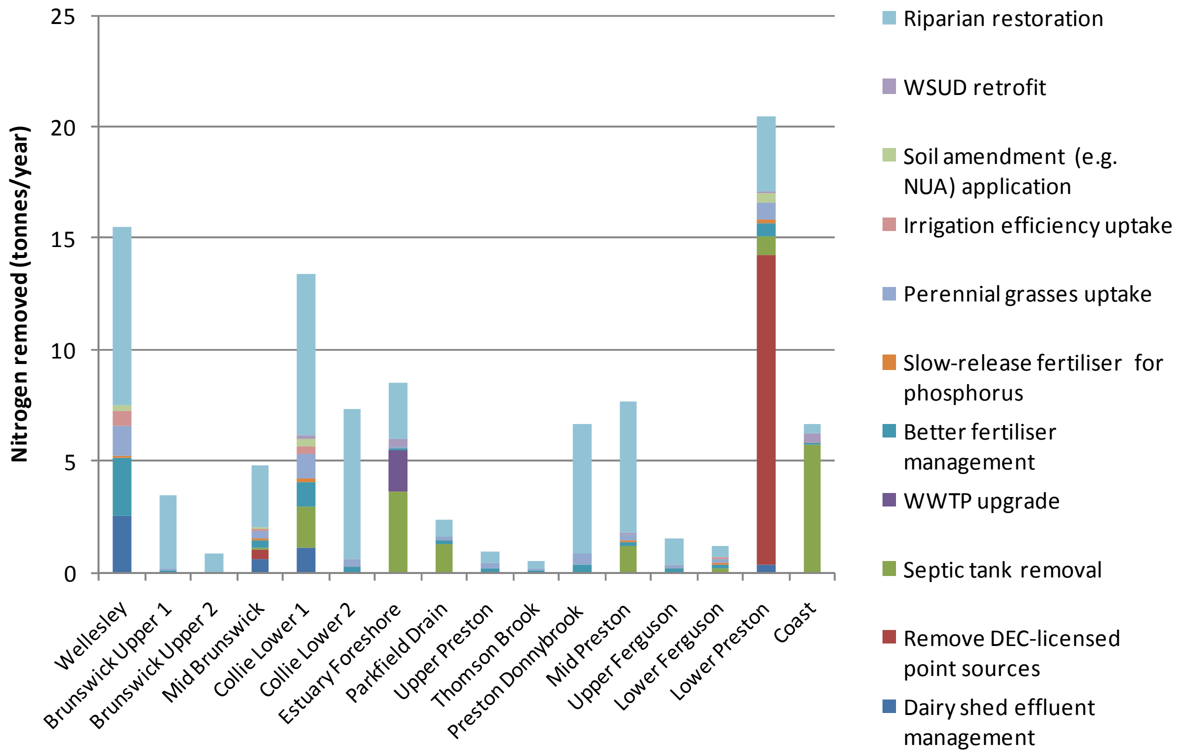


Figure 6-4: BMPs load contribution total for each subcatchment for nitrogen (tonnes/yr)

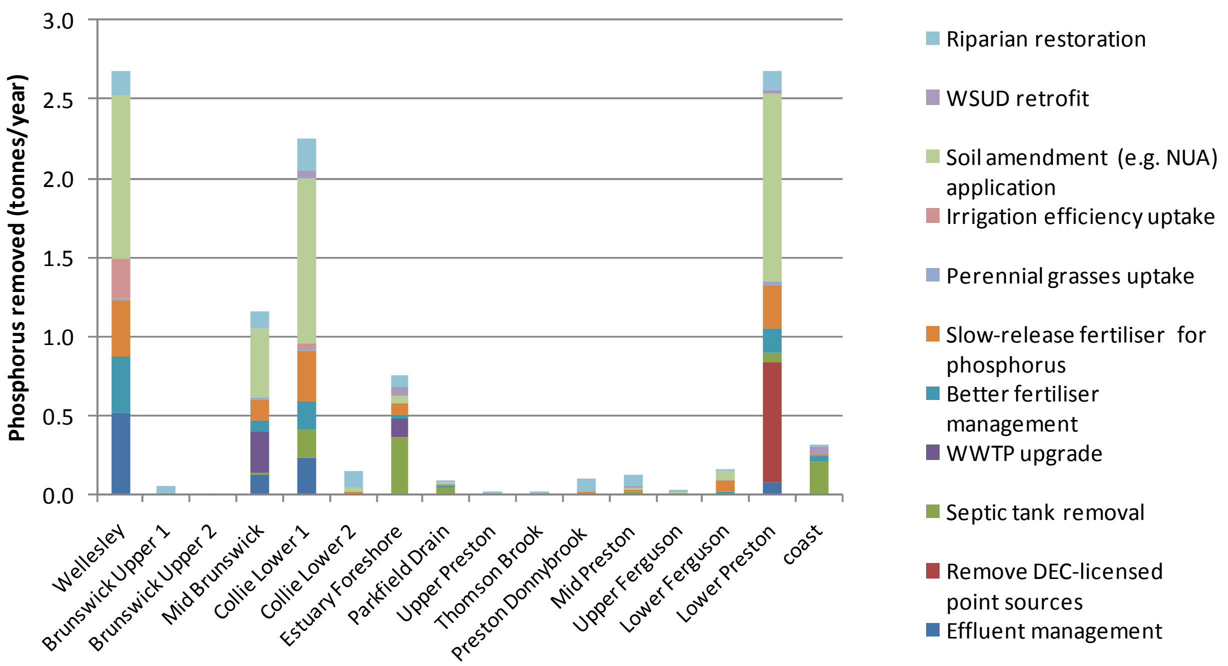


Figure 6-5: BMPs load contribution total for each subcatchment for phosphorus (tonnes/yr)

Table 6-9: Nitrogen load reductions for each BMP in each subcatchment

BMP	Effluent management		Remove DEC-licensed point sources		Septic tank removal		WWTP upgrade		Better fertiliser management		Slow-release phosphorus fertiliser		Perennial pasture		Irrigation efficiency		Soil amendment (NUA)		WSUD retrofit		Riparian zone restoration		Total load reduction	
	Load removed		Load		Load		Load		Load		Load		Load		Load		Load		Load		Load		Load	
	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]
Wellesley	2580	54	0	0	0	0	0	0	2548	39	127	21	1352	23	649	58	228	22	0	0	7987	16	15472	16
Brunswick Upper 1	0	0	0	0	0	0	0	0	90	1	0	0	117	2	0	0	0	0	0	0	3263	7	3470	4
Brunswick Upper 2	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	848	2	865	1
Mid Brunswick	645	14	413	3	34	0	0	0	388	6	49	8	370	6	66	6	95	9	0	0	2775	6	4835	5
Collie Lower 2	0	0	0	0	0	0	0	0	249	4	3	1	384	6	0	0	6	1	0	0	6722	14	7364	8
Collie Lower 1	1161	24	0	0	1818	20	0	0	1063	16	161	26	1127	19	350	31	290	29	184	30	7230	15	13383	14
Estuary Foreshore	0	0	0	0	3677	41	1808	100	103	2	33	5	65	1	0	0	18	2	283	47	2505	5	8492	9
Parkfield Drain	0	0	0	0	1277	14	0	0	212	3	2	0	99	2	0	0	3	0	0	0	824	2	2419	3
Upper Preston	0	0	0	0	0	0	0	0	189	3	0	0	295	5	0	0	0	0	0	0	510	1	994	1
Thomson Brook	0	0	0	0	0	0	0	0	75	1	0	0	117	2	0	0	0	0	0	0	310	1	502	1
Preston Donnybrook	0	0	0	0	0	0	0	0	359	6	0	0	554	9	0	0	0	0	0	0	5739	12	6651	7
Mid Preston	0	0	0	0	1186	13	0	0	199	3	48	8	296	5	0	0	3	0	45	7	5881	12	7657	8
Upper Ferguson	0	0	0	0	0	0	0	0	168	3	1	0	186	3	0	0	2	0	0	0	1211	2	1568	2
Lower Ferguson	0	0	0	0	227	3	0	0	177	3	37	6	167	3	54	5	21	2	0	0	566	1	1249	1
Lower Preston	387	8	13866	97	801	9	0	0	622	10	155	25	806	14	0	0	350	34	91	15	3398	7	20477	21
Estuary subtotal	**4774**	**100**	**14280**	**100**	**9020**	**100**	**1808**	**100**	**6458**	**100**	**616**	**100**	**5935**	**100**	**1118**	**100**	**1016**	**100**	**602**	**100**	**49770**	**100**	**95398**	**100**
Coast					5755				67		5						2		400		452		6681	
Total	**4774**		**14280**		**14775**		**1808**		**6525**		**621**		**5935**		**1118**		**1018**		**1002**		**50222**		**102079**	

[1] *Per cent total load reduction for this BMP*

Table 6-10: Phosphorus load reductions for each BMP in each subcatchment

BMP	Effluent management		Remove DEC-licensed point sources		Septic tank removal		WWTP upgrade		Better fertiliser management		Slow-release phosphorus fertiliser		Perennial pasture		Irrigation efficiency		Soil amendment (NUA)		WSUD retrofit		Riparian zone restoration		Total load reduction	
	Load removed		Load		Load		Load		Load		Load		Load		Load		Load		Load		Load		Load	
	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]	(kg)	(%)[1]
Wellesley	514	54	0	0	0	0	0	0	363	42	350	28	12	23	253	84	1030	27	0	0	161	16	2683	26
Brunswick Upper 1	0	0	0	0	0	0	0	0	3	0	2	0	0	1	0	0	0	0	0	0	47	5	52	1
Brunswick Upper 2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	1	6	0
Mid Brunswick	129	14	4	0	1	0	266	71	76	9	128	10	4	8	6	2	440	11	0	0	103	10	1156	11
Collie Lower 2	0	0	0	0	0	0	0	0	11	1	11	1	1	3	0	0	20	1	0	0	112	11	156	2
Collie Lower 1	231	24	0	0	182	27	0	0	174	20	321	25	14	25	39	13	1038	27	47	35	202	21	2247	22
Estuary Foreshore	0	0	0	0	368	54	110	29	23	3	71	6	1	1	0	0	57	1	54	41	70	7	754	7
Parkfield Drain	0	0	0	0	45	7	0	0	15	2	7	1	0	1	0	0	11	0	0	0	6	1	83	1
Upper Preston	0	0	0	0	0	0	0	0	7	1	4	0	1	2	0	0	0	0	0	0	4	0	16	0
Thomson Brook	0	0	0	0	0	0	0	0	3	0	2	0	0	1	0	0	0	0	0	0	3	0	7	0
Preston Donnybrook	0	0	0	0	0	0	0	0	13	1	8	1	2	3	0	0	0	0	0	0	69	7	91	1
Mid Preston	0	0	0	0	17	2	0	0	9	1	7	1	1	2	0	0	12	0	8	6	76	8	130	1
Upper Ferguson	0	0	0	0	0	0	0	0	7	1	6	0	1	1	0	0	7	0	0	0	10	1	31	0
Lower Ferguson	0	0	0	0	5	1	0	0	17	2	64	5	1	3	2	1	62	2	0	0	9	1	160	2
Lower Preston	77	8	761	100	62	9	0	0	151	17	280	22	16	29	0	0	1194	31	25	19	112	11	2677	26
Total for estuary	**951**	**100**	**764**	**100**	**679**	**100**	**375**	**100**	**872**	**100**	**1260**	**100**	**54**	**101**	**299**	**100**	**3870**	**100**	**133**	**100**	**988**	**100**	**10247**	**100**
Coast					209				32		11						6		49		10		317	
Grand total	**951**		**764**		**888**		**375**		**904**		**1271**		**54**		**299**		**3876**		**182**		**998**	**100**	**10564**	

[1] *Per cent total load reduction for this BMP*

6.4.3 Cost/benefit analysis

Capital costs

Estimated capital costs for the BMPs in the subcatchments draining to the estuary, and the Coast subcatchment which drains into the inlet, Big Swamp and the ocean, are listed in table 6-11 and Table 6-112. .

Figure 6-6 shows the breakdown of the capital expenditure (total) for both areas. The capital cost of the BMPs to reduce nutrient loads entering the estuary is $40.2 million. Capital cost for the Coast subcatchment is a further $23.9 million. Thus to implement the WQIP the estimated capital cost is $64.1 million.

The estimated capital costs do not include:

- Cost of implementing WSUD retrofit, the removal of point sources, the use of slow-release phosphorus fertiliser and WWTP upgrades. However, once commercially available the use of slow-release phosphorus fertiliser should cost approximately the same as current fertiliser.
- Staff and associated project costs required to implement the actions.

A large proportion of the capital cost is:

- $51.2 million to replace septic tanks in 7816 properties with reticulated sewerage or low-nutrient-emission ATUs (79.9% of total).

The capital cost of the other BMPs is much less costly with:

- $6.3 million dollars for riparian zone restoration and the creation of vegetated buffers on 228 km of waterways and major drains (9.9% of total)
- $2.05 million for perennial grasses on 6202 ha (3.2%)
- $1.9 million for soil amendment application to 5726 ha (3.0%)
- $1.3 million for effluent management of 37 dairy sheds (2.1%)
- $0.85 million for irrigation efficiency on 616 ha of dairyfarming land (1.3%)
- $0.42 million for better fertiliser management on 38 570 ha (0.7%).

Table 6-11: Cost benefit of BMPs implemented in the subcatchments draining to the estuary

BMP	Units	Area (ha), length (km) or sites treated	Annual load reduction		Capital cost	Annual ongoing net cost / return	Annual cost/return for 10-year project[1]	Annual cost/return per kg nutrient removed for 10-year project[2]	
			Nitrogen (kg)	Phosphorus (kg)				Nitrogen ($/kg/yr)	Phosphorus ($/kg/yr)
Dairy effluent management	#	37	4 774	951	$1 322 750	-$ 874 902	-$ 482 220	-$ 101	-$ 507
Remove DEC-licensed point sources	#	6	14 280	764			Not costed		
Septic tank removal	#	4 984	9 020	679	$27 365 792	$ 216 000	$2 888 289	$ 320	$ 4 252
WWTP upgrade	#	2	1 808	375			Not costed		
Better fertiliser management	ha	38 397	6 458	872	$ 422 369	-$ 908 092	-$ 595 569	-$ 92	-$ 683
Slow release phosphorusfertiliser	ha	18 098	616	1 260			Not costed		
Perennial pastures	ha	6 202	5 935	54	$2 051 419	-$ 239 332	$ 37 045	$ 6	$ 681
Irrigation efficiencies	ha	616	1 118	299	$ 846 472	-$ 46 725	$ 51 829	$ 46	$ 173
Soil amendment (eg NUA) application	ha	5 718	1 016	3 870	$1 922 735	-$ 265 217	$ 5 996	$ 6	$ 2
WSUD retrofit	ha	253	602	133			Not costed		
Riparian zone restoration	km	225	49 770	994	$6 260 808	$ 20 586	$ 640 539	$ 13	$ 644
Totals / Final loads			95 398	10 253	$40 192 344	-$2 097 683	$2 545 910	$ 33†	330†

[1] *Cost/return per year for 10-year project, includes capital cost and ongoing costs, as a net present value, Black = cost; red = return.*

[2] *Annual cost/return ($NPV) / nutrient load removed (kg)*

†Only includes BMPs that have both costs and nutrient load reductions

Table 6-12: Cost benefit of BMPs implemented in the Coast subcatchment draining to the inlet and ocean

BMP	Units	Area (ha), length (km) or sites	Annual load reduction		Capital cost	Annual ongoing net cost / return	Annual cost/return for 10-year project[1]	Annual cost/return per	
			Nitrogen (kg)	Phosphorus (kg)				Nitrogen ($/kg/yr)	Phosphorus ($/kg/yr)
Dairy effluent management	#	0	0	0	$ 0	$ 0	$ 0	$ 0	$ 0
Remove DEC-licensed point sources	#	0	0	0			Not costed		
Septic tank removal	#	2832	5 755	209	$23 820 044	$ 20 000	$2 396 052	$ 416	$ 11 475
WWTP upgrade	#	0	0	0			Not costed		
Better fertiliser management	ha	173	67	32	$ 1 906	-$ 4 097	-$ 2 687	-$ 40	-$ 84
Slow release phosphorus fertiliser	ha	113	5	11			Not costed		
Perennial pastures	ha	0	0	0	$ 0	$ 0	$ 0	$ 0	$ 0
Irrigation efficiencies	ha	0	0	0	$ 0	$ 0	$ 0	$ 0	$ 0
Soil amendment (eg NUA) application	ha	8	2	6	$ 2 573	-$ 355	$ 8	$ 4	$ 1
WSUD retrofit	ha	160	400	49			Not costed		
Riparian zone restoration	km	3	452	10	$ 74 407	$ 644	$ 7 893	$ 17	$ 813
Total			6 681	317	$23 898 929	$ 16 192	$2 401 265	$ 398†	$ 7577†

[1] *Cost/return per year for 10-year project, includes capital cost and ongoing costs, as a net present value, Black = cost; red = return.*

[2] *Annual cost/return ($NPV) / nutrient load removed (kg)*

†Only includes BMPs that have both costs and nutrient load reductions

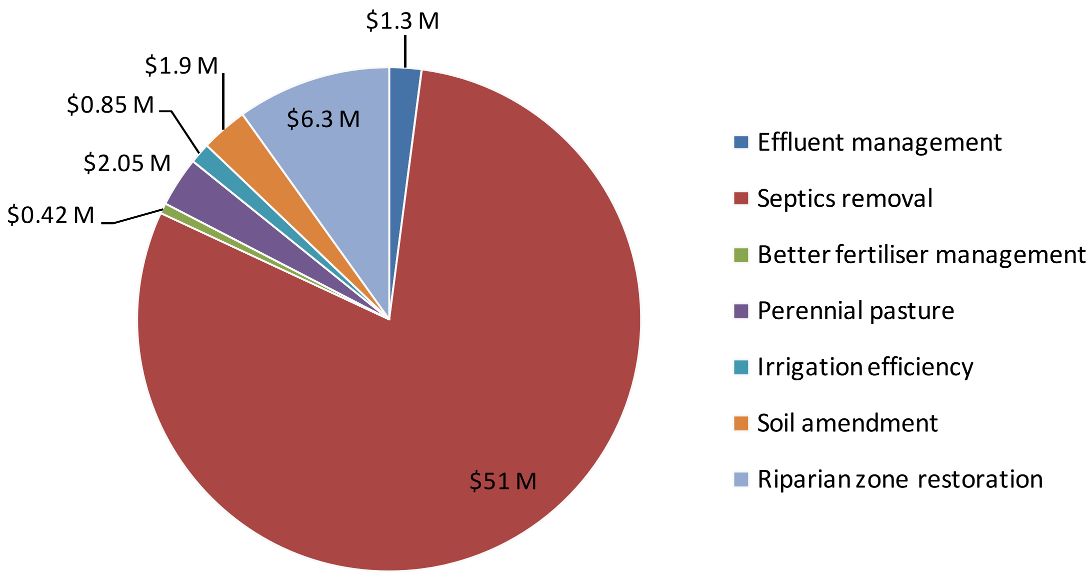


Figure 6-6: Capital cost of BMP implementation ($ million) for the whole catchment, does not include removal of DEC-licensed premises, WWTP upgrades, WSUD retrofit and adoption of slow-release phosphorus, which were not costed

Costs over the lifetime of a 10-year project

Many BMPs have ongoing annual maintenance costs, and some have monetary returns. Table 6-3 provides a comprehensive list of BMPs, highlights whether they have a monetary return and discusses their other benefits. Most agricultural BMPs have economic benefits; for example, dairy effluent management, better fertiliser management and use of slow-release phosphorus fertilisers, perennial pastures, irrigation efficiency, soil amendment, shelterbelts on farms and horticultural BMPs. Some urban BMPs also have economic benefits, mostly related to water savings.

DAFWA provided annual ongoing costs/returns for the seven BMPs for which costs were available (see Table 6-2).

The annual costs to implement these BMPs during a 10-year project, which includes the capital cost spread over the 10 years and the ongoing annual cost/return, as a net present value are shown in tables Table 6-11 and Table 6-12.

The modelling indicates that dairy effluent management and better fertiliser management will return an economic benefit over the 10-year period of approximately half a million dollars per year for each BMP. For the other BMPs that have a monetary return – perennial pastures, irrigation efficiencies and application of soil amendment – the returns are not enough to outweigh the capital expenditure, so over the life of the 10-year project these BMPs have small annual costs (tables 6-11 and Table 6-12) However, perennial pastures and application of soil amendment should show a return over a longer timeframe.

The cost/benefit analyses also give the cost per kilogram per year of nitrogen and phosphorus removed. Dairy effluent management and better fertiliser management have a return as discussed above. For nitrogen removal, for the other BMPs costed, the cost per kilogram is generally less than $100/kg/year except for septic tank removal, for which the cost in subcatchments draining to the estuary is $320/kg/year and in the Coast subcatchment is $416/kg/year. The costs per kilogram per year for phosphorus removal are an order of magnitude greater than for nitrogen removal, reflecting the order of magnitude difference between nitrogen and phosphorus loads.

Although the cost of removing septic tanks is high, the nutrients collected will be treated and completely removed from the catchment. Most other BMPs do not remove nutrients from the catchment, and thus if the BMP is not maintained the nutrient loads can return to former levels. The introduction of reticulated deep-sewerage and low-nutrient-emission ATUs is strongly supported.

6.5 Other BMPs

Although the BMPs discussed in the previous section are the key ones to implement, some others also need consideration. Table 6-1 provides a comprehensive list of BMPs. Of these, the ones expected to provide the greatest nutrient reductions in Leschenault waterways are:

- effluent management of feedlots, piggeries and other intensive animal industries (wastes should be recycled where possible and management actions should prevent animal wastes reaching surface and groundwaters)
- artificial wetlands to trap nutrients and other contaminants
- horticultural BMPs related to minimising nutrients leaching to waterways and water conservation
- WSUDs in all new developments – this is a requirement of the *Better urban water management* framework supported by the Department of Planning (DoP) and the Department of Water.

Other BMPs are also needed for other contaminants, especially:

- management of the risks associated with acid sulfate soils, particularly in relation to urban development and dewatering
- discharge regulations, appropriate design (e.g. to prevent spills) and possibly dedicated waste treatment for all new industrial precincts such that discharges of contaminants to drains and streams is eliminated
- consider relocating planned new industrial precincts away from waterways.

