Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System - Phosphorus Management

November 2008

Australian Government

Environmental Protection Authority
Government of Western Australia

ISBN 0-7309-7293-3

Preferred reference: Environmental Protection Authority (2008) Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System - Phophorus Management, Environmental Protection Authority, Perth, Western Australia.

Acknowledgments

This is an Environmental Protection Authority Report. The project was co-funded by the Australian and State Governments, with the Environmental Protection Authority responsible for preparation of the Water Quality Improvement Plan. The Environmental Protection Authority acknowledges with gratitude the 7 supporting project teams, which were also co-funded under the Coastal Catchments Initiative of the Australian Government with the State Government Departments of Environment and Conservation, Water, Agriculture and Food and the Peel Development Commission. The Environmental Protection Authority also acknowledges the extensive and unstinting support of the Peel Harvey Catchment Council, the Peel Waterways Centre and support of the Western Australian Planning Commission and Department for Planning and Infrastructure.

Cover photos courtesy of Peel Waterways Centre, Department of Water and Martin Heller.

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Foreword

I am pleased to release this final Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System - Phosphorus Management (the Plan). This Plan has been prepared by the Environmental Protection Authority in partnership with the Australian Government's Department of Environment, Water, Heritage and the Arts and State agencies including the Departments of; Environment and Conservation, Water, Agriculture and Food, the Peel Development Commission; and with the support of the Peel Harvey Catchment Council, Western Australian Planning Commission and Department for Planning and Infrastructure.

The Plan was co-funded by the Coastal Catchments Initiative, an Australian Government program to reduce pollution in coastal water quality hotspots.

The Plan takes the findings of seven supporting projects (also co-funded by the Coastal Catchments Initiative program) and recommends a combination of management measures to reduce phosphorus discharges to estuarine waters. It also recommends a framework to enhance water quality through landuse planning processes for the Peel-Harvey catchment.

In particular, the Plan focuses on management measures to lessen the incidents of excessive and often toxic algal blooms and builds on current catchment management activities and research. As well as the environmental benefits of reducing the amounts of phosphorus entering the estuary, some of these measures, in regards to broad acre agriculture in the catchments, will increase the phosphorus uptake in the catchments where it is intended, increase productivity and prevent wastage of chemicals and money.

The Environmental Protection Authority thanks the community and government agencies for their input and views on the draft Plan and has made changes to create this final Plan for Government and community implementation.

The Environmental Protection Authority notes there will be financial implications associated with the implementation of this Plan that have not been reported here. These will need to be addressed through appropriate parts of Government along with the clarification of the roles and responsibilities for implementation. All levels of government, Local, State and Australian, will have important roles in implementing the Plan. The Australian Government may also give priority to relevant projects under Caring for our Country, the Community Water Grants programme and other environmental funding programs, as the Peel-Harvey coastal catchment is considered one of the country's top ten water quality hotspots.

Urgent, coordinated action is needed to reduce the phosphorus loads to the rivers and estuary of the Peel-Harvey system, one of the State's important environmental assets.

Dr Paul Vogel
CHAIRMAN

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Summary

The Peel Inlet-Harvey Estuarine System (the estuary) is located 75 km south of Perth in the South West of Western Australia. The system consists of two shallow lagoons, the Peel Inlet and the Harvey Estuary, into which three major rivers, the Murray, Serpentine and Harvey discharge.

After decades of declining water quality and subsequent severe algal blooms in the estuary, a Peel Inlet and Harvey Estuary Management Strategy (Peel-Harvey Study Group, 1985) (Kinhill Engineers Pty Ltd, 1988) (the Strategy) was announced and approved in January 1989. The Strategy consisted of construction of the Dawesville Channel; implementing catchment management measures (including a catchment management plan); continuing weed (nuisance macro-algae) harvesting; and implementing appropriate monitoring to measure the success of the Strategy (Environmental Protection Authority, 1988).

The 2003 Environmental Protection Authority report, Bulletin 1087, on the progress and compliance with the environmental conditions set by the Minister on the Strategy, found the Dawesville Channel (constructed in 1994) to have been successful in improving water quality in the main body of the Peel Inlet and Harvey Estuary. However, water quality and environmental problems remain in the rivers, and in areas such as the Serpentine Lakes. The second part of the Strategy, that of catchment management to "cap" the phosphorus input to the waterways, remains the aspect of the management package that still requires significant action (Environmental Protection Authority, 2003).

In 2003 a series of projects, co-funded by the State Government and the Australian Government's Coastal Catchments Initiative (CCI) commenced to reduce pollution in water quality hotspots, in particular the Peel-Harvey. These projects have now been finalised and include:

- Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System - Phosphorus Management (this report);
- Decision Support System for Water Quality Protection (Appendix B);
- Support System for the Phosphorus Reduction Decisions (Appendix C);
- Water Quality Monitoring Program (Appendix D);
- Water Sensitive Urban Design (Appendix E);
- Regulation/ Licensing Review (Appendix F);
- Assistance to Intensive Agricultural Industries (Appendix G); and
- Stock Exclusion from Catchment Waterways (Appendix H).

Findings from these projects have supported earlier findings and confirm that the main cause of algal blooms is nutrient discharges from the catchments that feed into the estuary (Zammit *et al.,* 2006).

This Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System - Phosphorus Management (the Plan) aims to improve water quality by reducing phosphorus discharges from the catchment through changes to agricultural and urban practices and landuse planning. Water Quality Improvement Plans are documents that detail strategies for water quality improvement in a defined area. Water Quality Improvement Plans prepared through the Natural Heritage Trust's (NHT) Coastal Catchments Initiative (CCI) are environmental management plans that codify and implement Australia's National Water Quality Management Strategy and the National Principles for the Provision of Water for Ecosystems.

This Plan identifies the current status of phosphorus loads; identifies the environmental values (EVs) of water bodies, and the water quality objectives (WQOs) that will protect the EVs and identifies a set of management measures and control actions to achieve and maintain those EVs and WQOs.

The Water Quality Objective of the Plan is:

Median loadings of total phosphorus to estuarine waters should be less than 75 tonnes per annum in an average year with –

- the median load of total phosphorus flowing in the estuary from the Serpentine River being less than 21 tonnes;
- the median load of total phosphorus flowing in the estuary from the Murray River being less than 16 tonnes; and
- the median load of total phosphorus flowing in the estuary from the Harvey River being less than 38 tonnes.

Water qualities in streams in winter are to meet mean concentrations of 0.1 mg/L at current mean flows.

The Plan has been developed to address catchment management measures and control actions relating only to phosphorus loads to the waterways. The Environmental Protection Authority recognises that there are other problems within the Peel-Harvey System. These include the nitrogen levels in estuarine waters; estuarine and riverine habitat loss; acid soil drainage; and bacteria levels – animal and human effluent – and action is required. Further investigations are already underway on these issues and the outcomes of these investigations will inform the Catchment Management Plan, as required in the 1989 environmental conditions, subsequently amended in 1991 and 1993 (Environmental Protection Authority, 2003).

As a result of years of nutrient input, there are large stores of phosphorus in the soils and sediments of the coastal portion of the Peel-Harvey catchment that will take years to leach out of the soil, and there would still be a time lag for the waterways to show the desired improvements in phosphorus levels. The Plan timeframe of 10-30 years may not show any significant changes in water quality of the estuary. Significant changes could be seen in 20-50 years. It is a long-term plan. On a small scale, changes could be detected in loads within a 10-year time scale. **The journey however has to start otherwise the problems will get worse.**

The Plan proposes management measures and control actions that are required across the coastal section of the Peel-Harvey Catchment to reduce phosphorus inputs to the estuary. The mix includes actions to address existing activities, and others to prevent and reduce phosphorus discharges in the future. The key components include:

- management of **agricultural land** practices using, better fertiliser, soil amendment, perennial pastures and better management of irrigation systems;
- management of **urban land** practices, better fertiliser and soil amendment practices, and water sensitive design that focuses on a 'whole of water cycle' approach, applied through the environmental and planning referrals and approvals processes;
- management of **urban and rural effluent**, including retrofitting of septic tanks with nutrient reducing alternatives, full connection to sewerage, and cleanup of livestock practices;
- management of **licensed discharges** entering the estuarine system through licensing of agricultural nutrient discharges;
- **protection and revegetation of wetlands and waterways** through maintenance of buffers and riparian vegetation and stock exclusion;
- modification to **drainage management** practices to reduce in-channel sediment movement as opportunities arise;
- continued **research and investigation** into best management practices available for nutrient reduction in the rural and urban landscapes of the Peel-Harvey Catchment to ensure improved understanding of how nutrient reduction measures are performing and to refine actions;
- implementation of a **monitoring** (at a range of scales) and **reporting** program of suitable indicators and targets to allow **evaluation** of the efficacy of the Plan;
- identify and address barriers to **uptake of best management practices** within the catchment and measures that may increase the rate of uptake; and
- fostering of **community partnerships**, to promote awareness of and collectively manage water quality issues.