Table 6-13: BMPs appropriate to the Leschenault catchment, highlighting other benefits besides nutrient removal

BMP	Monetry return	Other benefits / comments
Dairy effluent management	✓	Fly control, less mastitis in cows and use of effluent to replace fertiliser.
Remove DEC-licensed point sources	×	Removal of non-nutrient contaminants. Recycling of wastewater for fit-for-purpose use.
Septic tank removal	×	Removes *E. coli* , other pathogens and endocrine-disrupting chemicals from groundwater and waterways. Mitigates human health issues related to septage effluent in waterways.
WWTP upgrade	?	Removes *E. coli* , other pathogens and endocrine-disrupting chemicals from groundwater and waterways. Mitigates human health issues related to WWTP effluent in waterways. May have some economic benefits if effluent is used as fertiliser or for power production (biogas). Recycling wastewater for fit-for purpose use.
Better fertiliser management	✓	Cost savings due to less fertiliser application
Slow-release phosphorus fertiliser	✓	
Perennial pastures	✓	Prevents soil erosion and lowers watertable, thus reducing salinisation risk. Although perennial pastures have a monetary return, it was not sufficient to outweigh the capital cost over the 10-year life of the project. Also perennial pastures take several years to establish, require ongoing maintenance and reduce flexibility in terms of crop rotations. Thus perennial pasture are recommended where establishment and maintence is not onerous. Perennial pastures are strongly recommended for horse properties.
Irrigation efficiency	✓	Saves water. Recycles nutrients that would be lost in irrigation return flows.
Soil amendment (e.g. NUA) application	✓	Improves water holding capacity of soil and thus enhances productivity. Acid neutralisation potential.
WSUD retrofit	✓	Mitigates non-nutrient contamination. Captures water that can be used for irrigation and other purposes.
Riparian zone restoration	×	Reduces soil and bank erosion, thus mitigates sediment loads, provides economic and social benefits by adding value to properties, increases the recreational values of the waterways, improves riverine ecological integrity, and provides native wildlife habitat and biodiversity corridors.
WSUD in new urban developments	✓	Mitigates non-nutrient contamination. Captures water that can be used for irrigation and other purposes, thus reducing potable water use. Creates recreactional amenity.
Artificial wetlands	×	Provide recreational and visual amenity. Traps non-nutrient contaminants. Can provide wildlife habitat.
Shelterbelts in farms	✓	Reduces wind erosion, increases water efficiency in horticutural properties, controls groundwater table and salinisation, improves horticultural, pasture and livestock production. Provides wildlife corridors and enhances biodiversity.
Horticutural BMPs	✓	Reduces erosion, reduces water consumption and increases productivity.
Plantation forestry BMPs	×	Reduces erosion, reduces pesticide leaching to streams. It is a recommendation of this report that plantation forestry BMPs are developed for the Leschenault catchment
Ongoing inspections and audits of septic tanks and ATUs	×	ATUs have regulations that enforce this. Inspections of septic tanks would enable poorly-performing septic tanks to be remediated.
Effluent management of feedlots, piggeries, poultry farms and other intensive animal industries	?	Removes *E. coli* , other pathogens and endocrine-disrupting chemicals from groundwater and waterways. Mitigates human health issues related to animal waste in waterways. May have some economic benefits if effluent is used as fertiliser or for power production (biogas). Can help reduce methane release to the environment.
Acid sulfate soil management	✓	Management guidlines for acid sulfate soils in the Lescehnault catchment need to be established. Monetry return reflects savings due to prevention of infrastructure damage or loss of arable land.

6.6 Discussion

The cost/benefit analysis clearly demonstrated that no single BMP could reduce the nitrogen or phosphorus loads enough to achieve the load reduction targets at either the subcatchment or catchment scale. Scenario modelling suggests it is essential to select a series of BMPs suited to the landscape, land uses and localised water quality issues of each subcatchment to meet or get close to achieving the subcatchment's load reduction targets.

By implementing BMPs within the recovery subcatchments alone, neither the nitrogen nor phosphorus load reduction targets for the Leschenault Estuary could be met, and thus it is important to reduce nutrient runoff in all subcatchments.

At a catchment scale some BMPs do not seem to provide great nutrient load reductions to the estuary, but at a subcatchment scale they can make significant contributions to reducing loads and thus provide ecological benefits locally. BMPs such as WSUD retrofit, WWTP upgrades, infill of septic tanks and removal of DEC-licensed point sources are critical to protecting the environmental values of the lower Collie, Preston and Brunswick rivers.

It is also important to note that a lag time between BMP implementation and measurable water quality improvements will occur for all BMPs directed at diffuse pollution sources. This is particularly relevant in the case of phosphorus because large amounts are presently stored within the catchment's soils and would continue to leach out, even if nutrient inputs stopped. For example, with respect to replacing high-water-soluble phosphorus fertilisers with low-water-soluble fertilisers, the *Fertiliser action plan* (2007) states:

> ….we should not expect to see significant change in the condition of waterways within the 4-year period. Restoring the health of our coastal waterways is a long-term endeavour. It may take many years for these benefits to be fully appreciated. Without preventative action, the full impact of coastal waterway ill-health will be revealed in a much shorter period of time.

Water quality improvement should be more rapid when BMPs decrease or remove direct discharges (point sources such as DEC-licensed premises, dairy shed effluent and WWTP discharges) to the environment and into the waterways.

Although working on the recovery subcatchments is a priority – given they have the potential to contribute the greatest nutrient load reductions to the estuary and the lower Collie, Brunswick and Preston rivers – it is also important to carry out the recommended BMPs in the other subcatchments for the following reasons:

- the implementation of certain BMPs in the recovery subcatchments could take time due to the low uptake of BMPs and lack of funds to implement them
- the lag time between BMP implementation and water quality improvement may be long and improvements will be more rapid if BMP implementation is as widespread as possible
- the implementation of riparian restoration in all subcatchments, including the protection subcatchments, will provide other benefits such as reducing riverbank erosion, and thus sediment build-up in the lower Collie, Brunswick and Preston rivers.

Scenario modelling indicates that reduction of phosphorus fertiliser use to agronomic levels, particularly in areas with low PRI soils, is an essential BMP. Thus, substantial changes in agricultural practice are required, especially on the coastal plain, and these will require leadership by government agencies. Some direction is already apparent through the *Fertiliser action plan* and its successor the *Fertiliser partnership agreement* through the promotion of good fertiliser management. The availability of slow-release or low-water-soluble fertilisers is a key action and some degree of regulation may be necessary to bring these products to market.

The actions required to improve the Leschenault's estuarine waters – with its history of water quality problems, a large diversified catchment and extensive planned expansion of industrial and residential areas – are principally those associated with land use planning, location of industrial estates, waste and pollution management, urban design and water management. Very few of the effective BMPs are of the scale and type to substantially reduce nutrient losses without concerted government and industry action. However, NRM delivery organisations such as SWCC and the LCC play an important coordinating and enabling role. They also deliver on-ground works such as implementing river action plans and improving the ecological and aesthetic value of water assets. Implementing WQIPs is thus about partnerships.

7 Environmental flows

7.1 The role of flows

In considering water quality improvement, it is critical to determine environmental flow objectives and regimes, as well as their associated management recommendations. Sustainable ecosystem function relies on suitable water quality and the continuation of long-term flow patterns.

Sediment and solid matter transport, particularly during high flows, helps maintain physical substrate characteristics, provides snags and other physical habitat, maintains channel morphology, and provides material (including nutrients) for floodplains and estuaries.

Surface water flows are also the primary control over riparian, floodplain and estuarine vegetation, with flows also contributing nutrients and substrate and, in the case of floodplains, can transport biological material back into the waterway channel.

Freshwater fish depend on river flows for food, habitat and in some cases, for breeding cues.

Summer baseflows provide refuges for ecological communities. In some areas of the Leschenault catchment, supplementation of natural flows in waterways has occurred for a number of years to support social, economic and environmental values and in some cases has enabled degraded river systems to survive, albeit under an augmented regime.

Groundwater flows underpin abstraction for domestic and commercial uses, wetland maintenance, vegetation support and surface water contribution. Water availability from groundwater aquifers depends on rates of infiltration through recharge, permeability of the substrate and transmissive capacity between aquifers.

7.2 The effect of development on flow

In the Leschenault catchment, most waterways have been modified to impede or augment natural flow regimes. Flow regimes have been modified in several ways:

Impoundments (such as the Wellington and Glen Mervyn dams) *and barriers* (such as the Burekup Weir) have altered the surface-water flow patterns of the discharging river systems, often reducing medium-sized floods and augmenting flows during dry periods by providing flows to support irrigation.

Direct extractions (both licensed and unlicensed) of surface and groundwater for commercial and private purposes, which reduces the total volume of flow, particularly surface water baseflows during dry periods.

Surface water discharges from agricultural drainage, effluent and stormwater also affect flow patterns, often increasing dry season flows (and often introducing pollutants). The HWIA discharges significant flow into the Wellesley, Brunswick and Collie rivers and several significant tributaries during the summer irrigation period, which contributes unnatural summer baseflow to these systems.

Changes in catchment land use affecting rainfall-runoff relationships. Generally, total flow volumes are increased as native vegetation is replaced with agriculture or horticulture due to reduced evapotranspiration rates in pastures or crops, thus making more water available for runoff. Land use intensification also generally causes river flows to peak more highly during floods because either runoff is not retarded as much by agricultural or horticultural crops, or floods remain bounded by flood protection works for infrastructure.

Urban development changing the hydrology both through removal of deep-rooted vegetation and a larger impervious surface area. Urban catchments have typical water yields of 200 to 350 mm, whereas sandy rural catchments can have water yields of 30 to 40 mm. Urban catchments generally have more summer flow than rural catchments, because the drains connecting paved areas to streams efficiently convey water to receiving waterbodies from small rainfall events that are too small to generate runoff in rural (pervious) catchments.

7.3 Flow management objectives

National policies and strategies guide the provision of water for the environment as part of the allocation and management of water resources, and include:

- National Strategy for Ecologically Sustainable Development (1992)
- Intergovernmental Agreement on the Environment (1992)
- National Water Quality Management Strategy (1992)
- Council of Australian Governments' (COAG) Framework Agreement on Water Resources Policy Reform (1994)
- National Principles for the Provision of Water for Ecosystems (1996)
- National Strategy for the Conservation of Australia's Biological Diversity (1996).

There are also provisions for water for the environment within the *Environment Protection and Biodiversity Act 1999* (Cwlth), and the *Rights in Water and Irrigation Act 1914* (WA) and the *Environmental Protection Act 1986* (WA).

Consistent with the above strategies and legislation, Western Australia has adopted the concepts of:

- ecological water requirements (EWRs), which are the water regimes needed to maintain the ecological values of water-dependant ecosystems at a low level of risk. EWRs are determined on the best scientific information available and are the primary consideration in the determination of
- environmental water provisions (EWPs), which are the water regimes provided as a result of the water allocation decision-making process – taking into account ecological, social and economic impacts. They may meet in part or in full the EWR (WRC 2000b).

In maintaining sustainable environmental flows, the EWR/EWP determination identifies water requirements to meet objectives related to:

- channel morphology and hydrology
- distribution and extent of key habitat sites
- water quality
- macroinvertebrate fauna

- aquatic and riparian vegetation
- groundwater discharge
- fish migration and passage
- ecological processes supporting aquatic foodwebs.

The existing EWR/EWP studies for surface-water-dependent ecosystems undertaken in the Leschenault catchment are listed in Table 7-1 below.

Table 7-1: EWR and EWP studies undertaken in the Leschenault catchment for surface-water-dependent ecosystems

Title	Date	EWR/EWP
Ecological water requirements of the Preston River from Glen Mervyn Dam to Argyle, in the Shire of Donnybrook/Balingup Western Australia (Streamtec 2002)	2002	EWR
Lower Collie River and Henty Brook preliminary environmental water provisions – discussion paper (WEC 2002)	2002	EWP
Lower Collie River ecological water requirements review: Stream morphology, riparian vegetation and fish passage (Hardcastle et al. 2003)	2003	EWR
Ecological water requirements of Augustus River – Intermediary assessment (Wetland Research and Management 2005)	2005	EWR
Ecological water requirements – Brunswick River (DoW 2009)	2009	EWR
Environmental flow regime for the lower Collie River – Wellington Reach (DoW 2010)	2010	EWR
Environmental flow regime for the lower Collie River – Shenton's Elbow Reach (DoW 2010)	2010	EWR

7.4 Monitoring and modelling of river flows

Understanding current flow volumes and regimes is essential when managing flows for any waterway. As part of the Department of Water's state reference network, active gauging stations on each of the major rivers in the Leschenault catchment have been used in the development of this plan (Figure 7-1). The gauges include:

- Juengenup (Wellesley River) (612039)
- Beela (Brunswick River) (612047)
- Sandalwood (Brunswick River) (612022)
- Cross Farm (Brunswick River) (612032)
- Rose Road (Collie River) (612043)
- South West Highway (Ferguson River) (611007)
- Boyanup Bridge (Preston River) (611004)
- Donnybrook (Preston River) (611006)

- Lowden Road Bridge (Preston River) (611009)
- Woodperry Homestead (Thompson Brook) (611111).

The department uses data gathered at these sites to assess the response of runoff to rainfall against historical runoff and future runoff scenarios at each streamflow gauge, identifying changes in the frequency and magnitude of streamflow against the minimum flow thresholds.

The minimum flow thresholds describe the water depths and related flow rates which maintain populations of fish and macroinvertebrates, vegetation community structure and composition, water quality, channel geomorphology and ecosystem processes. The flow required to meet each flow-ecology linkage is estimated using survey information and observed streamflow (DoW 2010c, draft).

While the information gathered from gauging stations primarily supports aquatic ecology/flow linkages, it inherently also provides significant data, which when coupled with water quality monitoring, can be used to calculate nutrient loadings to waterways.

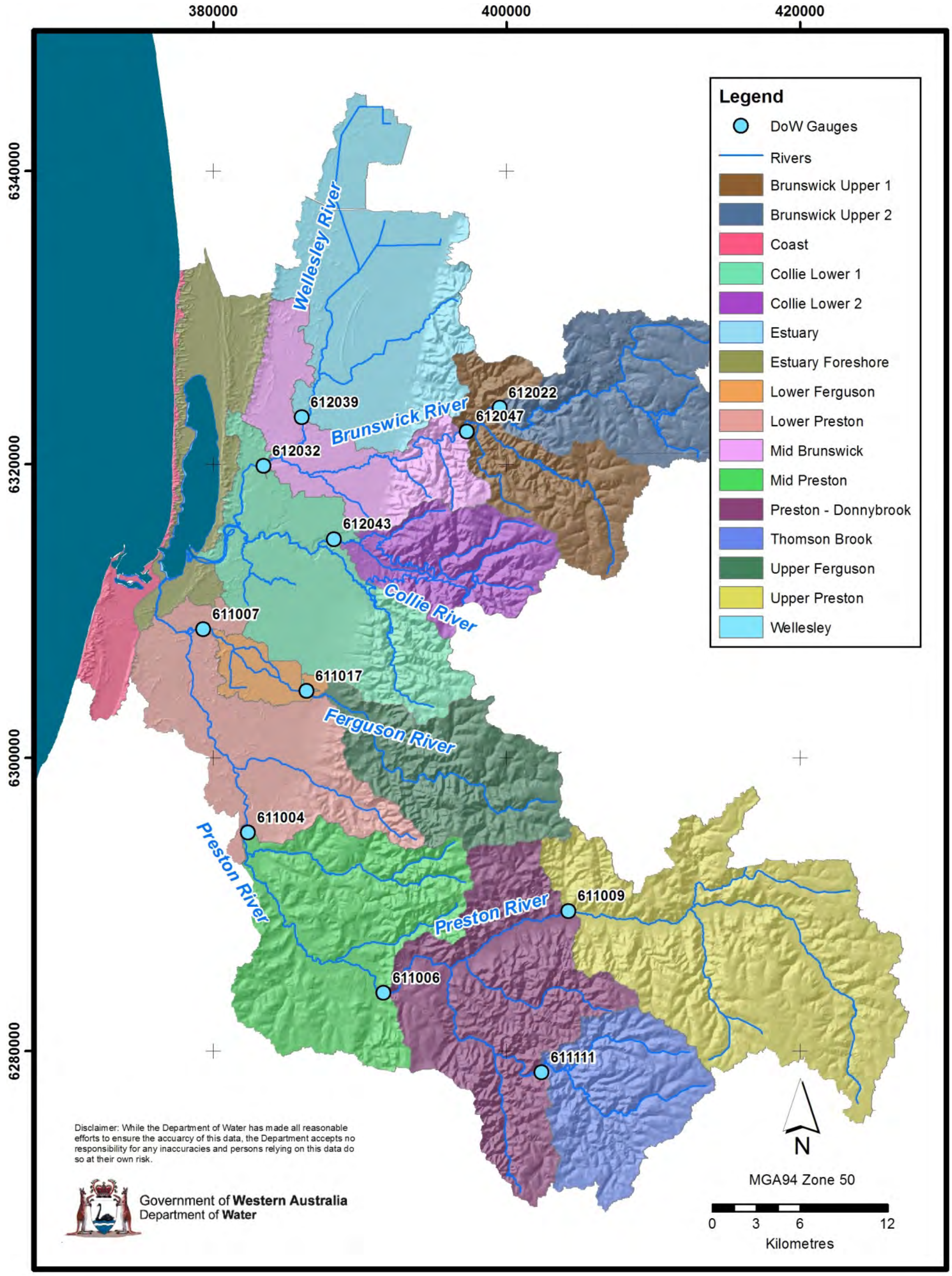


Figure 7-1: Department of Water flow gauges supporting environmental flow determinations

7.5 Allocation of surface water resources

The Department of Water is responsible for licensing the extraction and use of Western Australia's water resources by establishing allocation limits on surface and groundwater resources. An allocation limit is the annual volume set aside for use from a water resource. Allocation limits, licensing and compliance monitoring are the main tools the department uses to manage abstraction, aiming to minimise the impacts of the take of water on the environment (environmental flows), social values and other users (Figure 7-2).

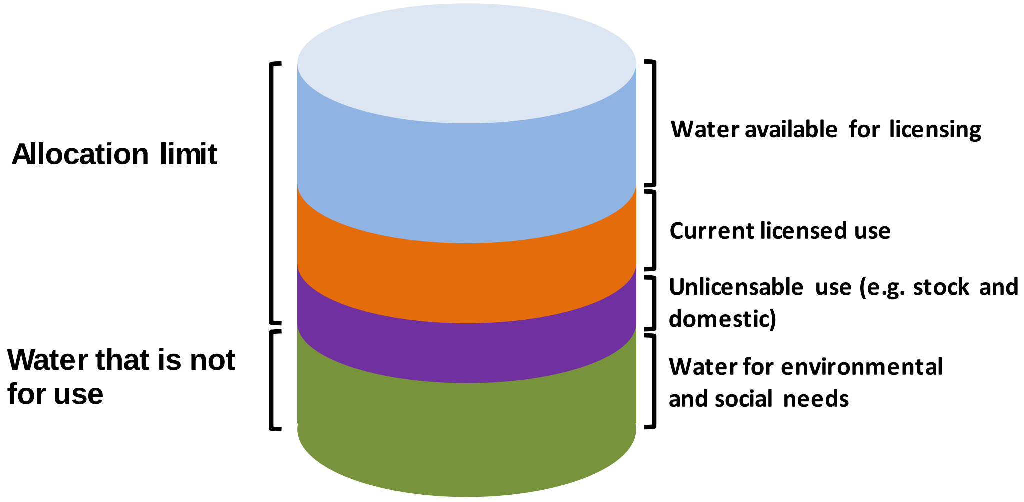


Figure 7-2: Partitioning of a water resource to highlight different uses. Note that the proportions are not to scale and vary depending on the particular resource.

The department considers the needs of all licensed water users and the community as a whole when making allocation decisions. The department uses water allocation plans to manage how water is taken from surface and groundwater systems.

All proclaimed groundwater resources under the WQIP are managed under the *South-west groundwater areas allocation plan* (DoW 2009c).

7.5.1 Approach for setting allocation limits

The Department of Water sets allocation limits for surface water resources in Western Australia in two steps:

1. Estimate how much water can be taken from a resource to supply water for use (yield estimate) and maintain ecological and social values, within and downstream of the resource at a low level of risk.
2. Examine management criteria such as current use, future demand and the impacts of water use on water quality (management input). We use this information and the resource and management objectives for each resource to set allocation limits.

The degree to which each step informs the allocation limit depends on the amount of information available, and the objectives for each resource. The fact that a full entitlement is not taken up every year is not evidence that a resource is under-used. It may mean that some wet years have occurred, which are a means to replenish drought reserves.

7.5.2 Sustainable diversion limits

Sustainable diversion limits (SDLs) have been accepted as the methodology for determining surface water availability across the plan area. SDLs provide a regional hydrologic estimate of the sustainable yield and they have been developed to underpin surface water abstraction entitlements and decision-making in south-west Western Australia. SKM (2008a, 2008b) provides further detail on how the SDL approach was derived.

The SDL represents the maximum volume of water available for diversion, beyond which there is an unacceptable risk that additional extractions may cause a lasting and detectable negative effect to the environment. If extraction greater than the SDL is desired, then detailed local investigations, such as an EWR study (see Section 5.3), are required to more accurately define, and potentially increase, the estimated sustainable yield.

The SDL volumes are calculated on the basis of an 80% reliability of supply. A reliability of 80% is typically associated with agricultural uses, which reflects the predominant land uses across the Leschenault catchment. The reliability of supply is defined as the probability of the SDL volume of water being able to be diverted from the surface water resource, in accordance with the ‘rules’.

The SDL volume and the reliability of supply are directly related. A lower level of reliability results in a higher volume of water being available for diversion and a larger impact on the resource. Conversely, a higher level of reliability results in a lower level of water being available for diversion and a lesser impact on the resource (DoW 2010d).

7.5.3 Collie River drainage catchment

The draft *Lower Collie surface water allocation plan* sets out how the Department of Water will manage water resources in the plan area (Figure 7-3). It establishes surface water allocation limits and water licensing policies for the proclaimed areas within the lower Collie catchment, consistent with the licensing powers of the *Rights in Water and Irrigation Act 1914*.

The plan sets out:

- the allocation planning boundaries for surface water resources (SDL resource areas)
- the amount of surface water available for allocation (allocation limits)
- the approach for managing surface water including:
  - the resource and management objectives for each resource
  - the state and local policies which guide the licensing and allocation of water in the plan area
- how to implement, evaluate and review the plan.