The estuary is under significant stress due to rapid urban development and agricultural practices. Government and the community working cooperatively will determine the future fate of the estuary. The estuary may be facing another ecological collapse including more fish deaths, algal blooms and continued deterioration unless urgent, coordinated and sustained action is taken.

The Environmental Protection Authority recommends that Western Australian government agencies agree on indicative costings and timelines to implement the recommended measures and actions of this Plan within six months of publication of this final Plan.

1. Introduction

1.1 Peel Inlet-Harvey Estuarine System and its catchment

The estuary is located 75 km south of Perth in the south west of Western Australia. The system consists of two interconnected shallow lagoons, the Peel Inlet and the Harvey Estuary, into which the three major rivers, the Murray, Serpentine and Harvey discharge. The estuary is the largest inland waterbody in south western Australia (Brearley, 2005). The estuary is connected to the ocean via two channels, the Mandurah Channel, a natural but narrow 5 km long channel connecting the northern end of the Peel Inlet to the Indian Ocean and the Dawesville Channel (constructed in 1994), connecting the southern end of Peel Inlet and the northern end of the Harvey Estuary to the ocean. The whole Peel-Harvey catchment is approximately 11 930km^2 (Jakowyna, 2000). This Plan covers the coastal portion of the Peel-Harvey catchment as shown in Figure 1. This area also includes the areas within the Cities of Rockingham and Cockburn and the Town of Kwinana that drain into the estuary via the Peel Main Drain.

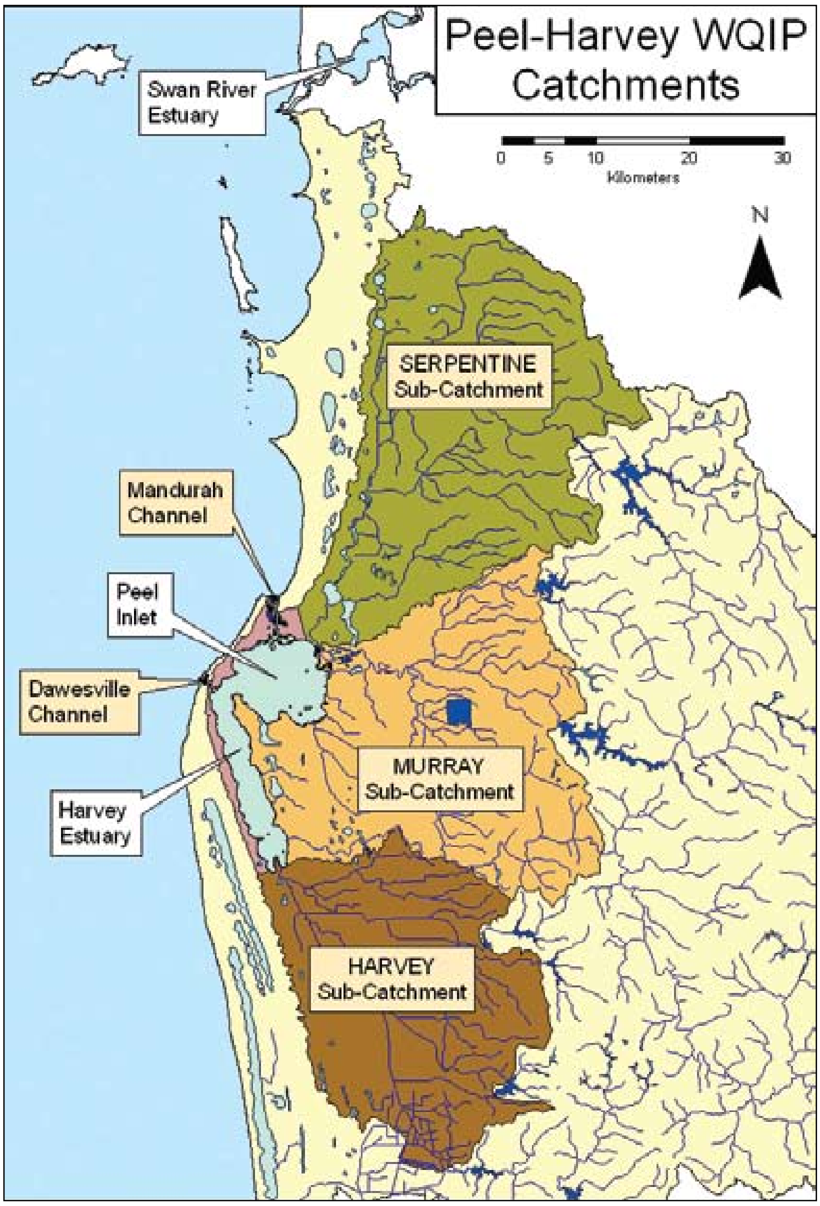


Figure 1: Showing the Peel Inlet-Harvey estuarine system and the coastal portion of its catchment (courtesy Department of Water).

Progressive nutrient enrichment of estuarine waters over several decades of catchment landuse practices has contributed to lowered estuarine and riverine water quality and the appearance of large accumulations of macroalgae and blooms of the toxic blue-green microalga *Nodularia spumigena* (see Figure 2) during the 1980s and the early 1990s — the former largely in the Peel Inlet and the latter in the Harvey Estuary (Water and Rivers Commission, 2004).

Figure 2: *Nodularia spumigena* **floating on the surface waters of Peel Inlet (courtesy Moira Wills).**

*1.1.1 Past activities in the catchment**

The lands of the Peel-Harvey Estuarine catchment had been utilised by communities of Noongar people prior to European settlement. Noongar communities within the region utilised fire-stick farming, as both a tool for rejuvenation of vegetation within the area, and to flush out game. In addition the communities had established fish traps along stretches of the Murray River whereby fish could be caught by hand. The Noongar activities within the catchment were subsistence practices and required large open areas to work effectively.

The first European settlers arrived in the Peel-Harvey catchment in the early 1800s, with the intent of using catchment land for agricultural practices. A small colony of people settled at "Peeltown" near the Mandurah Channel in mid 1830. By 1835 many people had settled along the Murray River between "Peeltown" and Pinjarra.

For the first few years, the settlers experienced many hardships. This was mostly the result of the nature of the soils and climate of the region, combined with the agricultural practices applied by the European settlers that had been developed in a location with very different environmental conditions. As such, the quest for the best areas of land acceptable for agricultural practices within the catchment commenced, and many of the first settlers chose land on the river flats, where soils were relatively organic-rich and could be accessed by boat.

Over the next decade, many more settlers arrived in the region. Livestock were introduced and allowed to roam free across large areas, as such a range was necessary due to the poor carrying capacity of the region, and clearing of land commenced with the commencement of pastoral activities.

By the 1850s, farmers in the catchment were producing enough fruit, vegetables, potatoes, wheat and running livestock to sustain the population and for export. In addition, impressive commercial catches of fish were being taken from the estuarine system by the 1880s and exported with the introduction of canning technology to the region.

In the 1890s it became evident that fish stocks were becoming depleted. In 1898 formal efforts to manage commercial fishing activities on the estuary commenced and regulations were gazetted. The first Fisheries Department of Western Australia was also established. Fisheries management has been ongoing since this time in an effort to manage the consistent and significant commercial and recreational fishing pressures the system has experienced over this extended period.

Within this period, it became evident that the full potential of agricultural production and land availability had not been realised due to the natural seasonal flooding experienced over much of the region and the hydrological nature of the upper riverine reaches of the catchment.

Bradby (1997) provides the following description of the upper riverine reaches of the catchment prior to human modification:

> *'In 1829, the Swan Coastal Plain was a wetland. Each winter it and the upstream jarrah forest would be hit by heavy and concentrated rains. Streams and brooks would flow onto the plain, dissipating their energy into a broad, interconnected chain of swamps many kilometres wide. Only the rivers of the largest system, the Murray and the Dandalups, stayed in clear stream beds for all their length. In larger floods, even these streams strayed across the flats.*
>
> *The other main rivers, the Serpentine and the Harvey, were well-defined watercourses in their upper and lower sections, but their middle reaches were a maze of swamps, with*

* Section 1.1.1 adapted from Water and Rivers Commission (2004) except where noted otherwise.

paperbarks, flooded gums and sedges. Here, the rivers would spread out in winter and join forces with the flow from all the smaller brooks and streams. Some of this water would eventually seep through to the river's lower reaches, and flow through the estuary to the sea. The plain would be flooded from the scarp through to the long ridge of tuart-covered Spearwood dunes towards the coast, with only occasional sandhills remaining exposed.'

With increased colonisation of the catchment came increased clearing of the land and this, combined with logging in the region resulted in rises in the groundwater table, which in turn exacerbated the extent of flooding. Eventually the government chose to address the problem of flooding by implementing a system of drains, after land holders in the region lodged numerous complaints relating to lost crops and property damage. In 1900, the first Drainage Bill was passed by State Parliament. Over the following seventy years, trees on the banks of the waterways were removed; lower riverine reaches were de-snagged; the rivers were straightened and deepened; a system of interconnecting drains was dug across pastoral lands; swamps were drained; flow rates of the river courses were increased.

Bradby (1997) recounts the drainage system that was implemented in the region. He ends the section with the point:

'Work commenced on the Meredith Drain in 1970 and had been completed by 1974. Within six years, scientists working on the algal problems of the Peel-Harvey were to target the Meredith Drain as a significant source of nutrient pollution affecting the estuary.'

There are 1330 kilometres of waterways (artificial and natural) in the Peel-Harvey coastal plain catchment, including 1014 km of waterways which make up the Mundijong, Waroona & Harvey Gazetted Drainage Districts (Del Marco, 2007).

1.1.2 Status of current landuse activities in the catchment

Landuse in the Peel-Harvey region is highly diversified. Residential, commercial and agricultural practices flank the estuaries, while agriculture is the dominant landuse activity on the coastal plain region. Stock grazing and pasture development are the most common agricultural activities, although horticulture and industry are also present. A small portion of the region is irrigated and has a developed network of drains. Approximately 75 percent of the coastal plain is cleared of native vegetation. The land immediately east of the Darling Scarp remains largely forested with native *Eucalyptus marginata* and all rivers except Murray in the region have been dammed. The land to the east of the plateau is largely cleared for stock grazing, pasture development and cereal crops (Jakowyna, 2000).

The Harvey catchment has been extensively cleared and drained for agriculture. Irrigated pastures in the south-east portion support a major dairy industry and some intensive horticulture, while clover-based pastures in the central and western portions support beef cattle, sheep and hay production. The Murray catchment contains mostly grazing and cropping. The Serpentine catchment has a diverse mix of landuses including horticulture, grazing, poultry farms, feedlots and hobby farms. Waters from the largely unmodified forested catchment of the upper Serpentine have been diverted for potable water supplies. Jakowyna (2000) describes the main catchment landuses of the Peel-Harvey catchment in detail and this is also summarised in Appendix D. Section 2.8 outlines the main sources of phosphorus to the estuary by landuse category.

Significant new urban development and rural landuse intensification are occurring within the Serpentine (including the Peel Main Drain) and Murray catchments in close proximity to waterways and wetlands, in response to peri-urban land pressures and in advance of new rail and highway infrastructure.

Agricultural practices are highly influenced by soil type. The Peel-Harvey coastal catchment is flat with low undulations of up to 3m. Soils are generally, with some exceptions, of alluvial deposition overlain by deep weathered sands that form low parallel dunes running north to south. Over 60 percent of the catchment has coarse sandy surfaces of varying depths on top of impermeable layers of ironstone or clay. Inundation is common during winter because of the flat landscape and short but relatively wet and intense winter rainfall season. Winter rainfall exceeds evaporation and when combined with ground saturation and soil types of the area helps contribute to as much as 30 percent run-off. Consequently there are many lakes and some areas of permanent water logging. The large drainage network constructed since the 1930s greatly reduces inundation (Summers *et al*., 1999) and has greatly reduced the wetland areas.

Despite the drainage network, stream flow rises and peaks over several days following rain events as water pools and is stored on the flat landscape. Nutrient run-off from clay soils is predominantly over the surface while sandy soils have combined subsurface drainage through the topsoil and surface flow when the soils, that are the overlaying sands, become saturated. The sandy soils become saturated because of the relatively impermeable ironstone and clay underlayers (Summers *et al*., 1999).

There are a large number of risk factors that influence the pathway of phosphorus loss from the landscape which include closeness to drain or streams, waterlogging, amount of phosphorus applied, how steep the land is, soil factors, the management practices and how far it is from the estuary. Figure 3 is a map of the Phosphorus Retention Index (PRI), which is one of the risk factors. Soils with a low PRI can leach phosphorus by movement with water through and across the soil; the soils with a high PRI lose phosphorus from across the surface. The lower the PRI the easier it is for phosphorus to move through these sandy soils. Below 5 is extreme risk (Summers *pers. comm.*).