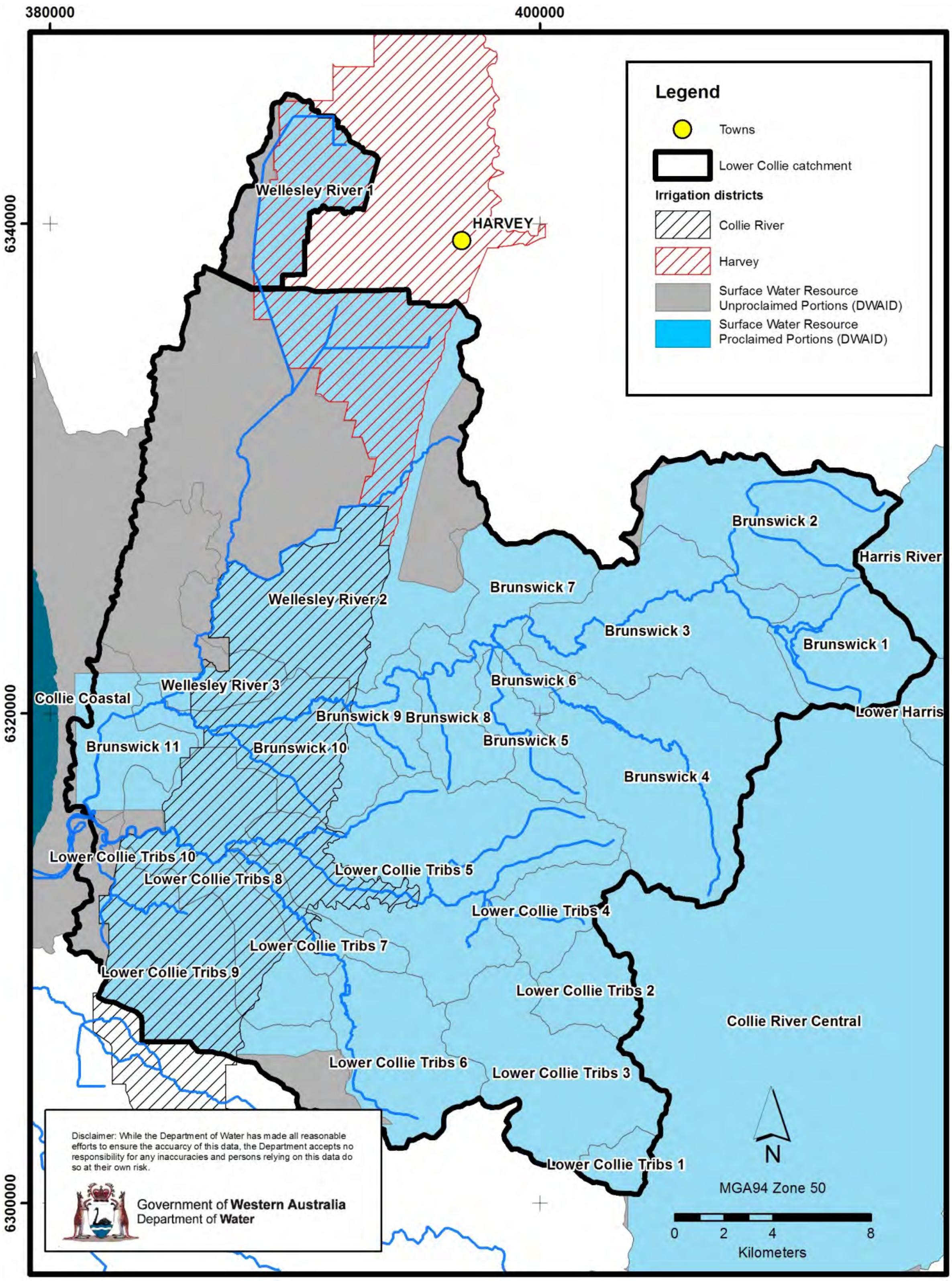


Figure 7-3: The lower Collie surface water allocation plan area, identifying proclaimed areas under the Rights in Water and Irrigation Act 1914

The plan covers the lower Collie surface water allocation area, which includes the lower Collie and its tributaries, as well as the subareas of the Brunswick and Wellesley rivers. The allocation limits apply to all water that flows over or is held in these watercourses. This includes water stored in the Wellington Dam, which is outside of the plan (and WQIP) area.

The plan takes account of existing and future water demands on the Wellington Dam, because water released from the dam contributes to flow in the lower Collie both directly and indirectly (through irrigation return flows and/or social releases into the lower Collie, Brunswick and Wellesley rivers). The plan area includes 24 smaller resources across the three subareas. These resources represent small catchments that contain a watercourse – it is the spatial unit used to set an allocation limit. There are:

- 10 resources in the lower Collie River and tributaries area
- 11 resources in the Brunswick River area
- three resources in the Wellesley River area.

The Department of Water has set an allocation limit for each resource (Table 7-2). It should be noted that some resources have more than one watercourse flowing through them and the allocation limit refers to the total amount of surface water available within the resource.

Of the 24 resource subcatchments identified, eight have no water available for further consumptive use, while a further five have limited availability. Several of these are located within the upper reaches of the Brunswick and lower Collie rivers to protect waters that are often of low salinity and low nutrient concentrations: this is necessary to dilute higher nutrient-concentration flows from the coastal plain where land use is intensified for agricultural pursuits. Conversely, water availability in the Wellesley is high to promote re-use and alternative use of nutrient-enriched flows.

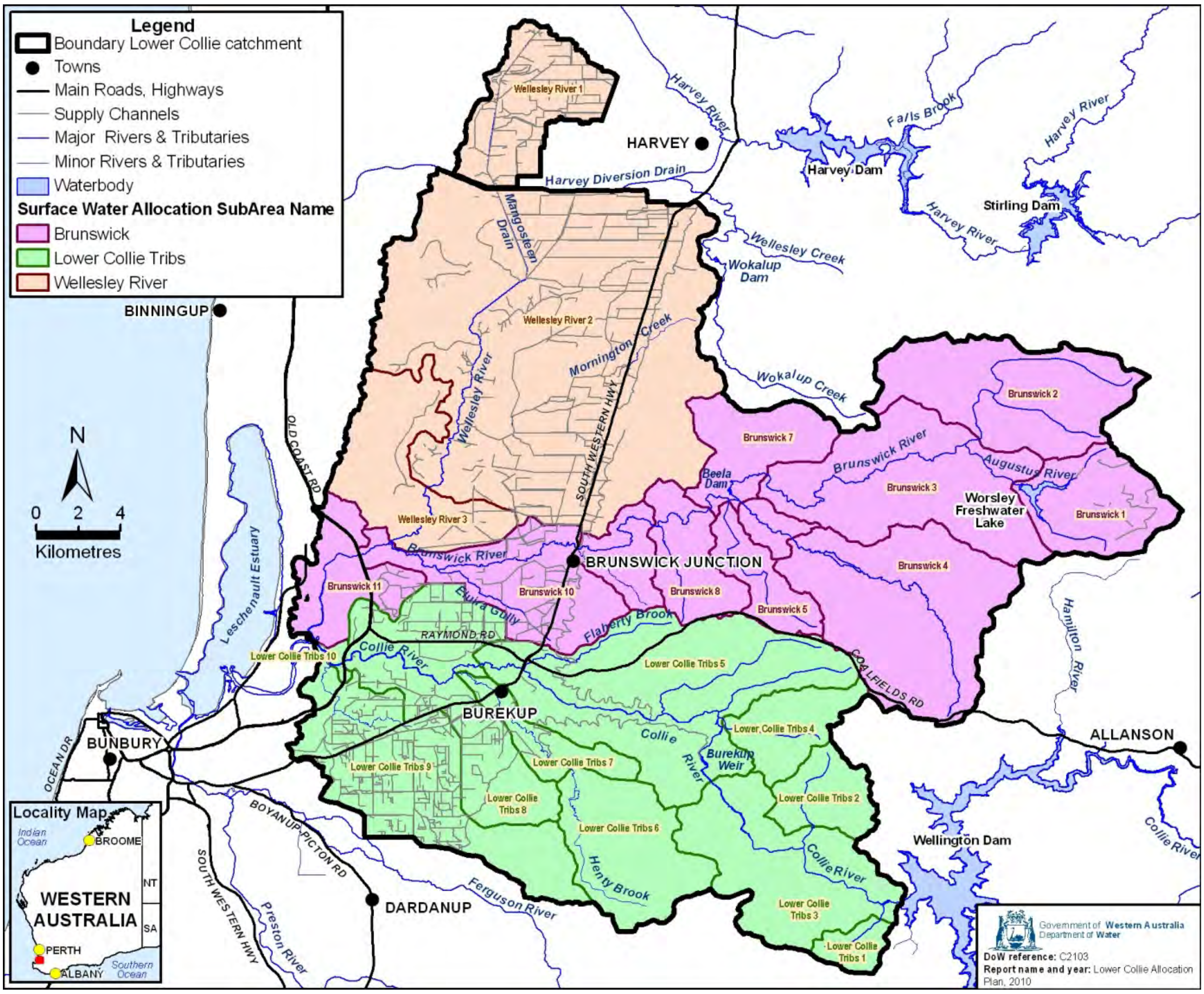


Figure 7-4: Surface water resource subareas under the lower Collie surface water allocation plan

Table 7-2: Allocation limits in the lower Collie area

Resource	Allocation limit ML/yr	Allocation limit components (ML/annum)		Is water available? (as at September 2010)
		Licensable	Unlicensed use	
Brunswick 1	2600	2600	0	No
Brunswick 2	201	187	14	Yes
Brunswick 3	28	0	28	No
Brunswick 4	97	53	44	Yes
Brunswick 5	317	280	37	Yes
Brunswick 6	74	50	24	Yes
Brunswick 7	218	166	52	Yes
Brunswick 8	237	196	41	Yes
Brunswick 9	120	90	30	Yes
Brunswick 10	142	40	102	Limited
Brunswick 11	40	10	30	Limited
Lower Collie Tribs 1	0	0	0	No
Lower Collie Tribs 2	0	0	0	No
Lower Collie Tribs 3	4	0	4	No
Lower Collie Tribs 4	43	0	43	No
Lower Collie Tribs 5	169	47	122	Limited
Lower Collie Tribs 6	742	636	105	Limited
Lower Collie Tribs 7	374	340	34	No
Lower Collie Tribs 8	47	12	35	Limited
Lower Collie Tribs 9	493	400	93	Yes
Lower Collie Tribs 10	10	0	10	No
Wellesley 1	600	578	23	Yes
Wellesley 2	3638	3566	72	Yes
Wellesley 3	41	29	12	Yes

[1] Available water is considered to be limited if estimated current use is greater than 70% of the allocation limit. No water available means that use has reached the allocation limit .

7.5.4 Preston River drainage catchment

There is no formal surface water management plan for the Preston catchment. However, the SDL approach has been applied in this catchment consistent with that of the lower Collie.

The catchment area includes the drainage catchments of the Preston and Ferguson rivers and has been divided into 32 smaller resources across two subareas (for the proclaimed areas under the *Rights in Water and Irrigation Act 1914)*.

There are 31 resources in the Preston River and tributaries area, made up of:

- four resources in the Bunbury area
- two resources in the Charley Creek area
- two resources in the Crooked Brook area
- one resource in the Joshua Brook area
- three resources in the Lyalls Mill Stream area
- six resources in the Middle Preston area
- three resources in the Thomson Brook area
- five resources in the Upper Preston area
- five resources in the Ferguson River area.

As with the Lower Collie area, the Department of Water has set a preliminary allocation limit for each resource. It should be noted that some resources have more than one watercourse flowing through them and the allocation limit refers to the total amount of surface water available within the resource.

At the time of publication, no water was available in only one of the 27 identified subcatchment resources, and limited in a further four. However, the Department of Water is undertaking a process to ensure that all historical use of surface water (as of May 2010) is acknowledged and accounted for, after which allocation limits for the area will be finalised. As an interim measure, the department will take a conservative approach to considering any new applications for consumptive use of surface water in the catchment.

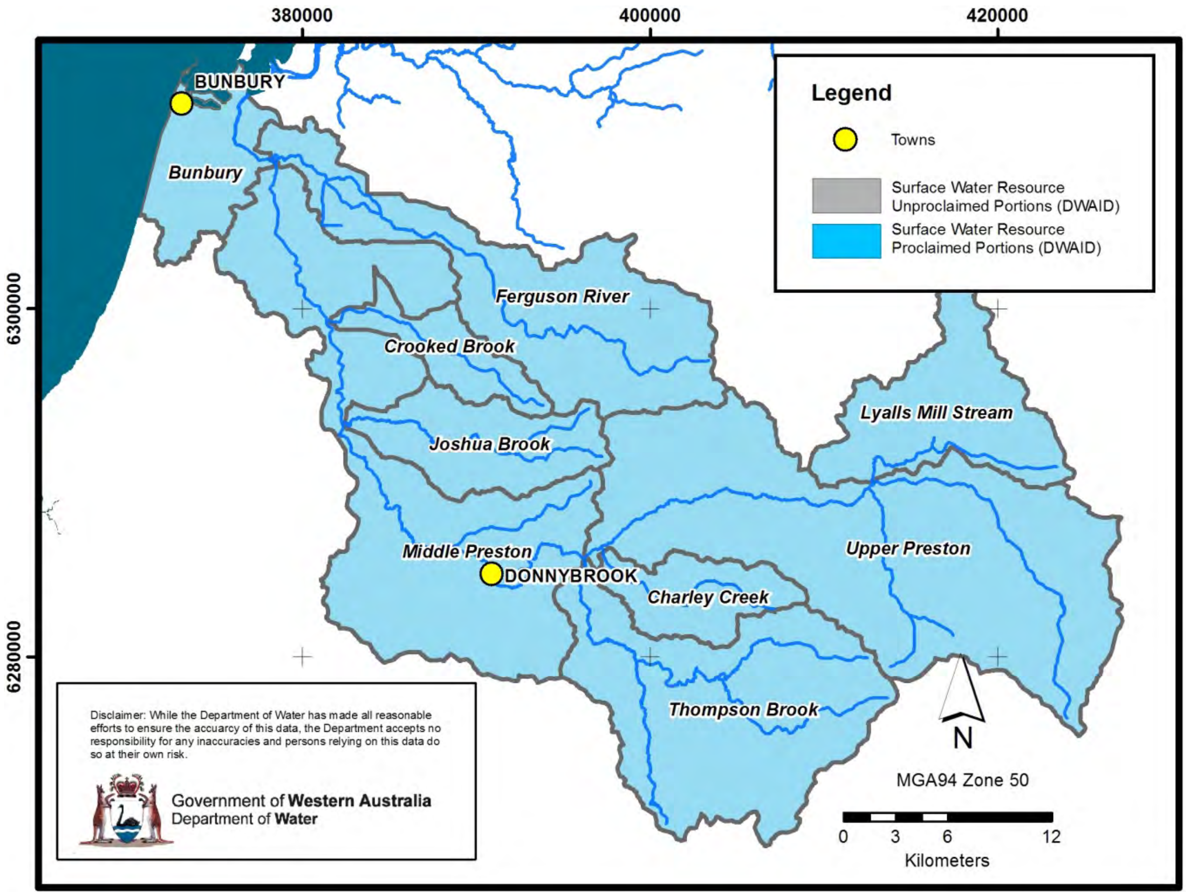


Figure 7-5: Preston River catchment and identified proclaimed areas and resource subcatchments

7.6 Integrating management of water quality and flow

Integrated management approaches can achieve positive water quality outcomes. The Department of Water considers water quality as part of its water allocation licensing process and conditions-of-license approvals can include requirements for nutrient management.

Such management arrangements can be streamlined through policy and/or strategy directions, particularly where WQOs have been clearly identified through a target-setting process. The development of this WQIP, along with those being developed concurrently and recently in other areas, has resulted in the Department of Water determining a south-west regional directive to support allocation licensing of both surface and groundwater areas with the aim of:

> …developing a transparent and efficient process to assess and manage the risk of the take and use of water impacting on the quality of high value resources.

This risk assessment determination supports the implementation of licence conditions requiring water quality monitoring and management outcomes commensurate with the risk to water resources presented by the allocation of water through the licensing process.

7.7 Future pressure and demand on water resources

The sustainable yield of south-west rivers has been 57% allocated and 28% used. Those figures are much higher than the state overall, due to population and development demand (McFarlane 2005). Furthermore, as a result of reduced streamflow since 1975, scheme water supplies have relied increasingly on groundwater. Because of environmental concerns, scheme supplies have also extracted proportionally more water from the deep, confined aquifers – which can have a wider impact and longer lag when compared with extraction from shallow aquifers (McFarlane 2005).

Regional water needs are growing with increased development at the same time as the south west is experiencing lower flows. Developing the surface water resources of the Collie to Warren river basins inclusive are important options for meeting current and future integrated water supply scheme (IWSS) demands, especially if the reduced streamflows of the past eight years become the norm.

McFarlane (2005) indicates the main areas with undeveloped resources are those with sensitive environmental flows (e.g. the Brunswick River which discharges into the Leschenault Estuary).

7.8 Climate change and environmental flows

Since the mid 1970s south-west Western Australia has been as or more affected by climate change than anywhere in the world (McFarlane 2005). The May to July rainfall for the south-west abruptly decreased by about 15% after 1975 (IOCI 2004). The 170 and 300 mm isohyets have moved 70 to 100 km closer to the south-west corner, while the 500 mm isohyet has moved by up to 200 km (see Figure 7-6).

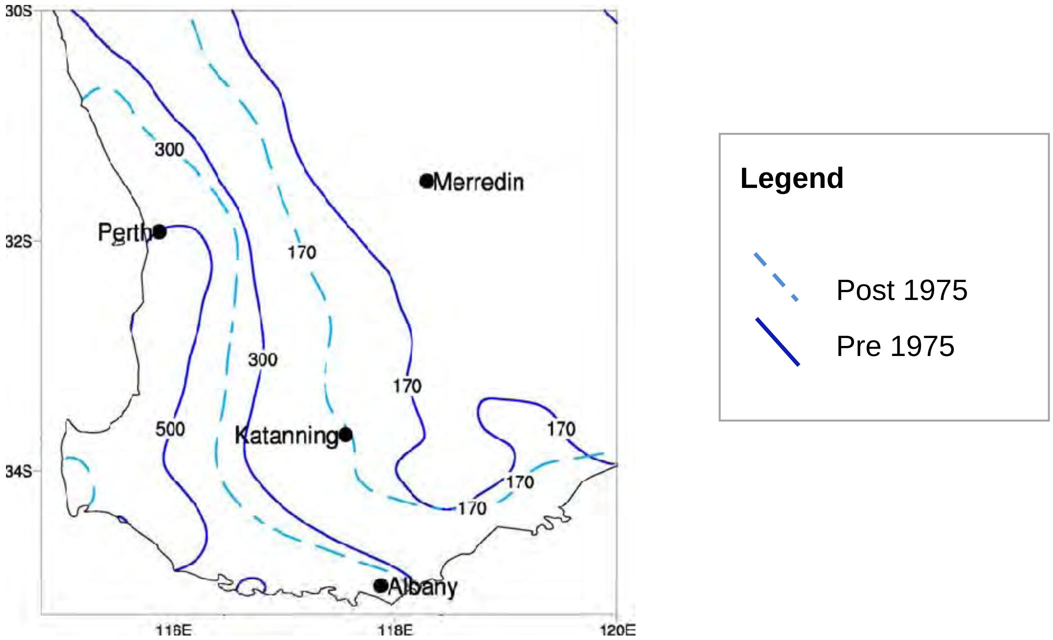


Figure 7-6: Rainfall reductions in south-west Western Australia (after McFarlane 2005)

As well as a reduced average rainfall, the absence of very wet years has resulted in greatly reduced runoff and recharge (with rainfall and runoff displaying a non-linear relationship).

Changing climate

Using almost all global climate models, the Intergovernmental Panel on Climate Change (IPCC) predicts that south-west Western Australia will experience a warmer and drier future climate (CSIRO 2009). With the clear non-stationarity in the climate, water resource assessment can no longer be based on what has occurred previously. For future allocation planning, the predicted drier climate must be considered.

The CSIRO's south-west Western Australia sustainable yields project (CSIRO 2009) examined the likely water yield of surface water and groundwater catchments in the region as a result of future climate and land management changes. As part of this project, climate (rainfall and areal potential evapotranspiration) and streamflow data representative of 2030 was produced under three scenarios: these were compared with a baseline for current hydrologic data which assumes the historical climate for the period from 1975 to 2007:

- wet scenario: -2% change in mean annual rainfall and a -6% change in mean annual runoff
- median scenario: -9% change in mean annual rainfall and a -24% change in mean annual runoff
- dry scenario: -15% change in mean annual rainfall and a -40% change in mean annual runoff.

The change in runoff values under these scenarios are shown in Figure 7-7. By applying a median future climate scenario in the determination of allocation limits, the Department of Water seeks to optimise the reliability of water supply for authorised users and the environment in a drier future.

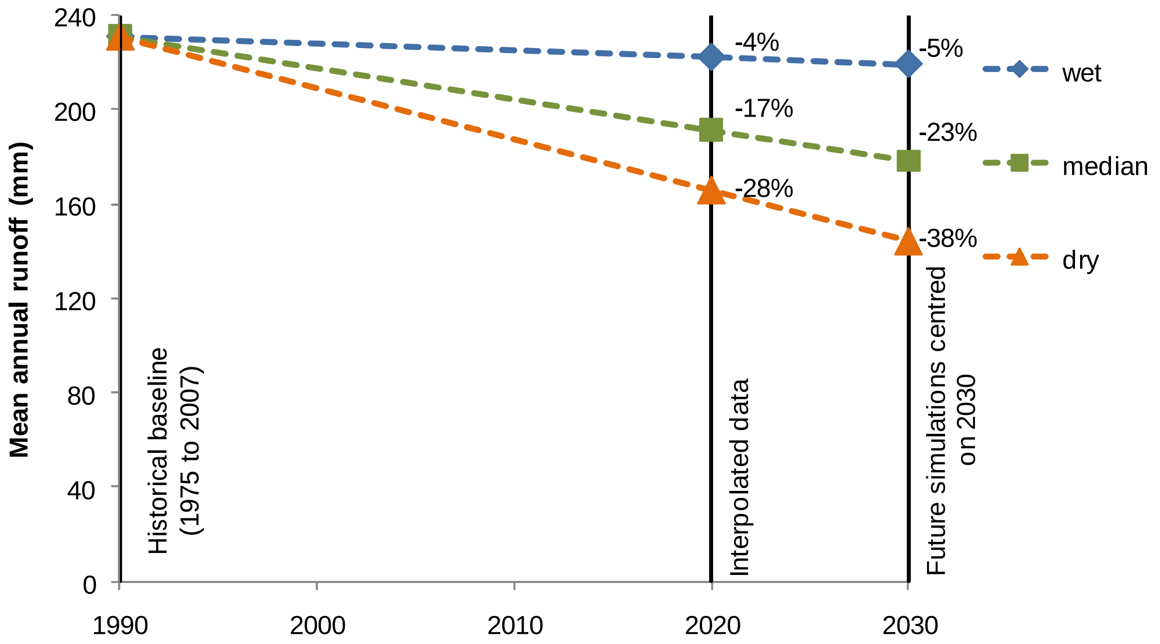


Figure 7-7: Diagram of interpolation between the historical baseline centred on 1990 and the future scenarios centred on 2030 to construct scenarios representative of a climate centred on 2020 (data is for Cross Farm, 612032, gauging station)

These climate change predictions are of particular concern for the Leschenault catchment in that the leading conclusion indicates:

> Under a median future climate, rainfall is likely to decline by an average of 9% and runoff by 24% relative to the historical climate (CSIRO 2009c) for the period 1975 to 2007.

Irrigation scheme dams will be even more impacted than they are at present. In the Wellington catchment, the recent trend of declining runoff is already evident (CSIRO 2009c). This could affect the current regime of environmental water releases from the dam into the Collie River.

Changing climate and impact on the Leschenault Estuary and its associated waterways

The seasonal freshwater inputs in winter and early spring associated with rainfall are critical to flushing the remnant tidal estuarine saline water and built-up organic material. For example, these freshwater inputs help reset the system and reduce conditions that predispose the Brunswick and lower Collie to year-round poor water quality; that is, organic matter and nutrient-rich benthic flocs in stratified bottom saline water (Rose 2004).

Reduced rainfall scenarios also lead to reduced surface runoff events but also higher nutrient concentrations in those events, because nutrients of terrestrial origin are not diluted through frequent rainfall events. These higher-concentration surface flows in waterways can lead to algal growth of larger proportions in the lower river systems, as conditions allow.

Thus reduced runoff in winter might no longer allow for sufficient flushing of the river systems and result in higher concentrations and longer residence times of nutrients in the waterways, which can lead to adverse impacts on aquatic ecosystems.

7.9 Recommendations

It is recommended that:

- a surface water allocation plan be developed for the Preston catchment
- this WQIP's WQOs be incorporated into the relevant existing and future water allocation plans (surface and groundwater)
- complementary policy and on-ground strategies be put in place to achieve integrated management of water allocation and water quality, particularly in the light of climate change predictions
- a better understanding of the groundwater/surface water interface in the catchment is established.

8 Knowledge and data gaps

8.1 Introduction

The estuary system's environmental values were assessed using known information, much of which was quite old. As such, there is a need to reassess the current environmental values the WQIP is intended to protect. At the same time it would be beneficial to survey how the community uses the estuary and the values deemed important by those users.

Sufficient, documented, objective measures of the currently recommended agricultural and urban BMPs are lacking. There is also a pressing need to develop more effective nutrient reduction measures, especially for agriculture.

It is important to consider research needs for informed management of the estuary and to integrate future learning as part of an adaptive management approach.

Future research projects will help to:

- refine the BMPs
- enable better and more targeted water quality monitoring programs
- provide additional tools for adaptive management
- provide greater confidence on certain recommendations that require localised case studies
- fill gaps in knowledge.

During this WQIP's development, a number of important research priorities have been identified, which are discussed in the following sections.

8.2 Ecological character description

Characteristics often used to measure ecosystem health include biomass, productivity, nutrient cycling, species population and diversity, foodweb complexity, niche specialisation, spatial diversity, size distribution of organisms and their lifestyles, disease prevalence and mortality rate. In the case of the Leschenault Estuary, despite some research and literature as presented earlier in this plan, the causal relationships between changes in indicators and stresses and the estuary's ecosystem health are not clearly established for some indicators, reflecting an inadequate understanding of this estuarine ecosystem and its processes. As indicated in Section 2, at present there is no single document providing the basis for an up-to-date ecological assessment of the estuary and its waterways including benchmarks on the ecological values.

An ecological character description (ECD) will set the current baseline for ecological values and enable managers to monitor and manage the estuary, its foreshore and associated biota and put in place preventative measures against further degradation, as well as remediation measures to improve ecological condition. The ECD itself will identify information gaps. Recent ECDs have been completed for the Peel-Harvey estuary and the Vasse-Wonnerup wetlands.

8.3 Ecological model of the estuary

The Department of Water is currently (2012) developing a hydrodynamic (circulation) model of Leschenault Estuary. The model will include all water fluxes – Wellesley, Brunswick, Collie, Ferguson and Preston rivers; Parkfield Drain; urban drains close to the estuary; groundwater; rain on the estuary; seawater and evaporation – and be driven by sea-level height and meteorological data. The aim is to determine the residence time and fate of all inflows, and thus deduce the relative importance of the nutrients in the inflows. This will help to guide management in the catchment. Nutrient inflows that remain in the estuary for long periods or are not flushed from the estuary (become bound to sediments) have greater potential to adversely affect the ecology than nutrients that are rapidly flushed to the ocean.

Once the hydrodynamic modelling has been completed and water flows and circulations in the estuary are better understood, it is recommended that an ecological model able to estimate algal growth and distribution under different ambient conditions be implemented: a suitable ecological model is available for the current hydrodynamic model. Such a model would enhance current knowledge of the estuary's ecology. The model would enable better assessment of the impacts of stresses such as nutrient and non-nutrient contaminants, decreased river flows and higher temperatures associated with climate change, and flood events. Changes likely to impact the foodweb and thus crab, fish, bird and dolphin habitat would be more easily identified. The impacts of land use changes in the catchment, such as replacement of septic tanks with reticulated deep-sewerage, would also be better quantified.

8.4 Understanding groundwater transport of nutrients and other contaminants

The Leschenault catchment has historical urban land uses near the estuary and the lower reaches of the Preston, Collie and Brunswick rivers.

At present there is limited knowledge of and information on nutrients and other contaminants leaching in groundwater to the waterways and estuary. Possible sources include septics, Kemerton WWTP, industrial estates and contaminated sites including historic landfill sites. It is important to gain a better understanding of the nature and risks of potential contaminants entering the waterways and estuary in groundwater, as well as the potential risk to the biota, human health, and integrity of the ecosystem.

Projects required are:

- Estimation of groundwater inflow to the Leschenault Estuary and Inlet.
- Development and application of forensic techniques to identify groundwater pollutants and sources. Stable isotope analyses have been used in botanical and plant biological investigations for many years (mostly carbon, nitrogen and oxygen). For instance, N^{15} enrichment is used as a marker for sewerage contamination (Dennison & Abel 1999).

8.5 Investigation of non-nutrient contaminants

Urban areas as well as some agricultural practices are associated with contaminants other than nutrients, such as metals (lead, aluminium, chromium, copper, iron, zinc, arsenic, cadmium, manganese and nickel), detergents, petroleum hydrocarbons, PAHs and endocrine-disrupting chemicals. Investigations should:

- measure contaminants other than nutrients in streams and drains entering the estuary, the Port of Bunbury and the inlet to include (at a minimum) samples in both low-flow, high-flow and first-flush conditions
- select analytes which include metals, pesticides, organic compounds and endocrine-disrupting chemicals and include bioavailable components
- measure contaminant accumulation in sediments of the streams, drains and estuaries including measures of ecotoxicity where indicated
- use data from the non-nutrient measurement program to undertake both a human health and ecological risk assessment to determine the management response.

8.6 Understanding sediment nutrient dynamics

The lower reaches of the Brunswick, Collie and Preston rivers are depositories for sediments derived from the catchment. Anecdotal evidence suggests that sediment is building up in those parts of the rivers. The potential for nutrients to bind to (and release from) sediments depends on their physical and chemical nature, as well as the history of the enrichment and flushing rate of the system (Hill et al. 1991). The prevailing physical conditions of the water column, such as stratification and oxygen concentration, also greatly affect nutrient release from sediments. Sediments also adsorb and (release) other contaminants, such as metals.

Sediments play an important role in water quality within estuaries and other aquatic systems. A recent study by the Department of Water indicates that sediments in the Leschenault Estuary (at the sites sampled) have high nitrogen concentrations, particularly relative to their phosphorus concentrations (Kilminster 2010).

> The Leschenault Estuary is commonly believed to be nitrogen limited, so additional inputs of nitrogen could drive excessive primary production. Without further investigation, it is not known whether the nitrogen within the sediment is available or if it is locked up in more recalcitrant organic matter

It is thus important to gain a better understanding of the role of sediments in the estuary and estuarine sections of the rivers in terms of the storage and release of nutrients and other contaminants, and the implications for the biota and other values. Preliminary studies of nutrient releases conducted by the Department of Water and Geoscience Australia did not include the riverine portions of the estuary most prone to sediment accumulation.

As such, the key research programs required are to:

- further investigate the nutrient dynamics (storage and release) in the estuary with an emphasis on the estuarine sections of the Collie, Brunswick and Preston rivers
- investigate the potential for non-nutrient contaminant release from the stored sediments in the estuarine sections of the Collie, Brunswick and Preston rivers
- consider effective methods to measure and predict sediment build-up in river pools and its delivery to the estuary, with a focus on management action to reduce soil loss from catchments.

8.7 Developing and evaluating nutrient best-management practices (BMPs)

While there is a good grasp of the effectiveness of some BMPs, which were included in the cost/benefit analysis, there is insufficient data for other BMPs – both in general and in relation to their application on the Swan Coastal Plain and in the Leschenault catchment.

Part of successful BMP adoption lies in presenting local examples that give stakeholders confidence in the BMP's worth. Most urban and some rural BMPs, including riparian zone management and dairy shed effluent systems, have insufficient data on potential benefits. The lack of information and/or confidence in suggested practices in addition to the implementation cost can affect adoption rates. The following research is recommended:

- Assessing WSUD efficiency in removing nutrients and other contaminants with demonstrated case studies that are monitored for a long-enough time to measure change.
- Implementing and monitoring sites of riparian zone rehabilitation in both the coastal plain and 'hills' areas to assess changes to water quality (nutrients, sediments, pesticides, herbicides and other contaminants), as well as ecological benefits.
- Establishing monitoring programs of all suggested BMPs in urban and rural settings for baseline data, using case studies at key sites representing a range of soil types and land uses; for example, dairy shed effluent management, better fertiliser management and use of slow-release phosphorus fertiliser, soil amendment, perennial pasture, irrigation efficiency, WSUD retrofit and in WSUD in new developments, riparian zone rehabilitation and horticultural BMPs.

8.8 Develop plantation-industry BMPs related to nutrient leaching and other contaminants

Forestry practices can have detrimental impacts on waterways, such as sediment delivery to streams. This mainly occurs after tree harvesting and other maintenance activities in the plantation. Erosion of roads and tracks can also be a major source of sediments (Parkyn 2004). Nutrient and pesticide contamination of waterways can result from poor forestry management.

As reported in Section 5.2 and Appendix H, plantations contribute significant nutrient loads in some subcatchments – phosphorus in particular.

The following projects are recommended:

- carry out studies to determine the nutrient-leaching capacity of plantations (range of species) across different soil types and landscapes
- establish BMPs and codes of practice for plantations in the Leschenault catchment including appropriate fertiliser application regimes.

8.9 Estuary management plan

Notwithstanding the lack of a governing body for the Leschenault Estuary, a management plan for the estuary is required. Thus a key project to deliver would be:

- A management plan for the estuary that aligns government agencies, local governments and to some extent the community on the management of this asset. The plan would identify roles and responsibilities, identify gaps in legislation and offer a coordinated approach to the management of the estuary, encompassing all environmental aspects (e.g. water quality, acid sulfate soils, biodiversity, foreshore vegetation protection and conservation, recreational usage), and help to inform the next stage of the GBRS.

8.10 Acid sulfate soil risk

A significant area around the Leschenault Estuary is underlain by acid sulfate soils. There is evidence that in some locations disturbance of these has already taken place, acidifying the soil and negatively affecting water quality. At present little is understood about the estuary ecosystem’s capacity to withstand the pressures from disturbed acid sulfate soils.

Acid sulfate soil disturbance can have a range of impacts that depend on the timing and magnitude of the acid release, and the capacity of the soil matrix to buffer the acidity. These impacts may include:

- concrete infrastructure damage
- vegetation scalds
- loss of agricultural productivity
- stress of terrestrial plants by metal exposure
- death of plants irrigated with affected water
- smothering of benthic aquatic animals by iron precipitates
- metal bioaccumulation in aquatic plants and animals.

Two actions are required:

- Improve knowledge of the magnitude of impact on water and biota as a result of acid sulfate soil disturbance. Include use of the newly developed sulfur isotope indicator to examine the spatial extent of impact.
- Estimate potential for development of monosulfidic black oozes in the Leschenault Estuary drainage incorporating findings from current work in the Peel Harvey.

9 Implementation strategy

9.1 Statutory context

As reported by White (2010), the Western Australian and Australian governments have a range of statutes and policies to help support the Leschenault WQIP's implementation. The list below contains some existing strategies and legislation relevant to water quality or to the management and protection of water-related assets. This is not an exhaustive list and no legal opinion was sought regarding gaps or recommendations.

State legislation and policies:

- *Waterways and Conservation Act 1976* under which the Leschenault Estuary is a declared waterway
- *Environmental Protection Act 1986*
- *Contaminated Site Act 2003*
- *Country Towns Sewerage Act 1948*
- *Health Act 1911*
- *Rights in Water and Irrigation Act 1914*
- *Soil and Land Conservation Act 1945*
- *Planning and Development Act 2005.*

State planning policies:

- *State planning policy no. 2: Environmental and natural resources*
- *State planning policy no. 2.5: Agricultural and rural land use planning*
- *State planning policy no 2.7: Public drinking water source policy*
- *State planning policy no 2.9: Water resources*
- *Better urban water management* framework
- *Wetlands conservation policy for Western Australia*
- Proposed water resource legislation: please note the state government is presently consolidating various water-related pieces of legislation into the Water Services Bill which has been passed in parliament but not promulgated and some form of Water Resource Management legislation

Federal legislation and policies:

- National Water Quality Management Strategy
- National Water Initiative
- *Environmental Protection and Biodiversity Conservation Act 1999*

Other existing mechanisms can be used to manage nutrients in the Leschenault Estuary and Inlet – these include departmental policies and programs.

9.2 Voluntary versus regulatory BMP uptake

The issue of diffuse pollution in south-west Western Australia is not a recent one. Water quality problems derived from diffuse pollution led to the demise of the Peel-Harvey estuary and consequent construction of the Dawesville Channel. DAFWA and other organisations have attempted to tackle diffuse pollution since the 1980s (Steele 2006). In particular DAFWA has promoted fertiliser efficiency programs to farmers with recommendations on timing of application, adoption of soil and plant-tissue testing and the use of slow-release fertiliser. Yet in the Peel-Harvey and the Leschenault catchments these recommendations have not been widely adopted.

A key issue to arise from this WQIP is the need to assess whether voluntary uptake of BMPs is sufficient and viable for reducing diffuse and point source pollution, or whether a more regulatory approach should be followed. A timeframe should be set to determine the effectiveness of voluntary methods (e.g. modifying on-farm fertiliser management to minimise nutrient losses to waterways). Failure to achieve the required outcomes may require regulation for adoption of BMPs with appropriate auditing and penalties, as is the practice in the European Union and New Zealand.

The same can be said of effluent management of dairy sheds, and other non-controlled point or diffuse sources. An option would be to licence dairy farms and feedlots under Part V of the *Environmental Protection Act 1986* (WA) and to assess the licence applications and audit their performance.

9.3 Implementation principles

To ensure the WQIP's management measures and recommendations are implemented and the water quality targets achieved, it is important to identify a set of clear principles. The key implementation principles recommended are that:

- Implementation will be based on a whole-of–government approach with cross-agency cooperation, resourcing and support primarily between the Department of Water, DAFWA, DoP, DEC, the five local governments (City of Bunbury and shires of Harvey, Dardanup, Capel and Donnybrook-Balingup), the South West Development Commission (SWDC) and other relevant government agencies, industries and community stakeholders.
- A strategic management body of these stakeholders, operating under a memorandum of understanding, should guide the WQIP's implementation.
- Agricultural-based management measures will mostly be implemented by collaboration between the Department of Water, DAFWA and relevant industry groups with support where possible from the LCC and SWCC. This will be done through various targeted and coordinated programs addressing research gaps, setting up demonstration sites and case studies, extension programs and potentially the introduction of regulatory measures.
- Urban-based management measures will be implemented by collaboration between the Department of Water, DoP, DEC, local governments and NRM groups (where possible). This will focus on meeting *Better urban water management* framework requirements,

improving fertiliser management of public open spaces and urban gardens, stricter regulation of point sources and evaluation of BMPs in the catchment.

The WQIP's implementation will also require:

- Appropriate planning at various levels (DoP, local governments and developers) that considers development impacts on receiving waterways and puts in place measures to minimise those impacts.
- Allocation of sufficient funds and resources to undertake recommended measures – whether internally in agencies, or through grant programs at the state or federal level.
- Sufficient funds to monitor flow and water quality, and to update modelling as necessary.
- The evaluation and setting of trials of BMPs where knowledge gaps have been identified. BMPs will have to be reviewed and edited based on the knowledge gained. This is a critical component of the WQIP's delivery, particularly for the riparian and WSUD BMPs for which lack of local evidence could hinder adoption. These 'research' activities may involve collaborations with CSIRO and universities.

9.4 Implementation of management measures

The management actions identified in this report are aimed at improving water quality to protect and maintain the environmental values afforded by the Leschenault Estuary and associated waterways.

Table 9-1 summarises all the recommendations identified within this document, which include agricultural and urban BMPs, environmental flow management, research and monitoring requirements. These recommendations are based on a 10-year delivery timeframe and are believed achievable if resources and political support are provided. Table 9-2 provides a matrix of which organisations are responsible for individual management measures.

Although the focus is on the estuary's subcatchments, guidance is also provided for the Coast subcatchment to benefit the Leschenault Inlet, and to a lesser extend Big Swamp and the ocean.

Implementation of the management actions requires a strategic approach to enable managers to assign adequate resources for individual recommendations and reporting subcatchments, as documented in the accompanying report, *Implementing the Leschenault Estuary water quality improvement plan* (DoW 2012).

Table 9-1: Implementation strategy recommendations

Management measures	#	Recommendations	Location and level of implementation	Lead agencies / organisation
Managing agricultural nutrients				
1. Improve fertiliser management throughout the catchment	1.1	Promote recently developed tools to interpret soil tests such as SPANA and educational DVD materials such as the *Making $ense of Fertiliser* DVD	The entire catchment (rural and urban land use)	DEC DAFWA DOW LCC and SWCC
	1.2	Develop other tools to help farmers and key stakeholders interpret soil tests (for industries other than beef). For pasture soil-test recommendations, see DAFWA's specific recommendations in Appendix J.		
	1.3	Provide farmers and key stakeholders with regular educational opportunities to build their understanding of how to interpret soil-test results.		
	1.4	Support the development of nutrient accounting packages and other tools that allow farmers to independently assess their fertiliser and nutritional requirements.		
	1.5	Support the development of specialist products for low sorbing soils.		
	1.6	Undertake demonstrations and case studies associated with BMPs, including low-water-soluble fertilisers, to help implement the *Fertiliser Partnership (formerly the Fertiliser Action Plan)*		
	1.7	Expand education activities to urban land use targeting local governments, turf clubs, golf clubs, and even residential populations, for efficient fertiliser management to reduce nutrient inputs – particularly for recreational turf – via extension programs, educational material, leaflets, television advertisements and others.		
2.Use of slow-release fertiliser	2.1	Support the development and evaluation of alternative low-water-soluble phosphorus (LWSP) products. Demonstrate the potential for use of LWSP fertilisers combined with application of lime or other elements to provide an improved production response.	The entire catchment. Priority on low PRI soils, recovery and intervention subcatchments	DEC DAFWA DOW LCC and SWCC
	2.2	Promote through extension programs and case studies.		
3.Using approved soil amendments on sandy soils	3.1	Undertake soil amendment trials, including NUA, to determine the applicability and effectiveness of reduction in nutrient export against productivity on a number of land uses.	On all low PRI soils, with priority work in the: Lower Preston Lower Collie 1 Wellesley Mid Brunswick and all new urban	EPA DAFWA DOW DEC LCC and SWCC
	3.2	Develop and promote reference sites to demonstrate best-practice application supported by good scientific data that identify impacts, risks and limitations.		
	3.3	Encourage Iluka and Alcoa to seek formal approval for targeted-use classification of NUA and Alkaloam so they are freely available for use in Western Australian catchments including the Leschenault.		

Management measures	#	Recommendations	Location and level of implementation	Lead agencies / organisation
	3.4	Establish soil amendment application guidelines for urban development (new and established) and complementary policy for water quality management.	developments or redevelopments	
	3.5	Recommend the use of NUA or NUA mixes in residential fill using Bassendean sands.		
	3.6	Recommend the use of NUA in all turf farms and public open space using turf.		
	3.7	Work with local governments and DoP to establish minimum PRI levels for proposed urban development sites as part of their water quality policies and require the use of soil amendments to reduce nutrients leaching from urban land use.		
	3.8	Undertake promotion, education and demonstration of approved products and techniques where clear benefits can be demonstrated and risks have been evaluated.		
4. Use of subtropical perennial pastures, in suitable locations, for broadacre dryland grazing	4.1	Establish demonstration or experimental perennial pasture sites to demonstrate profitability under reduced P inputs and describe benefits and constraints to establishment.	On broadacre dryland pasture	DAFWA Grazing industry LCC and SWCC
	4.2	Provide technical support to farmers that are willing to undertake replacement of annual pasture with perennial grasses in suitable locations.		
	4.3	Encourage rotational grazing for current annual pastures in areas where perennials grow well and are a suitable option, as well in areas where perennials have other environmental benefits such as reduced soil erosion by improving ground cover.		
	4.4	Continue research into the rooting depth and efficacy of perennials on reducing nutrient leaching.		
	4.5	Carry out further research in the catchment to quantify the impacts on the annual component of the sward of reducing P inputs.		
5. Implementing annual horticulture BMPs	5.1	Survey nutrient management and better management practices within the horticultural sector, particularly the annual horticulture sector in the Parkfield Drain catchment.	On any horticultural properties with priority on the Swan Coastal Plain and sandy soils	DAFWA Horticulture industry LCC and SWCC
	5.2	Continue developing and improving recommended management tools specific to respective crops.		
	5.3	Continue developing and improving existing recommended management tools, defined by Vegetables WA, specific to respective crops.		
6.Implement riparian management for water quality benefits and reinstating ecological function of waterways	6.1	Undertake monitoring and assessment to demonstrate nutrient uptake efficiencies of riparian management in a range of conditions specific to the Leschenault catchment (i.e. need to carry out additional local research to assess benefits of riparian revegetation on the coastal plain, hills and a range of soil types in the Leschenault catchment to obtain accurate and site-specific efficiency rates).	All waterways with priority work in recovery and intervention subcatchments	DOW DPI LGAs LCC and SWCC
	6.2	Undertake further research to assess the removal of other pollutants such as heavy metals, hydrocarbons, pesticides and herbicides via riparian buffers.		