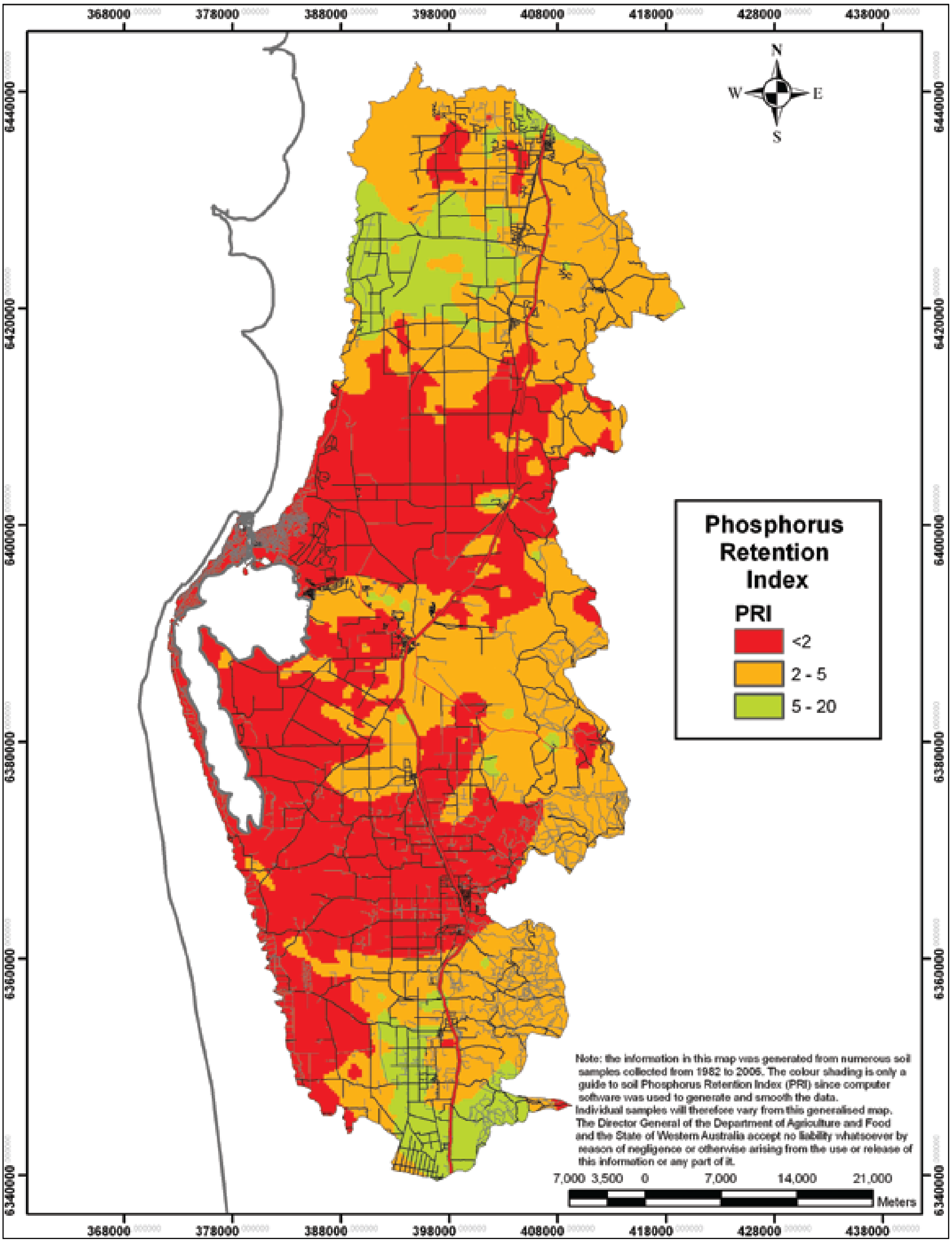


Figure 3. Map of the Phosphorus Retention Index (PRI) of the Peel-Harvey catchment (courtesy Department of Agriculture and Food).

1.2 Environmental Values of the Peel Inlet-Harvey Estuarine System

The Peel Inlet-Harvey Estuarine System is of considerable ecological, recreational, commercial and scientific interest and forms part of the Peel-Yalgorup System. Its fringing environment contains ecologically important wetlands and lakes and was placed on the list of Wetlands of International Importance under the Convention of Wetlands (Ramsar, Iran, 1971) on 7 June 1990. The estuary is an internationally significant habitat for waterbirds and migratory wading birds. Tens of thousands of waterbirds gather each year with over 80 species recorded, of which 27 are listed on the Japan-Australia Migratory Bird Agreement (JAMBA) and the China-Australia Migratory Bird Agreement (CAMBA) (Environmental Protection Authority, 2003). The system is also valuable as a commercial and recreational waterway and has spawned a development and tourist industry. Increased demands on the estuary have placed additional burdens on the system (for example, spraying for mosquito control, agricultural production, foreshore development and access, boat use and moorings and jetties).

The draft environmental values (ecosystem health or beneficial use) as shown in Figure 4 have been identified during key stakeholder workshops, and are consistent with the recent Natural Resource Management Strategy consultations (South West Catchments Council, 2005) (Land Assessment Pty Ltd, 2005). They apply to the estuarine waters including the tidal reaches of the three main rivers; They are as follows:

- aquatic ecosystem health;
- aquaculture and human consumption of aquatic foods;
- recreation and aesthetic – primary, secondary, visual amenity; and
- cultural and spiritual – sacred sites, heritage sites.

The environmental values that are not applicable here are drinking water and the primary industry uses for agriculture (irrigation, stock water). Commercial fishing is included in the environmental value ‘seafood safe for human consumption’.

As part of the development of the Peel Sustainable Development Strategy 2020 (Peel Development Commission, 2002) a survey was undertaken to determine community values of the region. The protection of the environment and of the Peel waterways in particular rated very highly through this process. Table 1 also describes the environmental values and whether they are currently being achieved.

For management purposes, the Dawesville Channel and the northern part of the Mandurah Channel are not included. These particular waterways are busy transit corridors and have a mix of water quality issues that will need other measures to be set in place. However all waters shown, including associated wetlands, will have an improved water quality if the catchment-derived phosphorus load is decreased.

Most recreational activities and supporting commercial activities are ecosystem based including fishing, crabbing, bird watching, boating including kayaking and canoeing, tourism and educational activities. These beneficial uses are likely to have an impact on the ecosystem health condition of estuarine waters but are dependant upon them being of good quality. Meeting the water quality objectives for ecosystem health will protect these beneficial uses and their condition will be monitored in parallel with that for ecosystem health.

Recognising the currently disturbed state of the estuary and the expressed community values, the Environmental Protection Authority has assigned a level of ecological health protection to these waters as a ‘Moderately Disturbed System’ consistent with the national guidelines (ANZECC and ARMCANZ, 2000). The Environmental Protection Authority also recognises the highly stressed tidal reaches of the Serpentine and Murray Rivers as measurably degraded ecosystems (experiencing algal blooms, bacteriological scums, fish kills, unsightly episodic decomposition of alga producing offensive odours). These reaches have continuing high amenity value and the Environmental Protection Authority has identified the riverine segments as the focus of management in the short term. This allows some flexibility in management so that wider variations might be acceptable while water quality trends improve in the longer term.

These values are consistent with the national approach that defines environmental values of waterbodies as: values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of pollution, waste discharges and deposits (ANZECC and ARMCANZ, 2000).

Table 1: Environmental values, water quality issues and water quality objectives (Department of Environment, 2004a).

Waterway segment	Environmental values		Water quality issues	Nutrient pollutant indicators	Water quality objectives for nutrients in waterways [1]
	Desirable EVs	Being achieved?			
Serpentine	Aquatic ecosystem health. Recreation (contact, passive) and aesthetics. Harvesting of fish and shellfish for human consumption. Cultural and spiritual.	No Not consistently Not consistently Not consistently	Nutrient enrichment. Algal blooms (occasionally toxic). Microbial contamination. Occasional fish kills. Odours from decaying algae. Potential remobilisation of pollutants from sediments. Accumulation of toxins in shellfish. Estuarine impacts add: loss of seagrass meadows, nuisance mosquitos, construction activities, disturbance of acid sulfate soils which are extensive in the area, dredging and disturbing estuarine sediments, propeller turbulence in shallower estuarine waters, spillages, illegal dumping.	High nutrient concentrations. High chlorophyll levels or algal numbers. Low oxygen conditions. High colour, suspended solids and turbidity.	Phosphorus load of 21 tonnes p.a., concentration of 0.1 mg/L.
Murray	Aquatic ecosystem health. Recreation (contact, passive) and aesthetics. Harvesting of fish and shellfish for human consumption. Cultural and spiritual.	No Not consistently Not consistently Not consistently	Nutrient enrichment. Algal blooms (occasionally toxic). Microbial contamination. Occasional fish kills. Odours from decaying algae. Potential remobilisation of pollutants from sediments. Accumulation of toxins in shellfish. Estuarine impacts add: loss of seagrass meadows, nuisance mosquitos, construction activities, disturbance of acid sulfate soils which are extensive in the area, dredging and disturbing estuarine sediments, propeller turbulence in shallower estuarine waters, spillages, illegal dumping.	High nutrient concentrations. High chlorophyll levels or algal numbers. Low oxygen conditions. High colour, suspended solid and turbidity.	Phosphorus load of 38 tonnes p.a., concentration of 0.1 mg/L.

Waterway segment	Environmental values		Water quality issues	Nutrient pollutant indicators	Water quality objectives for nutrients in waterways [1]
	Desirable EVs	Being achieved?			
Harvey	Aquatic ecosystem health. Recreation (contact, passive) and aesthetics. Harvesting of fish and shellfish for human consumption. Cultural and spiritual.	No Not consistently Not consistently Not consistently	Nutrient enrichment Algal blooms (occasionally toxic). Microbial contamination. Occasional fish kills. Odours from decaying algae. Potential remobilisation of pollutants from sediments. Accumulation of toxins in shellfish. Estuarine impacts add: loss of seagrass meadows, nuisance mosquitos, construction activities, disturbance of acid sulfate soils which are extensive in the area, dredging and disturbing estuarine sediments, propeller turbulence in shallower estuarine waters, spillages, illegal dumping.	High nutrient concentrations. High chlorophyll levels or algal numbers. Low oxygen conditions. High colour, suspended solids and turbidity.	Phosphorus load of 21 tonnes p.a., concentration of 0.1 mg/L.