Management measures	**#**	**Recommendations**	**Location and level of implementation**	**Lead agencies / organisation**
	6.3	Set up reference sites (pristine systems and degraded systems) to compare with targeted sites to measure and compare other factors influencing management effectiveness, such as climate change (i.e. temperature and rainfall decline), dieback and pest impacts on riparian vegetation health.		
	6.4	As part of high-level cost-sharing arrangements for riparian management, provide incentives including contributions to farm re-fencing, infrastructure redesign, weed control and revegetation programs.		
	6.5	Widely promote the benefits and potential limitations of riparian management to farmers through awareness programs and demonstration sites on minor streams but also on the larger systems.		
	6.6	Carry out river action plans on priority streams and tributaries where doing so will link existing vegetated streams, improve ecological and amenity value and reduce erosion.		
	6.7	Riparian management should also be used along waterways, drains and wetlands as a BMP adjacent to any agricultural practices (e.g. grazing, horticulture, forestry and other crops) likely to result in nutrient enrichment, soil erosion and other contaminants (pesticides, herbicides, fertiliser etc.) entering the waterways via surface and/or subsurface pathways.		
7. Improving effluent management of dairy sheds	7.1	Put cost-sharing arrangements in place to implement or upgrade best-practice dairy effluent management.	All dairy sheds but in order of priority for subcatchments: Wellesley Lower Collie 1 Mid Brunswick Lower Preston.	DEC DOW Dairy industry LCC and SWCC
	7.2	Widely promote the benefits of effluent management to farmers through awareness programs and demonstration projects.		
	7.3	Adopt an industry-based approach to promote the implementation of BMPs.		
	7.4	Promote adoption of the *Code of practice for dairy shed effluent – Western Australia* (draft) and assess acceptability.		
	7.5	Carry out farm surveys to confirm locations and status of dairy shed effluent management systems.		
	7.6	Revisit accurate costing of effluent management systems tailored to the catchment, topography, farmer circumstances etc.		
	7.7	Consider licensing dairy sheds under Part V of *the Environmental Protection Act 1986* and provide additional resources to DEC to assess the licence applications and then audit their performance.		

Management measures	**#**	**Recommendations**	**Location and level of implementation**	**Lead agencies / organisation**
		Managing urban nutrients and other contaminants		
8. Improving irrigation practices: going from flood irrigation to sprinkler irrigation	8.1 8.2	Promote the benefits of sprinkler irrigation/pivot irrigation on flooded dairy pasture where appropriate (adequate water quality, pressurised water source etc.). Consider trade of unused irrigation water and re-use of tail water.	All areas applying flood irrigation, but as a priority work in the: Wellesley Lower Collie 1 Lower Ferguson	DAFWA Dairy industry LCC and SWCC
9.Reducing nutrient land use and export risk in urban areas	9.1 9.2 9.3 9.4 9.5 9.6	Implement a comprehensive education and awareness program to widely promote the benefits of urban nutrient management, highlight the ecological values of receiving waters, and raise awareness of how nutrients can degrade these values. Implement cost-sharing arrangements to improve adoption of nutrient management practices by businesses in light industrial areas and encourage them to develop environmental management systems (EMS) Lead by example in the community by ensuring that facilities such as playing fields and landscaped town areas demonstrate best-practice nutrient management. Undertake survey and auditing work to assess variations in urban nutrient management across the community and gauge changes in adoption rates. Develop and implement policies to ensure future landscaping of new urban areas and public open space uses indigenous plant species with low nutrient and water requirements. Facilitate the use of modelling and decision-support tools to help local governments and DoP to assess the nutrient-transport risk of proposed new urban expansion areas – as part of broad strategic planning and major urban structure planning.	All urban areas, with priority work in the following subcatchment: Coast Estuary Foreshore Lower Collie 1 Lower Preston Mid Preston Mid Brunswick	DOW LGAs LCC and SWCC Community development industry Fertiliser industry
10.Ensuring new urban developments incorporate water sensitive urban design (WSUD)	10.1 10.2 10.3	Continue to develop and implement WSUD capacity-building programs which promote the *Better urban water management* framework. Develop assessment tools to aid local government decision-making on the performance assessment of drainage management plans. Implement on-ground research into the performance of structural and non-structural WSUD controls and water quality monitoring of WSUD in new developments and retrofitted sites to determine their effectiveness, obtain baseline data and provide demonstrated case studies specific to the Leschenault catchment.	New urban developments regardless of location	LGAs DPI DOW WALGA Development industry

Management measures	#	Recommendations	Location and level of implementation	Lead agencies / organisation
	10.4	Support local governments to adopt local water management planning policies and incorporate them into town planning schemes and/or local planning strategies.		
11. Stormwater from large urban developments	11.1	Negotiate with proponents of new developments to implement non-structural stormwater controls (in additional to structural WSUD).	New large urban developments	DOW DPI LGAs EPA Development industry
	11.2	Develop and adopt a policy and/or regulatory framework to formally link non-structural stormwater measures.		
	11.3	Undertake research and development into new urban water management practices.		
12.Undertaking strategic retrofitting of WSUD in existing urban areas	12.1	Development of stormwater management plans for local government areas to help identify opportunities and priorities for undertaking WSUD retrofitting projects.	Estuary Foreshore Lower Collie1 Lower Preston Mid Preston Coast	LGAs DOW LCC WALGA Community
	12.2	Undertake strategic monitoring to prioritise retrofit sites and evaluate BMP implementation.		
	12.3	Retrofit stormwater management systems where improved water quality outcomes can be achieved.		
	12.4	All redevelopments and infill/brownfield developments should address WSUD principles, consistent with *State planning policy no. 2.9: Water resources* (Government of Western Australia 2006).		
	12.5	Adopt the 'treatment train' approach by minimising or ideally preventing the generation of pollutants (at source), disconnecting pollutant transport pathways (in-system) and capturing or treating nutrients before they reach the main drain or receiving waterbody (end-of-pipe).		
	12.6	Provide training and awareness-raising forums for local government staff and councillors alike, tailored to individual needs.		
13.Reduce release of wastewater treatment plant (WWTP) effluent to catchment waterways to minimise the risk of adverse impacts from WWTP effluents.	13.1	Develop a policy of low nutrient contribution from WWTPs in recovery subcatchments.	Priority: Estuary Foreshore and Mid Brunswick subcatchments but all WWTPs overall.	Water Corporation EPA DEC DOW
	13.2	In protection subcatchments, maintain a policy of 'no net increase in nutrient loads' for WWTP upgrades. This can be facilitated through the EPA approvals process and may include technology upgrades and/or re-use options.		
	13.3	Where appropriate, investigate and implement options to reduce the potential impact of wastewater concentrates, toxicants, disinfection residuals, biosolids and salt loads.		
	13.4	Seek fit-for-purpose re-use of treated wastewater.		
14. Replace septic systems with low-nutrient-emitting aerobic treatment units (ATUs) or connect to reticulated	14.1	Support the provision of deep-sewerage in the priority subcatchments.	Priority 1: Estuary Foreshore Mid Brunswick Mid Preston Lower Collie 1 Lower Preston	Local governments DOW Water Corporation
	14.2	Influence and promote connection to reticulated sewerage through targeted mechanisms such as incentives and regulation.		
	14.3	Investigate the feasibility of alternative options such as replacement of septic tanks with ATUs for properties that cannot be connected to deep-sewerage systems.		

Management measures	#	Recommendations	Location and level of implementation	Lead agencies / organisation
deep-sewerage system.	14.4	Audit waste streams from the industrial areas in the catchment (Picton, Halifax, Preston industrial park and Kemerton industrial site) using the Water Corporation's criteria for acceptance of industrial waste into the WWTP.	Coast Priority 2: Lower Collie 2 Lower Ferguson Parkfield Drain	
15.Removing DEC-licensed discharges	15.1 15.2 15.3	DEC to consider revisiting its present licence conditions and see how it can help minimise the nutrient loads of the Lower Preston subcatchment as a matter of priority. DoP, local governments and DEC to ensure that no future DEC-licensed industries that emit nutrients to the environment are located within recovery subcatchments and more specifically in the Lower Preston subcatchment, unless effluents can be treated on-site and not add further loads to the river and estuary. Look at options for effluent water re-use that is fit-for-purpose.	Priority 1: Lower Preston Priority 2: Mid Brunswick and Estuary Foreshore	DEC DOW LGAs EPA
Managing environmental flows				
16.Ecological water requirements (EWRs)	16.1	Carry out an EWR for the estuary and estuarine sections of the Lower Collie, Brunswick and Preston rivers.	Estuary and estuarine section of the waterways	DOW
17.Surface water management	17.1	Undertake a surface water allocation plan for the Preston catchment.	Preston catchment	
18.Linking surface and groundwater	18.1	Establish better modelling science to link the surface water/groundwater interface in the catchment.	Surface and groundwater resources	
19.Integrate management of environmental flows with water quality management objectives	19.1 19.2	Incorporate the aims and recommendations of this WQIP, including its WQOs, into relevant existing and future water allocation plans for surface and groundwater. Develop complementary policy and on-ground strategies to achieve integrated management of water allocation and water quality, particularly in the light of climate change predictions.	Surface and groundwater resources	
Research and development				
20. Baseline ecological assessment status of assets and monitoring	20.1 20.2	Undertake an ecological character description (ECD) of the Leschenault Estuary and Inlet. As part of this ECD, identify keystone species for monitoring and to act as barometers of the estuary's health. Assess the status of seagrass beds in the estuary and develop and evaluate ecological indicators of the impact of nutrients. Carry out seagrass and macroalgae mapping every five years in the estuary.	The estuary and waterways	DOW DEC DoF DPI LGAs & LCC

Management measures	#	Recommendations	Location and level of implementation	Lead agencies / organisation
21. Understanding groundwater sources of nutrients and other contaminants derived from catchment land uses	21.1 21.2	Estimate groundwater inflow to the estuary. Develop and apply forensic techniques to identify groundwater pollutant sources.	Catchment wide	DOW DEC
22.Investigation of non-nutrient contaminants	22.1 22.2	Investigate non-nutrient contaminant presence, bioaccumulation and potential impacts on ecological values. Impacts on human health and recreational pursuits should also be examined. Monitoring and modelling of sediment and pesticide loads entering the waterways and the estuary.		DOW DEC DPI LGAs LCC DoF DEC LCC SWCC
23. Understanding nutrient dynamics and role of sediments in nutrient release	23.1 23.2	Investigate the nutrient dynamics (storage and release) in the estuary and in the lower estuarine sections of the Collie, Brunswick and Preston rivers. Investigate the potential of non-nutrient contaminant release from the stored sediments in the lower estuarine sections of the Collie, Brunswick and Preston rivers.	The estuary and estuarine sections of the waterways	DOW LCC SWCC
24. Understanding potential acid sulfate soils in the catchment	24.1	Obtain a better understanding of the effects of acid sulfate soil discharges on water quality and nutrients and contaminants, as well as the associated impacts on the environmental values of the estuary and its waterways.	Catchment wide with focus around waterways and estuary	DEC DOW DAFWA LCC
25. Estuary management plan	25.1	Deliver a management plan for the estuary with the main objective to align responsibilities between government agencies, local governments and to some extent the community on the management responsibilities of this asset. The plan will identify roles and responsibilities, identify gaps in legislation and offer a coordinated approach to the management of the estuary for all environmental aspects (water quality, acid sulfate soils, biodiversity, foreshore vegetation protection and conservation, recreational usage etc.) and should help to inform the next stage of the GBRS.	Estuary	DOW
26. Developing and evaluating nutrient BMPs	26.1	Address on-ground research into the performance of WSUD BMPs by assessing the efficiency of WSUD in removing nutrients and other contaminants in an urban setting. For more details, see the *Stormwater science plan for better urban water management* (Torres 2010) where key gaps and priorities have been documented.	Catchment wide	DOW DAFWA LCC SWCC LGAs

Management measures	#	Recommendations	Location and level of implementation	Lead agencies / organisation
	26.2	Develop and undertake further monitoring on riparian management in both the coastal plain and hills to assess its impacts on water quality (nutrients, sediments, pesticides, herbicides and key contaminants), but also ecological benefits.		
27. Carry out further studies on plantations and develop BMPs for the industry regarding nutrient leaching and other contaminants	27.1 27.2	Carry out studies to determine the nutrient-leaching capacity of plantations (range of species) across different soil types and landscapes. Establish BMPs and codes of practice for plantations in the Leschenault catchment including appropriate fertiliser application regimes.	Catchment wide	DOW Forestry sector Forest Products Commission DEC
28. Carry out ecological model of the estuary	28.1	Implement an ecological model linked with the hydrodynamic model, which includes biogeochemical processes of nutrient storage and release and algal growth estimates, as well as higher-end ecological models as appropriate.	Estuary	LCC and SWCC DOW DEC
Condition assessment, monitoring and reporting				
29. Carry out adequate monitoring	29.1 29.2 29.3 29.4 29.5	Continue water quality monitoring for nutrients across the catchment at the sites listed in Section 10 of the plan (at the minimum). Undertake routine estuary water quality monitoring to allow reporting of changes over time including nutrients, oxygen, physical measures, and micro and macroalgal accumulations. Measure estuarine health indicators such as seagrass extent and distribution, macroalgal extent and species composition, sediment organic matter and nutrient storage and other biotic indicators as appropriate to allow reporting of estuarine condition (health). Measure the concentrations of contaminants other than nutrients in drains and streams entering the Leschenault Estuary, Port of Bunbury and Leschenault Inlet including measures of accumulation in sediments. Ongoing maintenance and review of the catchment model to reflect changes in land use, water quality, hydrology, irrigation releases, knowledge of existing and additional BMPs, and management measures so that the plan's progress can be assessed and evaluated over time.	Across catchment	DOW LCC SWCC

Table 9-2: Summary of agencies and organisations responsible for each BMP

	Best management practices														
	Improve fertiliser management	Use of slow-release fertilisers	Soil amendment on low PRI soils only	Effluent management of dairy sheds	Perennial pasture	Implementing annual horticulture best practice	Improving irrigation	Reducing land use nutrient export risk	Ensuring new urban development incorporates WSUD	Adressing nutrient loads in large urban development	Undertake strategic retrofitting for WSUD in existing urban areas	DEC-licensed point sources mitigation	Replace septic systems with low nutrient emission ATUs or connect to reticulated deep sewerage	Decrease discharges from WWTPs to minimise adverse impacts	Riparian restoration
Local governments & WALGA	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓
DAFWA	✓	✓	✓	✓	✓	✓	✓								
DOW	✓	✓	✓	✓			✓	✓	✓			✓		✓	✓
DEC	✓	✓										✓		✓	
DPI			✓					✓	✓			✓			✓
EPA				✓				✓				✓		✓	
Water Corporation													✓	✓	✓
South West Development Commission											✓		✓		✓
Harvey Water							✓								
Agriculture industry/sector	✓	✓		✓		✓	✓					✓		✓	
Urban industries and stakeholders	✓	✓	✓					✓	✓		✓	✓	✓	✓	✓
NRM groups (LCC, SWCC and other community groups)		✓	✓	✓	✓		✓			✓					✓
Community and individuals	✓	✓		✓			✓	✓		✓			✓		✓

10 Reporting and review

The success of this plan will be measured in terms of water quality improvement. A prescribed program to monitor the interventions implemented and the water quality of the receiving waterways is required and discussed below.

10.1 Reporting on the implementation of this plan

Reporting to the public and the government (several state ministers and the federal environment minister) on the implementation of this WQIP will be achieved by:

- reporting the progress towards implementation of the recommended management actions, research needs and monitoring proposed in this plan
- reporting of progress and changes toward meeting the water quality targets set for each subcatchment and for the estuary itself
- a holistic review of the WQIP to be completed every two years.

Progress toward implementation of management measures

An annual assessment and review on the adoption of management measures and outcomes should be undertaken. This is to provide the basis for adaptive management, monitoring and evaluation of the adoption of the WQIP's management measures.

This should be coordinated and overseen by one organisation (Department of Water or another organisation to which this responsibility has been devolved, such as the SWCC or LCC), but with the joint effort of all responsible parties. This form of reporting will guide government agencies and NRM organisations on progress toward implementing the management measures and facilitate discovery of new science and data gaps.

The progress reports will require annual:

- stakeholder surveys in both rural and urban areas, which describe the BMPs implemented and have information on fertiliser use and other management practices in place (e.g. effluent management or perennial pasture)
- review of policies and new regulations that may change/affect BMP recommendations and adoption
- mapping of BMP adoption (and existing BMPs) with associated monitoring (if occurring) through geographical information systems (GIS) across the catchment
- investigation of the latest improvements and recommendations for BMPs arising from government agencies, industries and key stakeholders
- assessment of compliance against WQIP implementation presented in this document.

Progress toward water quality targets

A report card has previously been produced for the Leschenault (McKenna 2007) (see Appendix M) and provides a good avenue to report to the community on the progress against the water quality targets set and defined under this plan. It is recommended that this form of reporting should be continued during the life of the WQIP's implementation and at least every two years for the Leschenault Estuary as a whole, and for each of the subcatchments. Additionally, it is suggested that through the Department of Water website, maps of water quality status at each sampling point in the catchment be updated annually for public consultation.

These reviews should include:

- water quality monitoring data for the reporting subcatchment and assessment of compliance against water quality criteria
- non-nutrient water quality variables, where relevant
- known incidences of algal blooms, fish deaths and other responses to nutrient enrichment
- non-nutrient pollution events
- trends in nutrient concentrations and loads in the waterway
- changes in the sources of nutrients within the subcatchment or catchment (reflecting known changes in land use, land use management or reductions in point sources)
- changes in the management category of the subcatchments.

10.2 Accounting for the impacts of climate change

The water quality targets were set for the current climate and hydrology. We may need to refine these to reflect any altered hydrology caused by southern Western Australia's changing climate (if these changes are large). As the WQIP's implementation proceeds, it is essential that any changes are accounted for and the necessary adjustments made to the modelling. The following steps will have to be undertaken every five years:

- update meteorological information (rainfall and evaporation) to determine whether trends indicate a change in climate
- in instances where rainfall regime changes are detected, undertake recalibration of the water quality models
- update concentration and load reduction targets
- run a new set of cost/benefit scenarios with updated load reduction targets (where relevant) and review recommendations on BMPs accordingly.

10.3 Water quality and flow monitoring requirements

The preparation of this plan and the modelling that supports its targets and recommendations would not have been possible without the extensive flow and water quality monitoring conducted by the Department of Water. Further updates to this plan will rely heavily on the availability of continued and updated flow and water quality data. The report *Nutrient loads, status, and trends in the Leschenault catchment* (Kelsey & Hall 2010) discusses past water quality monitoring and the current nutrient concentrations and status at 42 sites.

The future water quality monitoring of the estuary and associated waterways should support the WQIP's reporting requirements and provide sufficient data for model calibration.

Table 10-1 lists suggested water quality monitoring locations and their purpose (see also Figure 10-1). The criteria for site selection are:

- at least one site in every reporting subcatchment
- data for model calibration – the 15 sites highlighted are the minimum required to obtain a reasonable model calibration
- continued monitoring of sites with poor water quality due to intensive agricultural uses so that changes due to improved management practices can be detected
- monitoring of some urban areas to determine current water quality and to detect changes due to improved management practices
- monitor at flow gauges to enable load calculations
- monitor at sites with deteriorating water quality.

In addition to water quality, flow data are also required for model calibration to determine catchment loads and to assess trends in water quality.Table 10-2 lists the flow sites that have provided data for model calibration and which will be required for ongoing data analyses and modelling.

It is recommended that physical data: conductivity, salinity, temperature, DO and pH; and nutrient data: TN, TP, ammoniacal nitrogen (NH4-N/NH3-N), nitrous oxides (NOx-N), soluble reactive phosphorus (SRP-P), dissolved organic carbon (DOC), dissolved organic nitrogen (DON-N) and total suspended solids (TSS) are collected at the 27 sites in Table 10-1 fortnightly when the waterways are flowing. The data should be collected following Department of Water protocols (Figure 10-2) and managed through the department's Water Information Network (WIN) database. Annual reporting of catchment data is recommended with trend calculations undertaken every three years and load calculations annually when flow data are available.

Non-nutrient contaminants

Non-nutrient contaminants (such as metals, hydrocarbons, ECDs and pesticides) are commonly found in urban and industrial areas, but also may be associated with intensive agricultural land uses. There is known historic contamination of the Preston River with organochlorines (Atkins 1982; Klemm 1989). It is recommended that a non-nutrient contaminant sampling program is undertaken to collect baseline data throughout the catchment. Contaminated areas could then be targeted for remediation or continued monitoring as appropriate.