[1] Targets: Phosphorus loads set in *Environmental Protection (Peel Inlet-Harvey Estuary) Policy 1992*, concentration value set in Swan Canning Cleanup Program for the Swan Canning system and used in modelling the Peel Harvey catchment. The modelling calculates the load reductions required to meet the concentration target. If this concentration value is met then the phosphorus load targets should also be met in time.

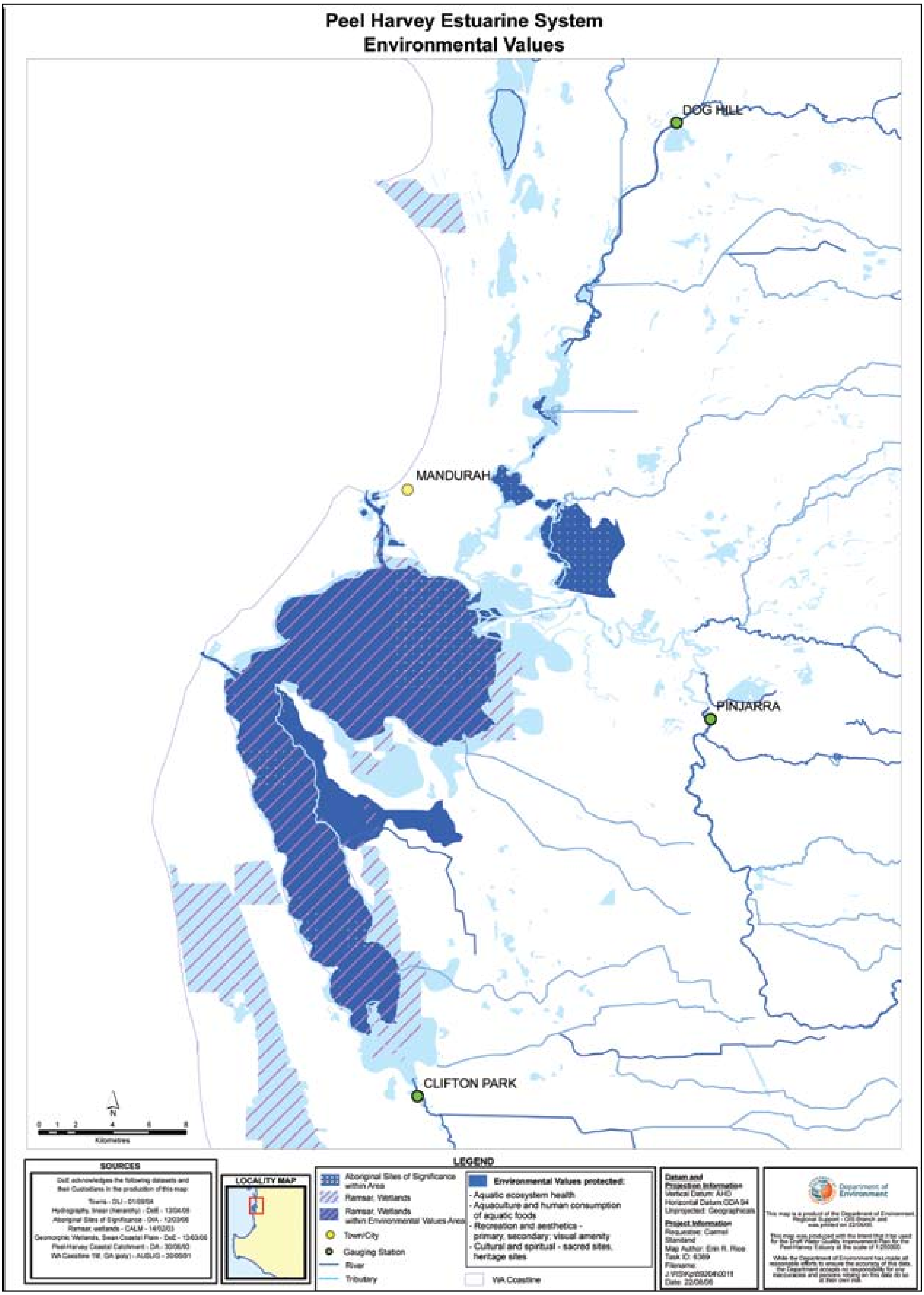


Figure 4: Environmental Values in the Peel Inlet-Harvey estuarine system (courtesy of Department of Water).

1.3 Environmental issues and management in the Peel Inlet-Harvey Estuarine System *

Prior to the opening of the Dawesville Channel, the estuary had limited tidal exchange with marine waters via the narrow 5 km long Mandurah Channel. Poor exchange resulted in a high level of retention of nutrients from catchment run-off, and this nutrient enrichment resulted in large accumulations of macroalgae in the Peel Inlet in summer and autumn, and massive *Nodularia spumigena* blooms in Harvey Estuary in late spring/early summer.

The salinity regime in Peel Inlet was less variable than in Harvey Estuary. The Inlet had higher salinities than the estuary during winter and spring: marine salinities re-established one or two months earlier (e.g. by the end of December instead of the end of January); and the degree of hypersalinity was less in late summer and autumn. Deoxygenation of bottom waters in Peel Inlet mostly occurred during periods of stratification, although *Nodularia* blooms spreading out from the estuary affected both oxygen levels and turbidity in the western part of the Inlet. Unlike the estuary, water clarity in the Inlet was sufficient to allow the growth of extensive stands of macroalgae in summer and autumn, and macroalgal uptake of nutrients helped to maintain low levels of organic nutrients and chlorophyll a in the water column during these seasons. The variable salinity regime and periods of poor water quality in the estuary were tolerated by only a few species of aquatic plants and invertebrates, but these species were nonetheless highly productive due to the nutrient-enriched conditions. The high productivity of these aquatic plants and invertebrates in turn helped maintain large populations of fish and waterbirds.

Water quality was particularly poor in the Harvey Estuary due to its physical and chemical features, particularly its greater distance from the Mandurah Channel and close proximity to phosphorus-rich inflows from the Harvey River. The estuary was generally less saline (except in autumn), more prone to salinity stratification, was more turbid (due to both *Nodularia* blooms and continued re-suspension of fine sediments by wind-driven waves) and had higher levels of nutrients and chlorophyll a than Peel Inlet (due to *Nodularia* blooms). De-oxygenation of bottom waters in the estuary also occurred during periods of stratification and *Nodularia* blooms, continuing after the bloom's collapse. Periods of severe de-oxygenation in turn caused the death of benthic invertebrates and fish.

The presence of regular and extensive toxic phytoplankton and macroalgal blooms (Figure 5), de-oxygenation events and fish kills were symptoms of an ecological collapse that had occurred across the estuarine reaches. Collapse within the estuarine system rendered it unusable not just for much of the resident flora and fauna necessary for continued ecological function of the estuarine system, but also for the local human population reliant on the system. Ecological collapse of the estuary led to socio-economic problems: commercial fishermen had difficulties harvesting fish catches due to the physical impediment macroalgal accumulations posed; recreational users were not able to have contact with estuarine waters for extended periods of the year due to toxic phytoplankton blooms; the presence of a mosquito-borne virus in the area became evident posing a health risk for people living within 10 km of estuarine waters.

Figure 5: Macroalgal accumulation at Cox Bay, Peel Inlet (courtesy Dr Tom Rose).

Prior to opening of the Dawesville Channel, daily mean tidal range in the Peel Inlet and Harvey Estuary averaged 17 percent and 15 percent of the ocean tides respectively. Now the tidal ranges in the Peel Inlet and Harvey Estuary are 48 percent and 55 percent of the ocean tides respectively.

* Section 1.3 adapted from Water and Rivers Commission (2004) except where noted otherwise.

With increased exchange with marine waters, water quality in the estuarine reaches has improved, particularly in the Harvey Estuary where periods of stratification and de-oxygenation are shorter and less frequent, *Nodularia* blooms have been absent and turbidity during spring has decreased. In contrast to pre-Channel years, water quality in the Harvey Estuary has become very similar to that in the Peel Inlet.

The more stable salinity regime and improved water quality in the estuary has resulted in an increased number of species of aquatic plants and animals in the system, particularly those requiring marine salinities. These organisms are also able to stay in the estuary for a larger part of the year. Compared to the salinity regime and resident biota of pre-Channel years, the estuary is more like a sheltered marine embayment for much of the year.

Gibson (2001) noted that the three dominant tree species, *Casuarina obesa*, *Eucalyptus rudis* and *Melaleuca rhaphiophylla*, of the riverine vegetation of the Harvey River delta showed a general decline in canopy condition with this change of salinity regime.

Seagrass distribution and production has increased and biological productivity has remained high, based on the numbers of fish, crabs, prawns and waterbirds present. Numbers of black swans appear to have declined, possibly as a result of loss in preferred food sources (*Ruppia* and certain species of macroalgae).

In November 2000, a preliminary survey of the estuary by the Aquatic Science Branch, Water and Rivers Commission, found the macroalga *Lyngbya* spp. along the Coodanup foreshore, and in Robert Bay, both areas located within Peel Inlet. *Lyngbya* spp. is a filamentous cyanobacterium that can be toxic, causing skin irritations, such as the populations of *Lyngbya* found in Moreton Bay, Queensland. *Lyngbya* spp. may also form dense aggregations that can smother underlying benthic habitats such as seagrass meadows. The macroalgal samples collected in Peel Inlet in November 2000 were not found to be toxic and it was recommended that future aggregations of the alga found be assessed for toxicity. A large outbreak of *Lyngbya* spp. occurred in Geogorup Lake and the Serpentine River in December 2006 and early 2007.

There have been improvements in parts of the estuary closest to the Dawesville Channel however weed-harvesting operations are still required for nuisance algae in the eastern portions. Significant macroalgal growth occurs in Austin and Robert Bay. Significant algal blooms and associated symptoms occur frequently in the estuarine reaches of the Serpentine and Murray Rivers.

A noticeable change in the peripheral lands of the estuary since construction of the Dawesville Channel has been the establishment of waterside urban development. Along with establishment of waterside urban development have been subsequent changes to fringing wetlands traditionally found bordering the estuarine system. The wetlands fringing the estuary are an important component to the ecological functioning of this Ramsar Listed estuarine system. Fringing wetlands act as filters to the estuary, as often both groundwater and surface runoff pass through these waterbodies prior to entering the estuary. Much of the sediment and nutrient load that could potentially enter the estuarine system is assimilated during residence time in the fringing wetlands, thus improving the quality of waters entering the estuary. In turn, nutrients added to fringing wetlands are utilised within these systems and passed on as increased productivity to the estuarine system rather than as nutrients, and provide a resource for waterbirds that are an important feature of the Peel-Harvey region. Despite the critical part that fringing wetlands play in the ecological functioning of the estuary, a clear understanding of the qualitative or quantitative impacts of urban development around the periphery of the estuary on fringing wetland habitats and their function is not known.

A soil sampling program undertaken by the Land and Water Quality Branch, Department of Environment and Conservation in early 2004 in the Peel-Harvey Catchment indicated that about 5,000 ha of shallow (<3 m deep) sediments in this region contained significant amounts of iron sulfide minerals that have the potential to be disturbed by local development. Acidic drainage has been linked to accelerated orthophosphate delivery to catchment waterways. If disturbed, there is the potential for an acid-sulfate condition to develop in the area, resulting in the discharge of acidic surface run-off and contaminated groundwater carrying soluble metals and other toxic pollutants (Stephen Wong *pers. comm*.). The new urban development near the Creery wetlands on the northern shore of the Peel Inlet and near the Dawesville Channel have disturbed approximately 500 ha of soils. This disturbance has the potential of generating 75,000 t of sulphuric acid. Fortunately, the high acid-buffering capacity of marine waters reduces the potential environmental impact of sulphuric acid discharging into the aquatic environment.

However, if this were to occur in riverine reaches of the estuary, buffering of the acidic discharge would be much more limited resulting in potentially serious impacts on the aquatic environment.

1.4 Consultation processes used in developing this Water Quality Improvement Plan

A collaborative effort with significant community support is required to implement the Plan. The State of the Environment Report (Environmental Protection Authority, 2007) stressed that unless a systematic approach is used to reduce phosphorus discharges, water quality will continue to deteriorate. The main aim of the Plan's communication strategy (Environmental Protection Authority, 2006) was to engage the community and stakeholders in the preparation of the Plan and implementation framework and to provide feedback for improving the Plan.

The Plan complements and closely links with the Peel-Harvey Catchment Natural Resource Management Plan of the Peel Harvey Catchment Council Inc. (Land Assessment Pty Ltd, 2005) and the Regional Natural Resource Management Plan of the South West Catchment Council (South West Catchments Council, 2005). It draws information from historic and current projects in the Peel Harvey Catchment, including seven other projects funded as part of the Coastal Catchments Initiative (CCI).

A preliminary consultation stage, limited in scope, was undertaken in 2004 (Department of Environment, 2004a) in three regional workshops with key stakeholders. Participants were asked to identify where and what activities or social amenity and uses of waterways and estuarine waters (including drains) they currently enjoy (or value) and want to continue to enjoy, and what they want the quality of these waters to be like. The feedback reported to the Environmental Protection Authority at that time included:

- water quality values: healthy wetlands, rivers and estuaries to support wildlife and people;
- preferred uses: fish, swim, boat, farm, flood protection; and
- management measures: reduce phosphorus, restrict access to banks of drains and streams.

This was used to spatially define the draft environmental values and beneficial uses set out in Figure 4. During the workshops it was explained that these environmental values would be used by the Environmental Protection Authority to set the level of protection for water quality in the estuarine waters, and to define the water quality targets to be achieved.

Since then progress reports and opportunities for input have been provided to stakeholders and the community as various CCI project findings have been released. In particular, comment has been sought at various stakeholder meetings and community fora on the interim findings of the modelling and monitoring projects, which have identified catchment hot spots and a range of phosphorus-reducing management actions by subcatchment. Feedback from this engagement was incorporated in development of the draft Plan.

The main round of consultation commenced with the release of the draft Plan for a 10 week period when the community had the opportunity to engage on key issues.

These comments have now been considered and where appropriate issues and concerns have been taken on board in preparation of this final Plan.

Importantly, the indigenous community has been engaged in the process of consultation, and will continue to be involved.

2. Water Quality

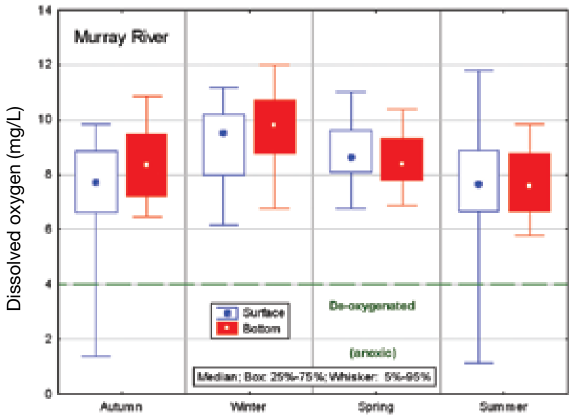
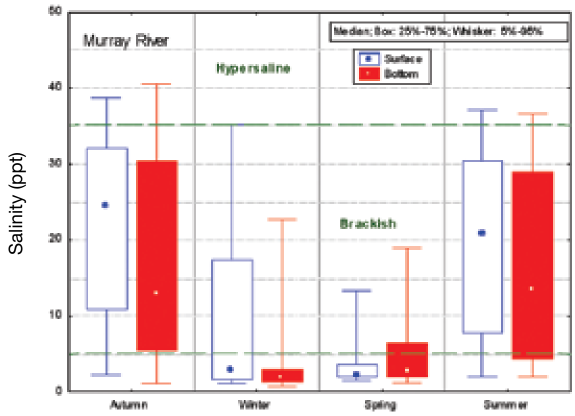
2.1 Water quality issues