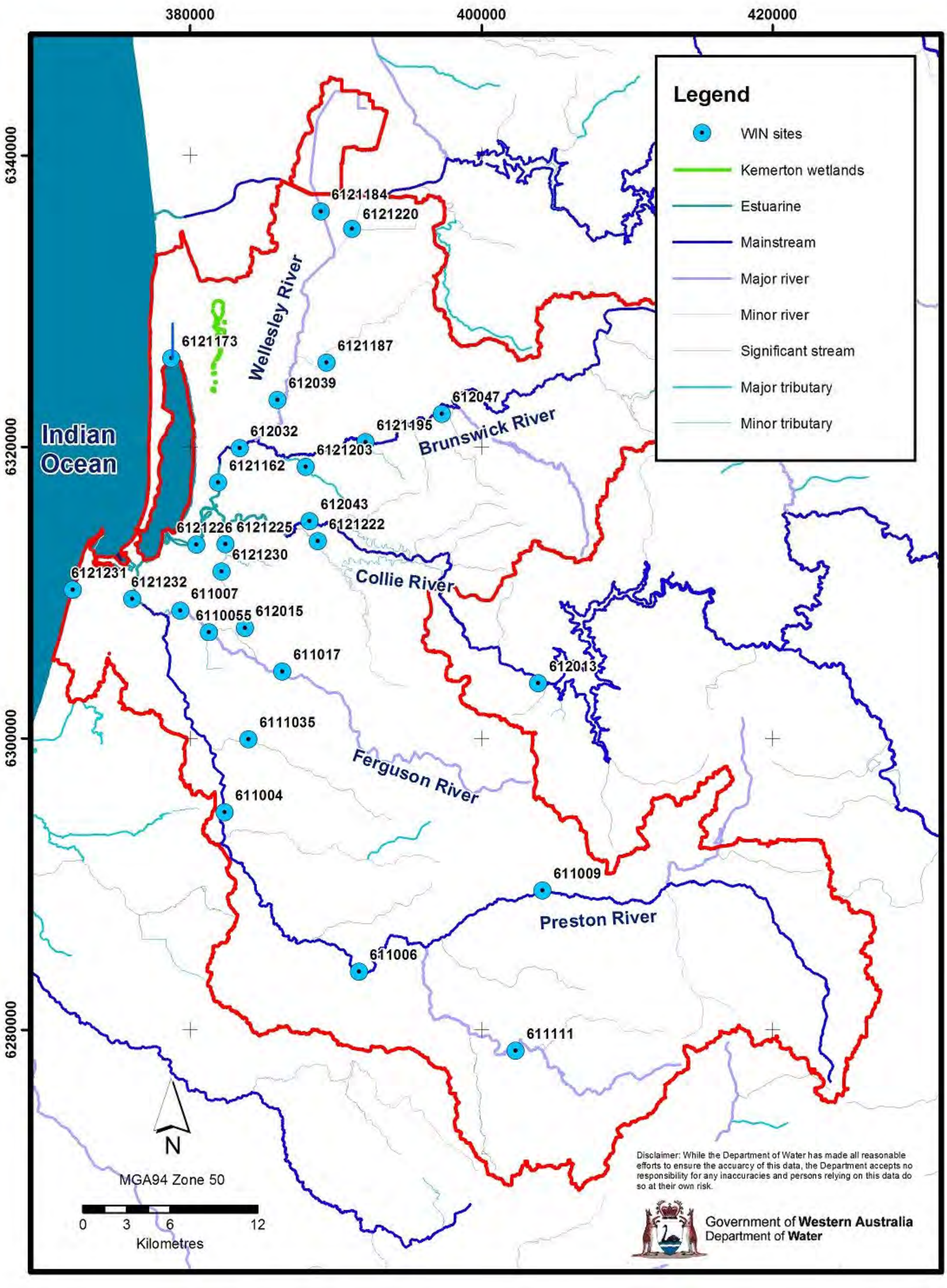


Figure 10-1: Recommended water quality monitoring sites

Table 10-1: Recommended sites for water quality monitoring in the Leschenault catchment

AWRC ref	Site name	River	Subcatchment	Purpose/comments
Parkfield Drain				
6121173	Parkfield Drain	Leschenault Estuary	Estuary	Poor WQ, horticulture, calibration
Wellesley				
6121184	Leitch Road	Mangosteen Drain	Wellesley	Poor WQ, intensive agriculture
6121187	Campbell Road	Mornington Creek	Wellesley	Poor WQ, intensive agriculture
612039	Juegenup Wellesley	Wellesley River	Wellesley	Poor and worsening WQ, intensive agriculture, calibration
6121220	Hope Ave	Wellesley River	Wellesley	Poor WQ, intensive agriculture
Brunswick				
612047	Beela	Brunswick River	Brunswick Upper	Calibration
6121195	Caravan Park Brunswick	Brunswick River	Brunswick Middle	Worsening WQ
612032	Cross Farm	Brunswick River	Brunswick Middle	Poor WQ, calibration
6121203	Elvira Gully	Elvira Gully	Brunswick Middle	Poor WQ, point source discharge
6121162	Brunswick 2	Brunswick River	Brunswick Lower	Poor WQ, calibration
Collie				
612013	Wellington Flume	Collie River	Dam	Poor WQ, calibration
612043	Rose Road	Collie River	Collie Lower 2	Poor WQ, calibration
6121222	Henty	Henty Brook	Henty	Poor WQ, calibration
612015	Harris Road	Vindictive Drain	Collie Lower 1	Poor WQ
6121230	Hynes Road	Canal	Collie Lower 1	Poor WQ
6121225	Millars	Millars Creek	Collie Lower 1	Poor WQ
6121226	Hands Street	Collie River	Collie Lower 1	Poor WQ, urban
Ferguson				
611017	Doudell Road Bridge	Ferguson River	Ferguson	Calibration
611007	SW Hwy Ferguson	Ferguson River	Ferguson	Calibration
6110055	Canal	Ferguson River	Ferguson	Poor WQ
Preston				
611009	Lowden Road Bridge	Preston River	Preston Upper	Calibration
611111	Woodperry Homestead	Thomson Brook	Thomson	Calibration
611006	Donnybrook	Preston River	Preston-Donnybrook	Calibration
611004	Boyanup Bridge	Preston River	Preston Middle	Calibration
6111035	South West Hwy	Crooked Brook	Preston Lower	Poor WQ
6121232	St Marks Park Lake	Charterhouse Street	Preston Lower	Urban
Bunbury				
6121231	Hayward Road	Punchbowl Canal	Coast South	Poor WQ, urban

Figure 10-2: Water quality monitoring (courtesy Ken Okamitsu, LCC 2010)

Table 10-2: Flow monitoring sites

AWRC ref	Site name	River	Subcatchment
612039	Juegenup Wellesley	Wellesley River	Wellesley
612022	Sandalwood	Brunswick River	Brunswick Upper
612047	Beela	Brunswick River	Brunswick Upper
612032	Cross Farm	Brunswick River	Brunswick Middle
612013	Wellington Flume	Collie River	Dam
612043	Rose Road	Collie River	Collie Lower 2
611017	Doudall Road Bridge	Ferguson River	Ferguson
611007	SW Hwy Ferguson	Ferguson River	Ferguson
611009	Lowden Road Bridge	Preston River	Preston Upper
611111	Woodperry Homestead	Thomson Brook	Thomson
611006	Donnybrook	Preston River	Preston-Donnybrook
611004	Boyanup Bridge	Preston River	Preston Middle

Confounding factors

The water quality monitoring discussed above provides a minimum requirement. However, depending on the scale of BMP implementation, it may not be sufficient to detect regional water quality changes: monitoring at a greater number of locations or closer to management interventions may be required. It is envisaged that the water quality monitoring will change during the WQIP's implementation to best support the reporting requirement outlined above for the least cost. Additionally, specific monitoring to determine the impacts of BMPs will be required to improve our knowledge and data on BMP effectiveness. This component is separate to the regional-scale monitoring discussed above and may be funded from the BMP implementation costs.

It is also important to account for the lag in measurable water quality improvement after the implementation of management practice change for diffuse sources (such as agriculture).

> Unless recognised and dealt with, long lag time will frequently confound our ability to successfully document improved water quality resulting from treatment of non-point sources and may discourage vital restoration efforts (Meals & Dressing 2010).

Meals and Dressing (2010) point out that watershed projects often fail to meet expectations for water quality improvement due to this lag time. The main components affecting the lag time are represented in Figure 10-3 below. The monitoring program must be of sufficient duration to account for the lag between BMP implementation and improved water quality.

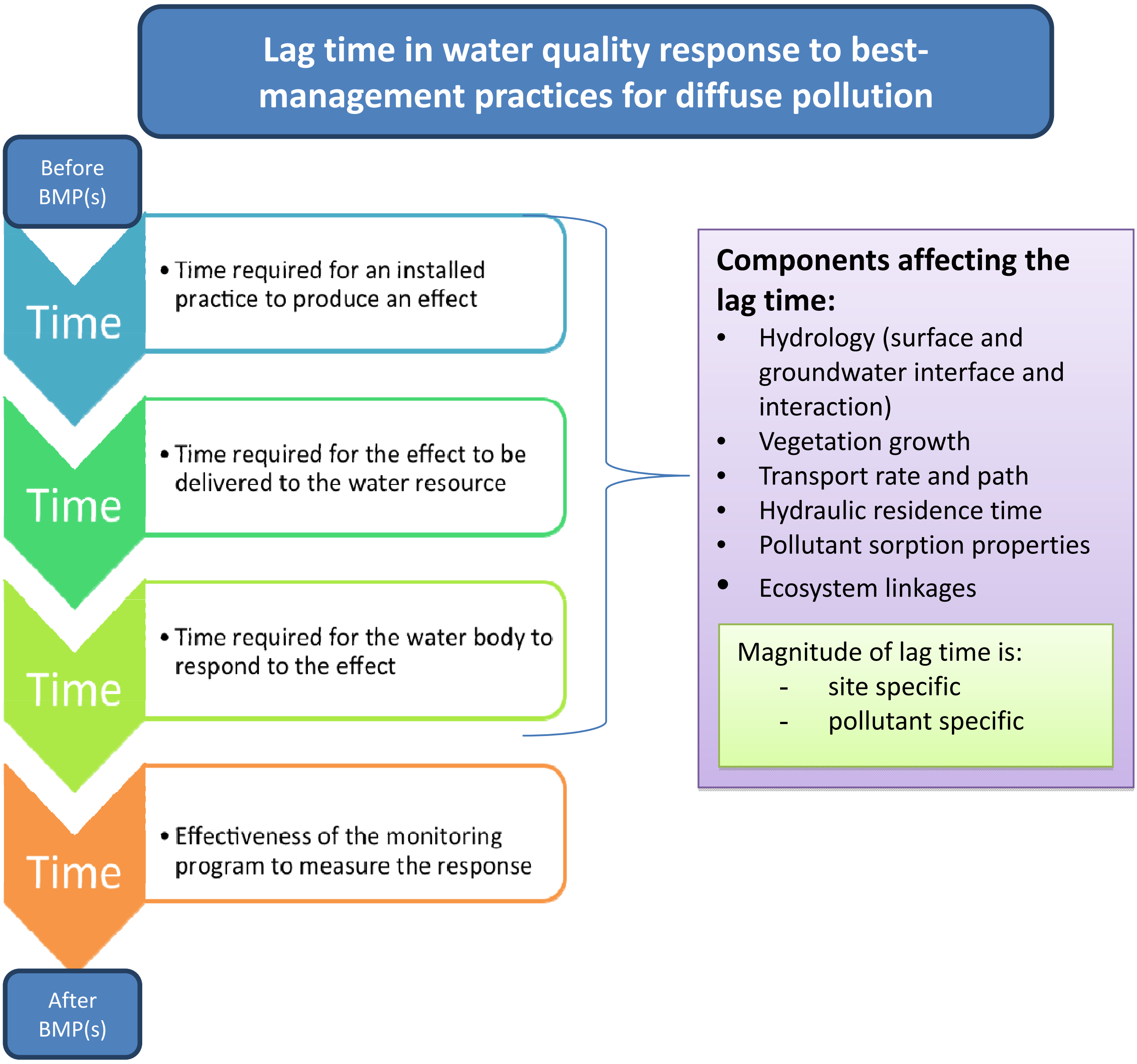


Figure 10-3: Representation of the lag time effect (information extracted from paper by Meals and Dressing 2010)

Another common difficulty is that potential improvements in water quality due to management interventions are often masked by deteriorating water quality in other areas of the catchment due to land use intensification. It is imperative that land use and management changes are accurately mapped at the property scale during this project so that changes in water quality in the receiving waters can be correctly explained.

It is recommended that the following monitoring programs are reviewed annually:

- BMP implementation and land use changes
- flow and water quality monitoring
- non-nutrient monitoring

Estuary monitoring

The Department of Water currently monitors physical data: secchi depth, conductivity, salinity, temperature, DO and pH; and water quality data: chlorophyll-a, b, c and Pheaeophytin, TN, TP, NH_4-N/NH_3-N, NO_x-N, SRP-P, DOC, DON-N and TSS at four sites in the main body of the Leschenault Estuary and five sites in the estuarine portions of the Brunswick, Collie and Preston rivers as listed in Table 10-3. Phytoplankton are identified by the Department of Water's Phytoplankton Ecology Unit. The sampling regime is monthly and samples are collected at the surface and bottom (if sufficiently deep). Data from these sites will be used to assess the ecological and water quality condition of the estuary and will be reported in the estuary report card. Thus, the WQIP supports ongoing monitoring at these sites.

Table 10-3: Estuary monitoring sites

Main estuary		Estuarine river reaches	
Name	**AWRC ref.**	**Name**	**AWRC ref.**
Estuary 3	6121206	Preston 1	6111043
Estuary 4	6121207	Collie 2	6121166
Estuary 5	6121253	Brunswick 1	6121161
Estuary 6	6121254	Collie 4	6121168
		Brunswick 2	6121162

10.4 Water quality implementation plan review

The annual reporting of BMP implementation and land use changes, two-yearly reporting of water quality changes and five-yearly updates of water quality modelling and targets were discussed in the last section. These reports will support two-yearly reviews of the WQIP's implementation. It is assumed the Department of Water, in partnership with the LCC and possibly SWCC, will be responsible for the reviews. While the two-yearly review will represent a substantial consolidation of information and outcomes affecting the plan, it is imperative a structure is established to support ongoing review and adaptive management as new information emerges.

The two-yearly annual review of the WQIP should:

- measure the engagement of state government agencies and local government authorities in achieving the WQIP's outcomes
- document changes to long-term regional planning
- summarise funding received and projects initiated
- summarise the land use changes
- describe the BMPs implemented including location, extent and cost
- summarise current catchment and estuary water quality and changes
- summarise outcomes of implemented BMPs
- recommend future BMP investment and implementation

- recommend future monitoring.

An assessment of the success (or not) of the program should be made and communicated to stakeholders. A measure of water quality improvement in terms of changes and investment in the catchment should be made.

What if the WQIP is not improving water quality?

The causes for this could include:

- inadequate land use planning – slow inclusion of WQIP recommendations in planning and development strategies
- intensification of land uses, causing deterioration of water quality which masks gains made through changed management
- lack of investment in BMPs
- lack of uptake of BMPs by landholders
- insufficient monitoring to detect changes.

Any reasons for the WQIP's failure would be communicated to stakeholders and government. Recommendations and actions to increase the likelihood of success would then be discussed and implemented, such as:

- more stringent land use planning guidelines
- relocation of polluting industries to less-sensitive sites
- regulation of agricultural point sources, such as dairy farms, piggeries and feedlots
- legislation to support sustainable agriculture such as sustainability certifications and nutrient accounting schemes. (Nutrient accounting schemes, such as MINAS (Mineral Accounting System) in The Netherlands and OVERSEER® in New Zealand are used to promote efficient fertiliser use, minimise nutrient surpluses and reduce nutrient losses to waterways. These schemes are enforced by a system of regulations, audits and fines.)
- mandatory fertiliser management plans in agricultural land uses
- limited fertilisation inputs in urban areas
- water sensitive designs in urban areas, as promoted in the Department of Water stormwater manual (DOW 2007)
- mandated and financial support by government of management practices such as soil amendment application and the *Fertiliser action plan*
- more investment in BMP implementation by all levels of government.

11 Conclusions

The Leschenault Estuary and associated waterways provide an important habitat for native wildlife and migratory species (18 JAMBA- and CAMBA-listed species). Although further investigations of the ecological values are required, it is evident from existing literature that these ecosystems are of international, national and regional importance.

The estuary is also an iconic recreational asset for the state and the Greater Bunbury area, providing throughout the year a range of recreational activities such as fishing and crabbing, as well as ecotourism associated primarily with dolphins, bird watching and water contact activities – all of which depend on a healthy environment and good water quality. Yet these values are now at risk from the present land uses within the Leschenault catchment.

Water quality degradation

Under the present land uses, the Leschenault Estuary and associated waterways are showing signs of stress. In the estuarine portions of the Preston, Brunswick and Collie rivers and at the estuary's northern end, symptoms of estuary decline and collapse are evident as excessive algal growth (including toxic species), lack of oxygen leading to fish deaths and odours – all exacerbated by low flows. Ecosystem decline also manifests as large-scale macroalgal blooms along the estuary's shores. These incidents have the potential to increase due to changes in land use, urbanisation and intensification of agriculture. The poor water quality could also worsen with the reduced rainfall and runoff and higher temperatures associated with climate change, and by increased water abstraction.

Long-term exposure to excessive nutrients can drastically degrade biodiversity in aquatic ecosystems (EPA 2007), and thus render the waterbody unsuitable for recreational fishing and other water-related activities, lessen tourism opportunities and reduce land values as a result of lowered amenity.

There is a limited understanding of the nutrient cycling and residency time of nutrients and other contaminants in the Leschenault Estuary. However, elevated concentrations of nutrients are the likely cause of seagrass losses during the past two decades. Seagrass meadow losses have a serious impact on ecology, given their important role as a nursery for invertebrate fauna and fish that birds, larger fish and dolphins rely on for food.

A partnership approach

This WQIP is a partnership response, the aim of which is to improve the estuary's current water quality (and that of the streams and rivers in its catchment). One of its main recommendations is land use planning controls on site activities that emit nutrient and non-nutrient contaminants in areas with high potential to pollute waterways. The *Better urban water management* framework and the Department of Water's stormwater manual provide guidance on including WSUDs in new urban developments during their construction. However, urban development and intensive animal industries should be in areas with high nutrient-retaining soils and low water tables at large distances from waterbodies.

Other recommendations include implementation of BMPs to reduce nutrient pollution, other measures to address non-nutrient contaminants, and the rehabilitation of riparian zones not only to attenuate sediment and nutrient loads, but also to stabilise banks, increase the recreational value of waterways, improve riverine ecology and provide wildlife habitat and biodiversity corridors.

Nutrient load reductions

The cost/benefit analysis estimated the benefit in terms of nutrient reductions for BMP implementation in the catchment draining to the Leschenault Estuary, and also the area that drains to the coast, Big Swamp and the Leschenault Inlet (the Coast subcatchment). The selected scenarios were a compromise between maximum adoption of BMPs to ensure greatest improvement in water quality and realistic adoption rates that could be achieved in a 10-year timeframe. A cost/benefit analysis using capital costs and ongoing annual expenditure or return for each BMP over the 10-year project life was done. The analysis was based on DAFWA modelling in the Geographe Bay catchment (in 2008), updated to reflect the different location and changes in cost. Note that these costs do not include those related to salaries, project management, administration or water quality monitoring. Many agricultural management actions have a monetary return once in place, such as dairy effluent systems, which enable dairy shed effluent to replace fertilisers that would otherwise be purchased.

Only BMPs for which costs and benefits were known could be included in the analysis. Other BMPs that address water quality should also be implemented in the Leschenault catchment, and their costs and benefits assessed over time.

For the BMPs modelled the estimated average annual load reductions were:

	Nitrogen	**Phosphorus**
To the estuary:	95 tonnes	10 tonnes
To the inlet and ocean:	6.7 tonnes	0.3 tonnes

The load reductions to the estuary were within approximately 5% of the nitrogen and phosphorus load reduction targets. It is anticipated that other BMPs that were not modelled – such as horticultural BMPs and effluent management of intensive animal industries other than dairies – would also contribute to load reductions.

The estimated capital cost and annual project cost, as net present values were:

	1. Capital cost	**2. Cost per year**
To the estuary:	$ 40.2 million	$ 2.55 million
To the inlet and ocean:	$ 23.9 million	$ 2.40 million
Total	$ 64.1 million	$ 4.95 million

The breakdown of approximate capital expenditure on the BMPs costed is:

- $51.2 million to replace septic tanks in 4984 properties with reticulated sewerage or low-nutrient-emission ATUs (79.9% of total)
- $6.3 million dollars for riparian zone restoration and the creation of vegetated buffers of 225 km of waterways and major drains (9.9% of total)
- $1.9 million for soil amendment application to 5718 ha (3.0%)
- $2.1 million for perennial grasses on 6202 ha (3.2%)

- $1.3 million for effluent management of 37 dairy sheds (2.1%)
- $0.85 million for irrigation efficiency on 616 ha of dairy farming land (1.3%)
- $0.42 million for better fertiliser management on 38 397 ha (0.7%).

Four BMPs – removal of DEC-licensed point sources, WWTP upgrades, introduction of slow-release phosphorus fertiliser and WSUD retrofit – were included in the modelling of nutrient reduction, but not included in the cost/benefit analysis because costs were not known. (However, the cost of slow-release phosphorus fertilisers is likely to be similar to the current fertilisers that they are replacing). The relatively small cost per year for the subcatchments draining to the estuary (compared with the capital cost) is due to the economic returns from many agricultural BMPs once they are in place. The high cost per year for the Coast subcatchment, which drains to the ocean and inlet (compared with the capital cost), is due to the costs being associated mostly with removal of septic tanks for which there is no economic return.

Most of the expenditure ($51.2 million) is for the replacement of septic tanks with the reticulated sewerage system or low-nutrient-emission ATUs. The capital cost of the other interventions for which costs were available is approximately $12.9 million. Although the cost of removing septic tanks is high, the nutrients collected will be treated and completely removed from the catchment (however a proportion of those nutrients will be released into the environment at the points of discharge at the WWTPs). Most other BMPs do not remove nutrients from the catchment, and thus if the BMP is not maintained the nutrient loads can return to former levels.

Other BMPs not modelled due to lack of information on cost and/or benefit, but strongly recommended for adoption are:

- effluent management of feedlots, piggeries and other intensive animal industries
- artificial wetlands to trap nutrients and other contaminants
- horticultural BMPs related to minimising nutrient leaching to waterways and water conservation
- WSUDs in all new developments – this is a requirement of the *Better urban water management* framework supported by DoP and the Department of Water
- shelterbelts in farms
- plantation forestry BMPs
- annual inspection and audits of ATUs and septic tanks.

While soil amendments and slow-release phosphorus fertiliser are the most effective BMPs for phosphorus load reduction, accounting for 50% of the reductions predicted here, these products are not yet commercially available or approved. Without them, in a 10-year implementation plan, the phosphorus load reductions would be much less. The optimistic outcome, if the other management measures are adopted, is a five-tonne reduction to phosphorus load to the estuary, which is less than half of the required load reduction. It is thus imperative to accelerate the commercialisation of soil amendments and slow-release fertilisers (testing and approval process) to ensure they are made available, particularly for beef and dairy land uses on low PRI soils and for new urban developments.

Other contaminants and associated risks

Organochlorine contamination of the Preston River from horticulture was observed in the 1980s. It is recommended that a baseline study of non-nutrient contaminants in waterways is undertaken to determine existing problems and whether remediation is required.

A significant area around the Leschenault Estuary is underlain by acid sulfate soils, with evidence that some of these may be oxidising. Poor acid sulfate soil management could have grave environmental consequences in the estuary and catchment tributaries.