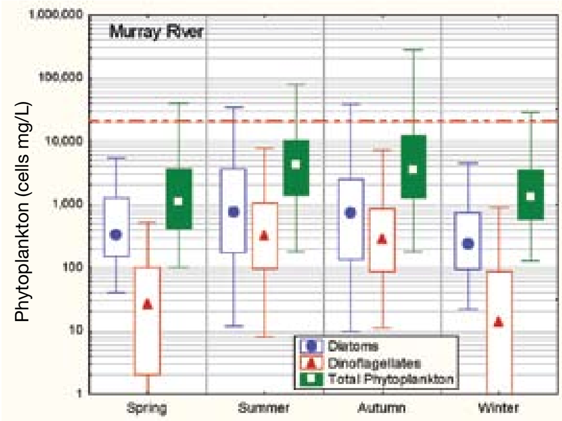
A number of environmental issues of concern have been observed in the Peel Inlet-Harvey Estuarine System over recent and past years. These include deteriorating water quality in the lower reaches of the Murray and Serpentine Rivers, associated with which are de-oxygenation events, increased nutrient concentrations, toxic phytoplankton blooms and fish kills. In the Peel Inlet, the toxic macroalga *Lyngbya* spp. has been found, while along the banks of the Harvey Estuary changes in fringing vegetation have been observed and bank erosion associated with increased tidal regimes has been reported. Finally, in the Harvey River, a deterioration in tree health has been reported.

A summary of the present environmental conditions of concern in the Peel-Harvey Estuarine System has been summarised in Table 2 according to region.

Table 2: A summary of environmental conditions of concern in the estuarine reaches of the Peel Inlet-Harvey Estuarine System (adapted and updated from (Water and Rivers Commission, 2004).

Region	Condition	Example
Peel Inlet	Appearance of the potentially toxic blue-green macroalga *Lyngbya* spp. at Robert Bay and along Coodanup foreshore in December 2000. *Dinophysis accuminata* typically occurs in Peel Inlet early spring each year. Has been detected above health guidelines regularly since 2002. Small fish kills of approximately 1000 blowfish investigated in Coodanup in January 2005.	 *Lyngbya* spp. in Peel Inlet (courtesy of Wasele Hosja, December 2000).
Harvey Estuary	Decrease in numbers of fringing trees and shrubs along the shores of the Harvey Estuary.	 Dying fringing vegetation along the shoreline of Harvey Estuary (courtesy of Tracey Calvert, April 2001).
	Prickly algae *Acanthophora spicifera* detected near the Dawesville Channel in January 2007. This nuisance algae is a sub-tropical marine species that has numerous microscopic spines and is highly invasive. Small fish kills of approximately 1000 blowfish reported and investigated February – April 2005.	 *Acanthophora spicifera* blooms near the Dawesville Channel (courtesy of Wasele Hosja, January 2007).

Region	Condition	Example
Harvey Estuary		 Close up of the prickly algae *Acanthophora spicifera* detected near Dawesville Channel (courtesy of Wasele Hosja, January 2007).
Murray River	Strong salinity stratification and subsequent deoxygenation events in surface waters outside winter river-flow periods.	 Seasonal dissolved oxygen (mg/L) in the Murray River between 1995 and 2003. The green dotted line indicates oxygen levels that affect fish (courtesy of Christian Zammit).  Seasonal salinity (ppt) in the Murray River between 1995 and 2003 (courtesy of Christian Zammit).

<table>
<tr><th>Region</th><th>Condition</th><th>Example</th></tr>
<tr><td>Murray River</td><td>Phytoplankton (diatom) blooms in summer and autumn, presenting as a thick, surface-forming scum. In addition, the potentially toxic dinoflagellate Alexandrium minutim has been detected in moderate densities (summer 1996).</td><td>

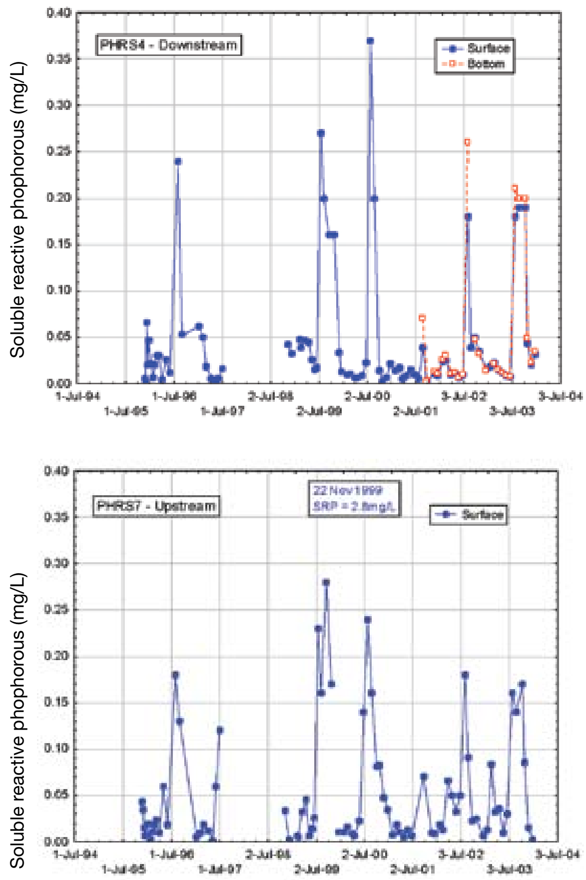
Seasonal diatom, dinoflagellate and total phytoplankton abundance in the Murray River between 1995 and 2003. Red line indicates 20,000 cells/mL, or bloom conditions (courtesy of Christian Zammit).</td></tr>
<tr><td></td><td>Fish kills have been reported in:
Winter 99 – approx. 50 fish dead; deaths likely due to the presence of Gyrodinium cf. Galatheanum.

Spring 00 – approx. 400 fish dead; deaths attributed to low dissolved O_2 associated with decomposing surface scum and presence of Gymnodinium.

Summer 00/01 – 3 incidents; 600–700 Bony Herring dead on these occasions; attributed to low dissolved O_2 associated with decomposing scum on one occasion.

Autumn 02 – approximately 700 herring.
Summer 02 – less than 10 fish dead; very thick scum present in the area at the time. Upper Murray 100s-1000s.
Autumn 07 – 900 gobbleguts, 100 bony herring.</td><td>
Fish kill on the Murray River (courtesy Department of Water Mandurah Office, January 2002).</td></tr>
<tr><td></td><td>The seasonal appearance of surface scum on waters of the Murray River from late spring through to autumn has contributed to the aesthetic deterioration of this section of the waterbody. Investigations into the origins of the scum have been initiated through the “Six Point Action Plan for the Murray River”.</td><td>
Microalgal scum on the Murray River (courtesy Department of Water Mandurah Office, January 2002).</td></tr>
</table>

Region	Condition	Example
Murray River	The accumulation of monosulphide black ooze (MBO) in the Yunderup Main Drain. MBOs create anoxic "blackwater" flows that kill fish.	 Monosulphide black ooze accumulating in the Yunderup Main Drain (courtesy Department of Environment and Conservation, Steve Appleyard, 2004).
Serpentine River	Extensive *Lyngbya* spp. bloom in Serpentine River and Goegrup Lake from November 2006 to January 2007. Bloom stretched for 6 kilometres from Barragup Bridge to Ibis Retreat, Stakehill.	 *Lyngbya majuscula* along the Serpentine River at the Serpentine Bridge (courtesy of Rob Summers, November 2006).
	Nodularia blooms in late spring through to early autumn, often followed by dinoflagellate and other flagellate blooms. In addition, a bloom of Prymnesium, which can be lethal to fish, occurred in autumn 1997. Massive fish kills- February 2003 (>500,000 (Bob Pond pers. comm.); February 2004 (120,000 Smith *et al.,* 2005); and 2005 (~150,000 (Bob Pond pers. comm.). March 2006 (3000 blowfish and large mats of *Lyngbya* at Geogrup Lake). Linked with deoxygenation along lower tidal stretches of river from delta to Lakes Road Bridge. Sampling in weeks prior to event revealed huge bloom of *Heterocapsa* spp that was not present during and after the kills. Rapid collapse of bloom is thought to have contributed to hypoxic slug of water.	 *Nodularia spumigena* blooms on the Serpentine River (courtesy of Water and Rivers Commission, June 2000).