BMP effectiveness

While there is a good grasp of the efficacy of certain BMPs, which were modelled in the cost/benefit analysis; for others there are huge information gaps or a lack of evidence on their effectiveness on the Swan Coastal Plain and in the Leschenault catchment.

Part of successful BMP adoption lies in presenting local examples that give stakeholders confidence in the BMP's worth. Most urban and some rural BMPs, including riparian zone management and dairy shed effluent systems, have insufficient data on potential benefits. The lack of information and/or confidence in suggested practices in addition to the implementation cost can affect adoption rates. It is recommended that local trials of BMPs are established and monitored to demonstrate and better quantify their effectiveness.

Voluntary or mandatory uptake of BMPs

One of the key issues to arise from this WQIP is the need to assess whether voluntary uptake of BMPs is a sufficient and viable option to reduce diffuse and point source pollution, or whether a more regulatory approach should be followed. For example, despite the efforts of DAFWA in extension and education programs, there has not been a large uptake of recommendations related to fertiliser management to minimise nutrient losses to waterways. A timeframe should be set to determine how effective these voluntary methods are. Failure to achieve the required outcomes should invoke the option of regulation to enforce the adoption of BMPs with appropriate auditing and penalties.

Knowledge data gaps and further research required

While the management recommendations were made using known information, there are major gaps in our present understanding of a range of issues affecting the estuary and nutrient management, as well as the environmental values the WQIP is intended to protect.

It is important to consider research needs for informed management of the estuary and to integrate future learning as part of an adaptive management approach.

During this WQIP's development, a number of important information gaps and research priorities have been identified. These include:

- undertaking an ECD to set benchmarks for the ecological values to be protected or improved through implementation of the WQIP
- creating an ecological model of the estuary to complement the hydrodynamic model
- understanding groundwater transport of nutrients and other contaminants
- characterising non-nutrient contaminants delivered to the estuary from drains/streams
- extending measures of sediment nutrient dynamics to riverine parts of the estuary

- developing new and evaluating the performance of current nutrient BMPs
- developing BMPs for the plantation industry for nutrients, sediments and other contaminants
- formulating an estuary management plan
- extending the understanding of acid sulfate soil impacts on the aquatic environment
- improving knowledge of the magnitude of impact on water and biota as a result of acid sulfate soil disturbance, including use of the newly developed sulfur isotope indicator to examine the spatial extent of impact
- estimating the potential for development of monosulfidic black oozes in the Leschenault Estuary drainage incorporating findings from current work in the Peel Harvey.

Monitoring

To determine the effectiveness of the actions invoked by this WQIP, a comprehensive monitoring program is recommended. The minimum requirement is water quality monitoring at 27 sites in the tributaries and rivers and seven sites in the estuary and estuarine reaches of the rivers, and continued flow measurement at 12 sites. Additionally, specific monitoring to determine the impacts of BMPs will be required to improve our knowledge and data on their effectiveness, as discussed above.

WQIP review

Two-yearly reviews of the WQIP are recommended. The reviews will document land use and management changes in the catchment and determine if these changes are improving the water quality. An assessment of the success (or not) of the program will be made and communicated to stakeholders.

What if the WQIP is not improving water quality?

This would occur if BMPs to attenuate nutrient loads were not introduced, in which case increased funding and/or greater regulatory controls to increase BMP uptake would be required. The recommended actions would include:

- more stringent land use planning guidelines
- relocation of polluting industries to less-sensitive sites
- regulation of agricultural point sources, such as dairy farms, piggeries and feedlots
- introduction of nutrient accounting schemes for agricultural industries
- full support of the *Fertiliser action plan*
- limited fertilisation inputs in urban areas and more stringent WSUDs.

Shortened forms

APET	Areal potential evapotranspiration
ASS	Acid sulfate soils
ATU	Aerobic treatment unit
BMP	Best-management practice
BOD	Biochemical oxygen demand
DAFWA	Department of Agriculture and Food Western Australia
DDT	Dichlorodiphenyltrichloroethane: an organochlorine insecticide
DEC	Department of Environment and Conservation
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DoP	Department of Planning
DoW	Department of Water
EDC	Endocrine-disrupting compounds
EPA	Environmental Protection Authority
EWP	Environmental water provision
EWR	Environmental water requirements
FAP	Fertiliser action plan
GBRS	Greater Bunbury regional scheme
GCM	Global climate model
GL	Gigalitres
HID	Harvey Irrigation District
JGFIWP	Joint Government and Fertiliser Industry Working Party
LCC	Leschenault Catchment Council
LGAs	Local government authority

LWSP	Low-water-soluble P
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
NRM	Natural Resource Management
NUA	Neutralised Used Acid
PAH	Polycyclic aromatic hydrocarbons: potent atmospheric pollutants that consist of fused aromatic rings
PCB	Polychlorinated biphenyls: were widely used as dielectric and coolant fluids, for example in transformers, capacitors and electric motors. PCBs are toxic and classified as persistent organic pollutants.
PCP	Pentachlorophenol: an organochlorine compound used as a timber preservative herbicide, insecticide, fungicide and algaecide
POC	Persistent organic compound
POP	Persistent organic pollutants: chemical substances that persist in the environment, bioaccumulate through the foodweb, and pose a risk of causing adverse effects to human health and the environment
PRI	Phosphorus retention index
PSU	Practical Salinity Unit
SDL	Sustainable Diversion Limit
SWCC	South West Catchments Council
TN	Total nitrogen
TP	Total phosphorus
UDIA	Urban Development Institute of Australia
US EPA	United States Environmental Protection Agency
WALGA	Western Australian Local Government Association
WAPC	Western Australian Planning Commission
WAWRC	Western Australian Water Resources Council (former)
WaterCAST	The Water and Contaminant Analysis and Simulation Tool
WQIP	Water quality improvement plan
WQOs	Water quality objectives

WSUD	Water sensitive urban design
WWAP	World Water Assessment Programme
WWTP	Wastewater treatment plant

Glossary

Allocation	The quantity of groundwater or surface water permitted to be abstracted by licence, usually specified in kilolitres/year (kl/a).
Ammonium	An important source of nitrogen to plants, particularly in low oxygen environments. Ammonium is a waste product of animals and enters waters either directly or as urea. It is a particularly important source of nutrients to phytoplankton.
Anoxic	A total decline in dissolved oxygen in the water column.
ANZECC guidelines	Guidelines published by the Australian and New Zealand Environment Conservation Council for ecological and recreational water quality in marine and freshwater environments. It is a framework for conserving ambient water quality in rivers, estuaries, lakes and marine waters.
Aquatic macrophytes	Aquatic plants that can be seen with the naked eye, and grow submerged, emergent or floating within marine, estuarine and riverine environments, e.g. seagrasses.
ATUs	Also known as home aeration units, the aerobic treatment unit, or ATU, provides wastewater treatment and storage functions similar to a normal septic tank. By contrast, however, the ATU has a mechanism to inject air into the tank, thereby turning the anaerobic environment aerobic. This allows aerobic bacteria to treat the wastewater, resulting in a cleaner effluent than that from a normal septic tank system. The basic ATU consists of an aeration chamber and a settling chamber, with some ATUs also having pre-treatment chambers and/or screens to reduce the amount of larger solids entering the aeration chamber. The aeration chamber contains a mechanical stirrer or diffuser lines to add air to the wastewater. Aerated wastewater treatment is more effective and produces a better quality effluent than anaerobic or septic treatment. The improved effluent quality allows ATUs to be used on sites that are not suitable for conventional septic systems (definition taken from the web: <www.websters-online-dictionary.org/definitions/Aerobic>.
Bar-built estuary	Estuaries with a connection to the ocean that can be periodically (months to years) interrupted by the formation of a sand bar.
Benthic	The collection of organisms living on or in the sea, estuary or lake bottom.

Biodiversity	Collective term for all the taxa of plants, animals and microorganisms.
Bioturbation	The disturbance of sediment layers by biological activity.
Crustacean	Any chiefly aquatic arthropod of the class Crustacea, typically having the body covered with a hard shell or crust, including lobsters, shrimp, crabs, barnacles and wood lice.
Cyanobacteria	Also known as blue-green algae, these are a photosynthetic bacteria that occur as single cells or as colonies (which can form filaments). Some species are nitrogen-fixing, converting nitrogen from the air to form ammonia and nitrates/nitrites.
Detritus	Disintegrated or eroded organic matter.
Dinoflagellate	Any of numerous minute, chiefly protozoans of the order Dinoflagellate, characteristically having two flagella and sculptured shell or pellicle that is formed from plates of cellulose deposited in membrane vesicles. They are one of the chief constituents of plankton. They include bioluminescent forms and forms that produce red tide.
Diatom	Any of various microscopic one-celled or colonic algae of the class Bacillaophycae, having cell walls of silica consisting of two interlocking symmetrical valves.
Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact, e.g. a lake. Includes all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
Estuary	The river mouth where tidal effects are evident and where freshwater and seawater mix (Moore 1988).
Extraction	Taking of water, defined as removing water from or reducing the flow of a waterway or from overland flow or groundwater.
Groundwater	Water that occupies the pores and crevices of rock or soil beneath the land surface.
Inorganic dissolved nutrients	These include nitrate/nitrite, ammonium and soluble phosphate and are in forms most readily available to plants.

Macroalgae	Photosynthetic plant-like organisms that can be seen with the naked eye. Macroalgae may be divided into the groupings: reds (rhodophytes), greens (chlorophytes), browns (phaeophytes) and blue-greens (cyanophytes). These divisions are primarily based on pigments in their tissues, which are also usually evident in their appearance.
Nitrate/nitrite	A dissolved inorganic form of nitrogen. Often used in fertilisers and the source of nutrients in catchment runoff. It is also a by-product of septic systems which can leach into groundwater.
Organic loading	The amount of organic matter or sediment being deposited into a specific area.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Soluble phosphate	A dissolved inorganic form of phosphorus. It is a form of nutrient readily available to plants. Binds readily to particulate matter, particularly those rich in iron. Is released from sediments in the absence of oxygen.
Total nitrogen	The sum of all forms of nitrogen found in the water column. This includes particulate and dissolved forms of an inorganic and organic nature.
Total phosphorus	The sum of all forms of phosphorus found in the water column. This includes particulate and dissolved forms of an inorganic and organic nature.
Stratification	The forming of water layers based on differences in salinity and oxygen.
Nutrient load	The amount of nutrient being deposited into the estuary. Calculated as median annual nutrient concentration x annual total flow volume.
Treatment train	A management process of intercepting and collecting or treating pollutants from the top to the bottom of the catchment. A number of treatments applied sequentially or in parallel.

Watercourse	(a) Any river, creek, stream or brook in which water flows (b) Any collection of water (including a reservoir) into, through or out of which anything coming within paragraph (a) flows (c) Any place where water flows that is prescribed by local bylaws to be a watercourse. A watercourse includes the bed and banks of anything referred to in paragraph (a), (b) and (c).
Water regime	A description of the variation of flow rate or water level over time. It may also include a description of water quality.
Waterways	All streams, creeks, stormwater drains, rivers, estuaries and coastal lagoons, inlet, estuary and harbours.
Xeriscape	A landscape area that has low-water-use plants such that supplementary irrigation is not required. Xeriscaped gardens also frequently have low nutrient requirements.

Appendices (see CD attached to plan)

Appendix A – Catchment characteristics

Appendix B – Ecological, economic and social values associated with the Leschenault catchment aquatic resources (estuary, inlet, rivers and lakes)

Appendix C – List of birds recorded on the Leschenault Estuary, inlet and outlying wetlands

Appendix D – Summary of values of regional, state, national and international significance of key assets within the Leschenault catchment

Appendix E – Phytoplankton communities in the Leschenault Estuary

Appendix F – TN and TP status and trends in catchment waterways

Appendix G – Model refinements

Appendix H – Nutrient sources in each subcatchment

Appendix I – Best-management practices

Appendix J – DAFWA guidance for *Fertcare* accredited advisors for grazing industries

Appendix K – Proposed characterisation scheme for Swan Coastal Plain soil amendment material

Appendix L – Septic infill cost benefit for targeted sites in Australind and Bunbury

Appendix M – Example of a report card produced for the Leschenault Estuary in 2006

References

Appleyard, SJ 1992 *Estimated groundwater nitrogen flux into Leschenault Inlet,* Hydrogeology report no. 1992/4, Geological Survey of Western Australia, unpublished report.

Atkins, RP 1982, *Organochlorine pesticide residues in the Preston River*, Western Australia, Waterways Commission.

Baker, AJ & Laurie, M 1992, *Excellent connections: Bunbury 1836–1990,* City of Bunbury.

Barton J 2003, *Estuarine health monitoring and assessment review*, commissioned by the State Water Quality Monitoring and Assessment Committee (SWQMAC).

Beckwith Environmental Planning 2010, *Brunswick River catchment social values studies,* for the Department of Water, Perth, Australia.

—2006, *Brunswick River – surface water management*, prepared for the Department of Water, Perth, Australia.

—2008, *Lower Collie River social values study*, prepared for the Department of Water, Perth, Australia.

Bennett, D & George, R 2001, *Environmental impacts and production effects of subsurface drainage at an intensive apple orchard near Donnybrook*, WA, Resource Management Technical Report, 2008, Department of Agriculture, Government of Western Australia, Perth.

Blanco-Canqui, H, Gantzer, CJ, Anderson, AH & Alberts EE 2004, Grass barriers for reduced concentrated flow induced soil and nutrient loss *Soil Sci. Soc. Am.J.* 68: 1963–1972.

Bolland, MDA, Allen, DG & Barrow NJ 2006, *Sorption of phosphorus in soils*, Department of Agriculture, Bulletin 4591, Perth, Australia.

Bolton, G 2008, *Land of vision and mirage, Western Australia since 1826*, University of Western Australia Press.

Brearley, A 2005, *Ernest Hodgkin's Swanland: Estuaries and coastal lagoons of south-western Australia,* University of Western Australia Press.

Butler, AJ & Jernakoff, P 1999, *Seagrass in Australia: Strategic review and development of an R&D plan,* FRDC Project 98/223.

Bunbury Heritage Trail 1988, A Commonwealth/state bicentennial project.

Conservation and Land Management 1992, *Benger Swamp Nature Reserve management plan*, No. 7, Como, WA.

—1998, *Leschenault Peninsula: Management plan 1998–2008.*

Chan, KY, Oates A, Liu Dl, Prangnell, R, Poile, G & Conyers MK 2010, *A farmer's guide to increasing soil organic carbon under pastures*, Industry & Investment NSW, Wagga Wagga NSW.

Churchward, HM & McArthur, WM 1980, ‘Landforms and soils of the Darling System’, 1981, *Atlas of Natural Resources Darling System Western Australia*, Department of Conservation and Environment, Western Australia.

Clifton, RB 1979, *Old Australind recalled.*

Commander, P 1982, *The Bunbury shallow-drilling groundwater investigation, annual report,* GSWA.

—1984, Hydrology report 2605, *Geology and hydrogeology of the ‘superficial formations’ and coastal lakes between Harvey and Leschenault inlets (Lake Clifton Projects),* Western Australia Geological Survey, Perth.

Cresswell, ID 2000, ‘Ecological significance of freshwater seeps along the western shore of the Leschenault Inlet Estuary’, *Journal of the Royal Society of Western Australia*, 83: 285-292.

CSIRO 2009a, *Groundwater yields in south-west Western Australia*, a report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project, CSIRO Water for a Healthy Country Flagship**.**

—2009b, *Surface water yield in south-west Western Australia*, a report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project, CSIRO Water for a Healthy Country Flagship.

—2009c, *Water yields and demands in the south-west Western Australia*, a report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project, CSIRO Water for a Healthy Country Flagship.

DairyCatch 2006, *Environmental best management practices guidelines, a partnership for sustainable and profitable dairy farming in Western Australia*, Bulletin 4689, Bunbury, Ed. Dr Robert Rouda.

Davis, G 1989, *The environmental impacts of agriculture on the Leschenault Inlet,* N 422, (Draft) Environmental Impact Assessment project.

de Graaf, M, Beatty, S & Molony, BM 2010, ‘Evaluation of the recreational marron fishery against environmental change and human interaction’, *Final report to Fisheries Research and Development Corporation on project no. 2003/027*, Baxter D & Larsen, R (eds), Fisheries Research Report no. 211, Department of Fisheries, Western Australia, 188pp.

Department of Environment and Conservation 2007, *Licence for Fonterra Brands Australia* (L4437/1988/10), Department of Environment and Conservation, Perth, Western Australia.

—2008, *Licence for V & V Walsh Meat Processors & Exporters* (L6001/1989/12), Department of Environment and Conservation, Perth, Western Australia.

—2009, *Licence for Willow Bridge Estate* (L7907/2004/6), Department of Environment and Conservation, Perth, Western Australia.

Degens, BP 2006, *Metadata statement for 1:50,000 acid sulfate soil risk map for the Swan Coastal Plain,* Department of Environment and Conservation, Government of Western Australia.

—1983, *Conservation reserves for Western Australia as recommended by the Environmental Protection Authority - 1983: The Darling System - System 6. Part 2: Recommendations for Specific Localities,* Perth, WA, Department of Conservation and Environment.

Department of Environment 2003, *Sedimentation of the Leschenault Inlet/Estuary*, Government of Western Australia.

—2004, *The Leschenault Inlet/Estuary, a changing environment,* Government of Western Australia.

—2004b, *Stormwater management manual for Western Australia*, Perth, Western Australia.

Department of Environment, Water, Heritage and the Arts 2002, *The framework for marine and estuarine water quality protection: a reference document*, Version 1, Department of Environment, Water, Heritage and the Arts, ACT.

Department of Planning 2002, *Greater Bunbury land release plan 2002.*

Department of Water 2006a, *Liege Street conducted wetlands*, Annual monitoring report 2005.

—2006b, WQPN 6, *Vegetation buffer to sensitive water resources*, Water quality protection note.

—2009a, *Donnybrook Water Reserve drinking water source protection plan, Donnybrook town water supply*, report no. 102.

—2009b, *Upper Collie water allocation plan*, Water resource allocation and planning series, report no. 20.

—2009c, *South-west groundwater areas allocation plan*, Water resource allocation and planning series, report no. 21.

—2009d, *Ecological water requirements – Brunswick River*, Department of Water.

—2010, *Vasse Wonnerup Wetlands and Geographe Bay water quality improvement plan,* March 2010.

—2010a, *Environmental flow regime for the lower Collie River – Wellington Reach,* unpublished.

—2010b, *Environmental flow regime for the lower Collie River – Shenton,* unpublished.

—2010c, *Draft lower Collie allocation plan*, Department of Water.

—2010d, *Surface water hydrology of the lower Collie catchment*, report no. HY35, unpublished.

—2012, *Implementing the Leschenault Estuary water quality improvement plan,* in prep.

Donohue R, Parsons, G & Deeley, D 1994, *Estimated annual loads of nutrients to the Leschenault Estuary, 1984-1992,* Waterway Rivers Commission report no. 47. 1994.

Donohue, R & Van Looij, E 2002, *Water quality targets for the Swan-Canning estuary,* Swan River Trust, Swan Canning Cleanup Program, report no. 29, unpublished.

Donohue, R, Van Looij, E, Tracey D & Shotter 2002, *Nutrient targets for tributary inflows to the Swan-Canning estuary,* Aquatic Science Branch, Department of Water, unpublished.

Douglas, GL, Wendling, L, Adeney, J, Johnson, K & Coleman, S 2010, *Investigation of mineral based by-product use as soil amendment: results from the Bullsbrook Turf Farm, WA,* July 2010b, CSIRO Water for a Healthy Country Flagship.

English LB & Doubikin ER 1994, *Country drainage – Waroona, Harvey and Roelands drainage districts,* Water Authority of Western Australia, publication number RS0045.

Environment Australia 2001, *A directory of important wetlands in Australia,* third edition, Environment Australia, Canberra.

Environmental Protection Authority 2007, *State of environment report*, Perth.

—2008, *Water quality improvement plan for the rivers and estuary of the Peel-Harvey system – phosphorus management,* Environment Protection Authority, Perth, Western Australia, November 2008.

—1993, *Status on the implementation of conservation reserves for Western Australia*, report 15, Perth, Western Australia.

—1998, *Industry 2030 – Greater Bunbury industrial land and port access planning, Western Australian Planning Commission,* a submission by the Environmental Protection Authority to the Western Australian Planning Commission prepared under Section 16(j) of the Environmental Protection Act.

Evans, SJ 2009, *A baseline study of contaminants in groundwater at disused waste disposal sites in the Swan Canning catchment*, Water Science Technical Series, report no. 4, Department of Water, Western Australia

Foulsham, G, Nice, HW, Fisher, S, Mueller, J, Bartkow, M & Komorova, T 2009, *A baseline study of organic contaminants in the Swan and Canning catchment drainage system using passive sampling devices*, Water Science Technical Series, report no. 5, Department of Water, Western Australia.

Geological Survey of Western Australia 1990, *Geology and mineral resources of Western Australia, Memoir 3*, Department of Mines, Western Australia.

GHD 2008a, *Report for Collie River Irrigation System planning*, environmental report for Harvey Water.

—2008b, *Report for Collie River Irrigation System planning*, community report for Harvey Water.

Gibson et al. 1994, *A floristic survey of the southern Swan Coastal Plain*.

Giller PS & Malmqvist 1998, *The biology of streams and rivers, biology of habitats,* Oxford University Press, New York.

Glossys, V 2000, *Bunbury's first settlers: John Scott.*

Goode, B 2009. *An Aboriginal heritage survey of the proposed 'Shotts industrial estate' Collie, Western Australia*, a report prepared for South West Aboriginal Land & Sea Council on behalf of Landcorp.

Government of Western Australia 2007, *Water source options in the Collie Wellington basin,* final report to the Minister for Water Resources, Collie-Wellington Basin Water Source Options Steering Committee.

Hajkowicz, SA & Wheeler, SA 2008, ‘Evaluation of dairy effluent management options using multiple criteria analysis’, *Environmental Management* 41:613-624.

Hardcastle, K, Rose, T, Pearcy, M & Storey, A 2003, *Lower Collie River ecological water requirements review: stream morphology, riparian vegetation and fish passage*, Department of Environment, unpublished.

Harvey Local History 2010, *The Australind settlement*, available from: <www.harveyhistory.com/site/history.php?ID=18> [accessed 1 June 2010].

Harvey Tourism 2010, *History of the Harvey Shire*, available from: <http://harveytourism.mysouthwest.com.au/History> [accessed 12 February 2010].

Harvey Water 2008, *Report for Collie River Irrigation System planning project, community consultation*, Nov 2008.

—2009, *Collie River Irrigation System planning project*, January 2009.

Heritage Council of Western Australia 1999, *Heritage Trail – Bunbury.*

—2003, *Register of Heritage Places – assessment documentation, Wellington Dam precinct*, available from: <www.perdaman.com/media/7564/appendix%20h%20-%20wellington%20dam%20heritage%20report.pdf>
[accessed 4 June 2010]

Hill, NA, Lukatelich RJ & McComb AJ 1991, *A comparative study of some of the physical and chemical characteristics of the sediments from three estuarine systems in south Western Australia,* report to the Waterways Commission, report no.23

Hillman, K, Bastyan, G, McComb, AJ & Paling, EI 1995, *Leschenault Inlet: macrophyte abundance and distribution,* report to the Waterways Commission.

Hillman, K, McComb, A J, Bastyan, G & Paling, E 2000, ‘Macrophyte abundance and distribution in Leschenault Inlet, an estuarine system in south-western Australia’, *Journal of the Royal Society of Western Australia*, 83:349-355.

Hodgkin EP et al.1979, *Environment and Science,* Chapter 5, pp100-145, University of Western Australia Press,for the Educational Committee of the 150th Anniversary Celebrations 1979, Brian, J. O’Brian (ed).

Joint Government and Fertiliser Industry Working Party 2007, *Fertiliser action plan, Phasing-out the use of highly water soluble phosphorus fertiliser in environmentally sensitive areas of south west Western Australia,* a report to the Western Australian Minister of the Environment.

Keipert, N 2007, *Summary audit progress in the Ellenbrook and Vasse Geographe areas*, unpublished, Coastal Catchments Initiative progress report, Department of Agriculture and Food, Waroona, Western Australia.

Keipert, N, Summers, R & Steele, J 2010, *Monitoring and evaluation of the effectiveness of fencing and riparian vegetation in the Peel Harvey catchment,* Department of Agriculture and Food, Government of Western Australia, unpublished.

Keipert, N, Weaver, D, Summers, R, Clarke, M & Neville, S 2008, 'Guiding BMP adoption to improve water quality in various estuarine ecosystems in Western Australia', *Water Science & Technology*, pp1749-1755, WA Publishing.

Kelsey, P & Hall, J 2010, *Nutrient loads, status and trends in the Leschenault catchment,* Water Science Technical Series, report no. 9, Department of Water, Western Australia.

Kelsey, P 2010, *Nutrient-export modelling of the Leschenault catchment*, Water Science Technical Series, report no. 11, Department of Water, Western Australia.

—Hall, J, Kitsios, A, Quinton, B & Shakya, D 2010a, *Hydrological and nutrient modelling of the Swan-Canning coastal catchments*, Water Science Technical Series, report no. 14, Department of Water, Western Australia.

—King, L & Kitsios, A 2010b, *Survey of urban nutrient inputs on the Swan Coastal Plain,* Water Science Technical Series, report no. 24, Department of Water, Western Australia.

Kiliminster KL 2010*, Sediment quality in the three south-western Australian estuaries*, Water Science Technical Series, report no. 18, Department of Water, Western Australia.

—Cartwright, I 2011, 'A sulfur stable isotope based screening tool for assessing impact of acid sulfate soils on waterways', *Marine and Freshwater Research,* vol. 62, pp152-161.

—Norton, S & Miller, FS 2011, *Draft, Assessing the influence of acid sulfate soil on water quality in south-western Australian catchments and estuaries*, Department of Water, Western Australia.

Kinhill Engineers Pty Ltd. 1990, *SCM Chemical LTD, post commissioning environmental monitoring studies in the Collie River Estuary December 1998 – December 1989*, prepared for SCM Chemical LTD.

Klemm V 1989, *Organochlorine pesticide residues in the Preston River Western Australia December 1985 to May 1986*, Leschenault Management Authority, Waterways Commission, report no. 12, July 1989.

Kvasnicka B & Krysl LJ 2010, *Nitrate poisoning in livestock, beef cattle handbook, University of Wisconsin – Extension, Cooperative Extension*. Available from: <www.iowabeefcenter.org/Beef%20Cattle%20Handbook/Nitrate_Poisoning.pdf> [accessed 24 September 2010]

Lenanton, R 2003, 'Historical fishery attributes and changing management expectations – a mismatch?' In Newman, SJ, Gaughan, DJ, Jackson, G, Mackie, MC, St John, J & Kailola, P (eds.), *Towards sustainability of data-limited multi-sector fisheries, Australian Society for Fish Biology Workshop Proceedings*, Bunbury, Western Australia 23–24 September 2001, Fisheries Occasional Publication no. 6, June 2003, Department of Fisheries, Perth, Western Australia, p49–55.

LCC 2007, *Leschenault NRM sub-region catchment management strategy*, Bunbury.

Lonely Planet 2010, Available from: <http://www.lonelyplanet.com/shop_pickandmix/previews/perth-western-aust-5-the-southwest-preview.pdf>. [accessed 10 March 2010]

Lovett, S & Price, P 2007, *Principles for riparian lands management*, Land & Water Australia, Canberra.

Lukatelich RJ 1986, *Leschenault Inlet – macrophyte biomass*, *report to the Waterways Commission*, Waterways Commission report no. Wp-86-028

Lund, MA & Martin HC 1996, *Historical association of wetlands and rivers in the Perth-Bunbury region,* Water resource technical series, Water and Rivers Commission report WRT3, 1996.

MacDonald, MA 2003, The role of corridors in biodiversity conservation in production forest landscapes: a literature review, *Tasforest* 14: 41-52

Malseed, BE, Sumner, NR & Williamson, PC 2000, 'A 12-month survey of recreational fishing in the Leschenault Estuary of Western Australia during 1998', *Fish. Res. Erp. Fis. West. Aust*. 120: 1-36

Marchant, L 1998, *France Australe, Publ. Scott Four Colour Print Perth.*

Marillier, B 2010, *WaterCAST nutrient modelling of the Leschenault catchment*, Water Science Technical Series, report no. 11, Department of Water, Western Australia.

—Hall J & Shakya, D 2009, *Water balance modelling of the Leschenault catchment*, Water Science Technical Series, report no. 10, Department of Water, Perth, Western Australia.

Mason, CF 1996, *Biology of freshwater pollution*, Longham Group UK limited, Singapore.

Mauger, GW, Bari, M, Boniecka, L, Dixon, R, Dogramaci, SS & Platt, J 2001, *Salinity situation statement Collie River*, Water and Rivers Commission, Water resource technical series no. WRT 29.

Mayer PM et al. 2005, *Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: a review of current science and regulations*, US Environmental Protection Agency.

McKenna 2004, *The Leschenault Inlet/Estuary: a changing environment*, Department of Environment.

McArthur, WM & Bettanay, E 1979, 'The land', *in Environment and Science* O'Brien J (Ed), pp 22-52, University of Western Australia.

McComb, AJ, Qiu, S, Paling EI & Hills HA 2001, 'Sediments of Leschenault Inlet: a comparison with other estuaries in the South-Western Australia', *Journal of the Royal Society of Western Australia*, 275-284, 2001.

McFarlane, DJ 2005, *Context report on south west water resources for expert panel examining Kimberley water supply options, Client report to WA Government*, CSIRO Water for a Healthy Country Flagship.

McKay, RJ 1985, 'A revision of the fishes and family Silaginidae', *Memoirs of the Queensland Museum* 22 (1):1-73.

McKenna 2007, *The Leschenault estuarine system, south-western Australia, Condition statement and recommendations for management*, Department of Water, Government of Western Australia.

—Derrington, C 2005, *The Leschenault Estuary and Lower Collie River: Community perceptions and recommendations*, Department of Environment, unpublished.

McKergow, LA, Weaver, DM, Prosser, IP, Grayson, RB & Reed, A 2003, 'Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia', *Journal of Hydrology* 270: 253-272.

Meals, DW & Dressing, SA 2010, 'Lag time in water quality response to best management practices: a review*', J .Environ. Qual*. 39:85-96.

Morgan, D & Beatty, S 2006, *Fish and freshwater crayfish communities of the Brunswick and Preston rivers*, Freshwater Fish Research, Murdoch University report to the Leschenault Catchment Council.

Nash, D 2004, *Phosphorus fertilisers, soil tests and off-site water quality*, Department of Primary Industries, Victoria. Available from: <www.fifa.asn.au/files/pdf/conf2004/papers/Nash%20Phosphorous%20Fertilizers%20Agronomic%20Soil%20Tests%20and%20Offsite%20Water%20Quality.pdf> [accessed 30 June 2010].

Neville, S 2008b, *SSPND: the Support System for Phosphorus and Nitrogen Decisions, BMPs costs and definitions for the Vasse-Geographe and Ellen Brook catchments.*

—2008c, *SSPND: the Support System for Phosphorus and Nitrogen Decisions, BMP scenarios for the Vasse-Geographe*.

Neville, S, Weaver, D, Ovens, R, Reipert, N, Summers, R & Clarke, M 2008a, *SSPND – Support System for Phosphorus and Nitrogen Decisions – modelling of management practices can guide the way ahead*, 12th International Conference on Integrated Diffuse Pollution Management (IWA DIPCON 2008) Khon Kaen University, Thailand; 25-29 August 2008.

Nice, H, DoW & SRT 2009, *A baseline study of contaminants in the Swan and Canning catchment drainage system,* Department of Water, Perth, WA.

Nicon Rural Services 2010, *Identifying current limitations to achieving optimum nutrient management practices on dairy farms.*

Ninox Wildlife Consulting 1989, *The significance of mosquito breeding areas to the waterbirds of Leschenault Estuary, Western Australia*, Waterways Commission, report no. 14.

Palone, RS & AH Todd (editors) 1997, *Chesapeake Bay riparian handbook: a guide for establishing and maintaining riparian forest buffers*, USDA Forest Service, Northeastern Area State and Private Forestry, publication NA-TP-02-97, Radnor, PA.

Parkyn, S 2004, *Review of riparian buffer zone effectiveness*, MAF Technical Paper no. 2004/2005.

Peel Development Commission 2006, *Peel-Harvey coastal catchment water sensitive urban design technical guidelines*, prepared for the Peel Development Commission, funded by the NHT Coastal Catchments Initiative October 2006, Mandurah.

Pen, L, Semeniuk, V & Semeniuk C 2000, ‘Peripheral wetlands habitats and vegetation of the Leschenault Inlet Estuary’, *Journal of the Royal Society of Western Australia,* 83 (4): 293-316-333.

Potter, I, Chalmer, P, Tiivel, D, Steckis, R, Platell, M, & Lenanton, R 2000, ‘The fish fauna and finfish fishery of the Leschenault peninsula estuary in South-Western Australia’, *Journal of the Royal Society of Western Australia*, 83 (4): 481-501, 2000.

—Tiivel, D, Valesini, F & Hyndes, G 1997, ‘Comparisons between the itchthyofaunas of a temperate lagoonal-like estuary and the embayment into which that estuary discharges’, *International Journal of Salt Lake Research*, Volume 5, Number 4 :337-358 (22)

Powell, J 1998, *Watering the Western Third: water, land and community in Western Australia, 1826-1998*, Water and Rivers Commission.

Putland Dale (personal communication) Feb 2010.

Raines, J, Youngston, K & Unno, J, 2000, ‘Use of the Leschenault Inlet Estuary by waterbirds’, *Journal of the Royal Society of Western Australia*, 83: 503-512.

Ramsey, A 2006, *Water quality of the Leschenault Estuary and estuarine reaches*, Department of Water, internal report.

Rivers M, Ramsey H & Clarke M 2001, *South West Irrigation Area water quality monitoring project,* prepared for South West Irrigation by the Department of Agriculture, Western Australia.

Rose, T 2004, *Interim environmental guidance position background paper: The Brunswick River: considerations for assessing small scale water extractions and possible effects on the river and the Lower Collie*, unpublished.

Royal Australian Survey Corps 1970, *Bunbury WA* 1:100 000 map 2031.

Royal Society of Western Australia 1980, Reprint, *Journals of several expeditions made in Western Australia*, publisher J. Cross, London 1833.

—2001, ‘Leschenault Inlet special issue’, *Journal of the Royal Society of Western Australia*, 84(4).

Sanders, T 1975, *Bunbury – some early history*, Roebuck Society Publication.

Schwinghammer, T 1978, *Waterways Commission: Leschenault Inlet Management Authority fact finding study.*

Semeniuk, V & Semeniuk, C 2005a, *A ‘snapshot’ of the Leschenault Inlet Estuary, May 2005, and comparisons with previous work*, Project: RFQ 0034-2005 for the Department of Environment, Perth, Australia.

—2005b, Results of survey of Leschenault Inlet *sensu strict,* May 2005: invertebrate fauna, mangroves, and pollutants.

—Withers, P (eds) 2000, ‘Preface: Leschenault Inlet Estuary species issue’, *Journal of the Royal Society of Western Australia*, 83 (4).

—Wurm, P 2000b, ‘Molluscs of the Leschenault Inlet Estuary: their diversity, distribution, and population dynamics’, *Journal of the Royal Society of Western Australia,* 83 (4): 377-418.

—Semeniuk, T & Unno, J 2000a, ‘The Leschenault Inlet Estuary: an overview’, *Journal of the Royal Society of Western Australia*, 83 (4): 2007-228.

—Tauss, C & Unno, J 2000c, ‘The white mangrove *Avicennia marina* in the Leschenault Inlet area’, *Journal of the Royal Society of Western Australia,* 83 (4): 317-333.

Shire of Capel 2008, available from:
<www.capel.wa.gov.au/aboutcapel/about.htm>
[accessed 25 Feb 2010].

Shire of Dardanup 2009, *Population and demographics: projection.*

—2010, available from:
<www.dardanup.wa.gov.au/Our%20Dardanup>
[accessed 24 Feb 2010].

Shire of Donnybrook-Balingup 2008, *Local rural strategy*.

Sinclair Knight Merz 2007, *Bunbury Harbour extension – hydraulic modelling of the Preston River realignment.*

—2008a, *Approach for determining sustainable diversion limits for south west Western Australia,* report for the Department of Water, Government of Western Australia.

—2008b, *Estimation of sustainable diversion limits for south west Western Australian catchments (regionalisation of sustainable diversion limits for catchments),* report for the Department of Water, Government of Western Australia.

—2010*, Identification and mapping of groundwater dependent ecosystems associated with the Collie River*, report for the Department of Water, Government of Western Australia.

Smith, H 2010, Personal communication, PHD candidate, Murdoch University.

South West Catchments Council 1995, *South west regional strategy for natural resource management.*

South West Development Commission 2010, *South west trends report, Statistical trends for the south west of Western Australia.*

State NRM Office 2007, *Agency statement of important natural resource management assets in Western Australia*, unpublished report prepared for NRM senior officers groups, Government of Western Australia.

Steele, J 2006, *Management of diffuse water quality issues in the Peel-Harvey coastal drainage system*, report by the Peel Harvey Catchment Council for the South West Catchments Council.

Stewart, BA 2010, ‘An assessment of the impacts of timber plantations on water quality and biodiversity values of Marbellup Brook, Western Australia’, *Environ Monit Assess* DOI 10.1007/s10661-010-1436-1.

Stokes J. Lort 1841, *Koombanah Bay and Leschenault Inlet*, Publ. London 1846.

Streamtec 2002, *Ecological water requirements of the Preston River from Glen Mervyn Dam to Argyle, in the Shire of Donnybrook/Balingup Western Australia*, for Water Corporation.

Summers, R 2002, *Nitrogen fertiliser management for high rainfall pastures*, Department of Agriculture, Farmnote no. 65/2002.

Summers, R, Guise, N & Summers, K 1996, 'Bauxite residue (red mud) improves pasture growth on sandy soils in Western Australia', *Australian Journal of Soil Research* 34 (4) 569-581.

Swan River Trust 1999, *Swan-Canning Cleanup Program action plan,* Swan River Trust, Western Australia, May 1999.

—2002, *Seasonal nutrient dynamics in the Swan Estuary, 1995–2000*, River Science Issue 8, Swan River Trust, Western Australia.

—2007, *Healthy Rivers Action Plan*, Swan River Trust, Perth, Western Australia.

Taylor, L 2006, *River action plan for the Brunswick River*, Leschenault Catchment Council.

Thompson McRobert Edgeloe 2005, *Shire of Harvey local planning strategy, volume 2 strategy report.*

—2007, *Bunbury Port inner harbour structure plan (draft),* Bunbury, Australia.

—Coffey, Environmental & William James Landscape Architect 2009, *Kemerton Industrial Park strategy plan*, prepared for Landcorp, Department of State Development.

Torres, A 2010, *Towards a water sensitive city, overview of the stormwater science plan for better urban water management,* Department of Water, Western Australia.

Trudgen, ME 1984, *The Leschenault Peninsula – a flora and vegetation survey with an analysis of its conservation value and appropriate uses,* Department Conservation and Environment. Bulletin 157, Western Australia.

UNESCO 2009, *Nations world water development report 3: Water in a changing world*, Paris, UNESCO and London, Earthscan.

URS 2010, *Summary report: bauxite residue (Alkaloam®) sustainability assessment: technical, community consultation, benefit cost and risk assessment*, prepared for Centre for Sustainable Resource Processing, Bentley, Australia.

URS Consultants 2008, *Collect information and data on rural drainage to develop a BMP toolbox,* report prepared for Department of Water, Western Australia.

USDA 2000, *Conservation buffers to reduce pesticide losses*, Washington, USA.

Van de Wiele, H 1987, *A study of recreational boating and aquatic vegetation of the Leschenault Estuary,* a report prepared for the Leschenault Inlet Management Authority and the Department of Conservation and Land Management.

Vegetables WA 2007, *Good practice guide.*

Ward, SC & Summers, RN 1993, 'Modifying sandy soils with the fine residue from bauxite refining to retain phosphorus and increase plant yield', *Fertiliser Research*. 36:151-156.

Water and River Commission 2000, *Water notes: The values of the riparian zone*, WN12 January 2000.

—2000b, *Environmental water provisions policy for Western Australia,* Statewide policy no. 5.

—2001a, *Collie River Islands management guidelines*, Water and Rivers Commission, Water resources management report, WRM 17.

—2001b, *Water and Rivers Commission position statement: Wetlands*. Available from: <http://portal.environment.wa.gov.au/pls/portal/docs/PAGE/DOE_ADMIN/POLICY_REPOSITORY/TAB1144266/WETLANDS%20POSITION%20STATEMENT.PDF> [accessed 12 October 2010].

Water Authority of Western Australia 1994, *Bunbury groundwater area management plan*, report no. WG 198, Perth.

—1994, *Country drainage – Waroona, Harvey and Roelands drainage districts.*

Water Corporation 2002, *Ecological water requirements of the Preston River from Glen Mervyn Dam to Argyle that lies within the boundary of the Preston Valley Irrigation District operating area in the Shire of Donnybrook/Balingup Western Australia*, Water Corporation project no. C-W 00707.

—2006, *Donnybrook water reserve drinking water source protection assessment, Donnybrook town water supply.*

—2010, *Infill sewerage program report 2006-2009*, Project Management Branch.

Waterways Commission 1992, Leschenault waterways management programme 1992, report 26.

Weaver, D, Reed, A & Grant, J 2001, 'Relationships between stream order and management priority: a water quality case study'. In *Proceedings of the Third Australian Stream Management Conference*, Rutherfurd, I, Sheldon, E, Brierley, G & Kenyon, C (eds), August 27–29, 2001, Brisbane, pp 647-652

Weaver, D, Ritchie, G, Anderson, G & Deeley, D 1988, 'Phosphorus leaching in sandy soils: short-term effects of fertiliser applications and environmental conditions', *Australian Journal of Soil Research* 26(1) 177-190.

Welker Environmental Consultancy & Streamtec Pty Ltd 2002, *Lower Collie River and Henty Brook preliminary environmental water provisions, Discussion paper*, for Water and Rivers Commission.

Wendling, L & Douglas, G 2009, *A review of mining and industrial by-product reuse as environmental amendments,* CSIRO Water for a Healthy Country Flagship, August 2009, CSIRO: Perth, Western Australia, 64 pp.

—2010, *Proposed assessment protocol for soil amendments for the attenuation of phosphorus leaching on the Swan Coastal Plain*, a report for the WA Fertiliser Action Plan Soil Amendment Expert Working Group, CSIRO.

Wendling, L, Douglas, G, Coleman, Yuan, Z & Klauber, C 2010, *Investigation of mineral-based by-product reuse for the removal of nutrients and DOC from Swan Coastal Plain surface waters,* CSIRO Water for a Healthy Country Flagship, May 2010, CSIRO: Perth, Western Australia, 81 pp.

Wenger, S 1999, *A review of the scientific literature on riparian buffer width, extent and vegetation*, Office of Public Service and Outreach Institute of Ecology, University of Georgia.

Western Australian Planning Commission 2005, *Western Australia Tomorrow, population projections for planning regions 2004 to 2031 and local government areas 2004 to 2031,* Population report number 6.

—2005b, *Greater Bunbury region scheme, Volume 1 report on submission.*

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

—2008, *Draft Ocean to Preston River Regional Park establishment plan*, Perth, Western Australia.

—2009, *South West Framework*, October 2009.

—2010, *Greater Bunbury region scheme amendment 008/41, Dardanup townsite expansion amendment report.*

—2011, Preston River to Ocean Regional Park establishment plan, final report, Department of Planning, Government of Western Australia, Perth.

Western Australian Water Resources Council 1987*, Recreational opportunities of river and wetlands in the Perth to Bunbury region.*

Wetland and Research Management 2009a, *Interim ecological water requirements of Boronia Gully,* unpublished.

—2009b, *Collie River ecological values assessment*, Department of Water, unpublished.

—2005, *Ecological water requirements of Augustus River – intermediary assessment*, for Worsley Alumina Pty Ltd.

White, K 2010, *Vasse Wonnerup Wetlands and Geographe Bay water quality improvement plan,* Department of Water, Western Australia.

Williams, M, Woods, M, Kumar, A, Ying, G, Shareef, A, Karkkainen, MP & Kookana, RS 2007, *Endocrine disrupting chemicals in the Australia riverine environment: a pilot study on estrogenic compounds*, a joint project between CSIRO and Land & Water Australia. Braddon, ACT: Land & Water Australia <http://lwa.gov.au/products/er071304>.

Windsor, D, Bolland, M, Weaver, D & Russel, B 2010, 'Implementing the *Fertiliser action plan:* an industry led approach based on *Fertcare*', *Proceedings of the Australian Fertiliser Conference.*

Woodcock, S 1994, *Collie and Brunswick rivers foreshore study*, Waterways Commission.

World Water Assessment Programme 2009, *The United Nations world water development report 3: Water in a changing world,* Paris, UNESCO and London, Earthscan.

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