Region	**Condition**	**Example**
Serpentine River	High phosphorus concentrations in both the water column and the sediments have been observed from monitoring data.	 Soluble phosphorus concentrations in the water column in the Serpentine River between 1995 and 2003 (courtesy of Christian Zammit).
Harvey River	Deterioration in tree health in the lower reaches of the Harvey River.	 Deteriorating tree health along the shoreline of the lower Harvey River (courtesy of Tracey Calvert, April 2001).

2.2 Addressing phosphorus loads

Although the permanent opening at Dawesville was completed in 1994, the additional tidal flushing of the estuary does not counter all the effects of continual nutrient input from the catchment.

The ecosystem decline within the estuarine system is due to nutrient discharge from intensifying landuses over many years. Recently, several initiatives have been introduced to reduce pollutant loads, including a review of licences (Department of Environment, 2005, Appendix F) and environmental improvement plans for industry, and improved standards for new development. Planning and licences will be discussed further in sections 4.3 and 4.7.

Major changes are occurring within the catchment. Major rapid transit routes and rapid expansion of residential and industrial developments are scheduled. Additional growth need not result in increased pollutant loads. Section 4.3 identifies new standards for urban development that can reduce loads, within a whole of water and nutrient cycle approach.

2.3 Existing programs addressing phosphorus load reductions

The Peel-Harvey Management Strategy proposed an expensive engineering measure to construct the Dawesville Channel (including sand-bypassing and dredging) designed to flush 'end of pipe' phosphorus loadings to the estuary. This was to be supported by catchment-based activities including fertiliser reductions, a moratorium on clearing, water quality monitoring, and a Catchment Management Plan (set in the Ministerial environmental conditions of 1989, 1991 and 1993). An Environmental Protection Policy (EPP) and Statement of Planning Policy (SPP) were introduced in 1992 to target phosphorus reductions within the Peel-Harvey Catchment.

The EPP sets out the environmental quality objectives for the Peel-Harvey estuary and the means by which the Environmental Quality Objective (EQOs) are to be achieved and maintained. The EPP set the EQOs as the median load of total phosphorus flowing from the entire catchment into the estuary of less than 75 tonnes, with the median load of total phosphorus flowing into the estuary being less than 21 tonnes for the Serpentine River, less than 16 tonnes for the Murray River and less than 38 tonnes for the Harvey River. The EPP states that this will be achieved through implementation of the Statement of Planning Policy No 2.1, appropriate land management by landholders and management authorities in the policy area, government extension services in the policy area, and local and State authorities ensuring that decisions are compatible with the achievement of and maintenance of the EQOs (Government of Western Australia, 1992a).

The objectives of the SPP are to:

- improve the social, economic, ecological, aesthetic, and recreational potential of the Peel-Harvey coastal plain catchment;
- ensure that changes to landuse within the catchment to the Peel-Harvey estuarine system are controlled so as to avoid and minimise environmental damage;
- balance environmental protection with the economic viability of the primary sector;
- increase high water-using vegetation cover within the Peel-Harvey coastal plain catchment;
- reflect the environmental objectives in the *Environmental Protection (Peel Inlet-Harvey Estuary) Policy 1992*; and
- prevent landuses likely to result in excessive nutrient export into the drainage system (Government of Western Australia, 1992b).

Other monitoring and management programs include the Statewide Algal Management Strategy, Murray River Six Point Action Plan to manage waste and bacterial scums, Dairycatch, programs of the Department of Water, and projects managed by the Peel-Harvey Catchment Council funded through the South West Catchments Council Water Quality Recovery Program (South West Catchments Council, 2005).

2.4 Management segments of the Peel Inlet-Harvey Estuarine System

The Plan focuses on the estuarine system, defined as: the Peel Inlet, the Harvey Estuary, and the tidal reaches of the Serpentine, Murray and Harvey Rivers below the gauging stations of Dog Hill, Pinjarra and Clifton Park respectively (Figure 4).

2.5 Water Quality Objectives for segments

A Water Quality Objective[1], as defined in The Framework for Marine and Estuarine Water Quality Protection and based on the Global Program of Action (Environment Australia, 2002) for the CCI program, means:

[1] Water quality objectives are equivalent to environmental quality standards in the ANZECC and ARMCANZ (2000) and Government of Western Australia (2004).

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

Water quality objectives to be achieved and maintained in respect of the estuary are a median load (mass) of total phosphorus flowing into the Estuary of less than 75 tonnes with the:

- median load (mass) of total phosphorus flowing into the Estuary for the Serpentine River being less than 21 tonnes;
- median load (mass) of total phosphorus flowing into the Estuary for the Murray River being less than 16 tonnes; and
- median load (mass) of total phosphorus flowing into the Estuary for the Harvey River and drains being less than 38 tonnes.

These objectives were also set within the Peel Harvey Stage II Report (1989) (Kinhill Engineers Pty Ltd, 1988) and *Environmental Protection (Peel Inlet-Harvey Estuary) Policy 1992* (Government of Western Australia, 1992a) and were confirmed in 2003 in the Progress and Compliance Review (Environmental Protection Authority, 2003).

The water quality objective to be achieved within the catchment waterways is set so that water quality at the draining point (outlet) of each catchment meets a median winter concentration value of 0.1 mg/L (0.2 mg/L in the shorter term) for Total Phosphorus (TP).

This methodology was based on Swan River Trust research and used in the catchment based modelling supporting this project, where it was predicted that if this concentration value is met then estuarine loadings of 75 tonnes p.a. set in the Ministerial environmental conditions can in time be met (Zammit *et al*., 2006).

2.6 Setting Load Reduction Targets

Predictive modelling tools have been developed as part of one of the CCI projects to estimate load reductions required to meet the water quality objectives. It is based on a large scale catchment model called LASCAM (described in Section 2.9). LASCAM can be used to assess management decisions and test how these will impact on water and nutrient delivery from the catchment to the estuary. It has been used to calculate load reduction targets for 48 outlets across 17 reporting catchments based on current climatic and landuse conditions.

These load targets represent the load reduction required in each catchment in order to meet the water quality concentration target (the median winter concentration target of 0.1 mg/L for total phosphorus) at each reporting catchment outlet. The method to calculate load reduction targets and the results are identified in (Zammit *et al*., 2006) (Appendix B). The 17 reporting catchments are shown in Figure 6.

The model provided a margin of safety. A 'reference' scenario was developed to compare the results of each scenario. The reference scenario assumed landuse and fertiliser applications remained at 2003 levels. The flow and nutrient results are presented as ratios between the tested scenarios and the reference scenario. This is so the impact of the proposed scenarios can be easily compared. Also, the uncertainties in the modelling results are difficult to estimate and reporting in this manner avoids reporting absolute values. The Annexes in Appendix B contain data on flow, concentration and yield for each reporting catchment.

2.7 Total maximum and the Plan's phosphorus loads

The total maximum pollutant load [2] is the maximum load of a pollutant that a water body can receive and still meet its water quality objectives and maintain or protect the designated environmental values. This scientific research has not yet been undertaken for the estuarine system, however the load reductions or maximum allowable phosphorus loads leaving each of the 17 catchments was estimated in the catchment based modelling.

The figures below show the model predictions of Total Phosphorus (TP) load and concentration as they are now (Figures 7 and 8) and how they need to change in order to meet the load and concentration targets (Figures 9 and 10). Most of the load is transported in the winter season and the load and concentrations presented in this report are expressed in terms of median winter load and concentration calculated over the period June to October. In order to incorporate climate variability the climate sequence modelled was the period 1990-2004.

[2] CCI methodology in the Framework for Marine and Estuarine Water Quality Protection (Environment Australia, 2002) and modelled on UNEP's Global Program of Action for the Protection of the Marine Environment from Land Based Activities

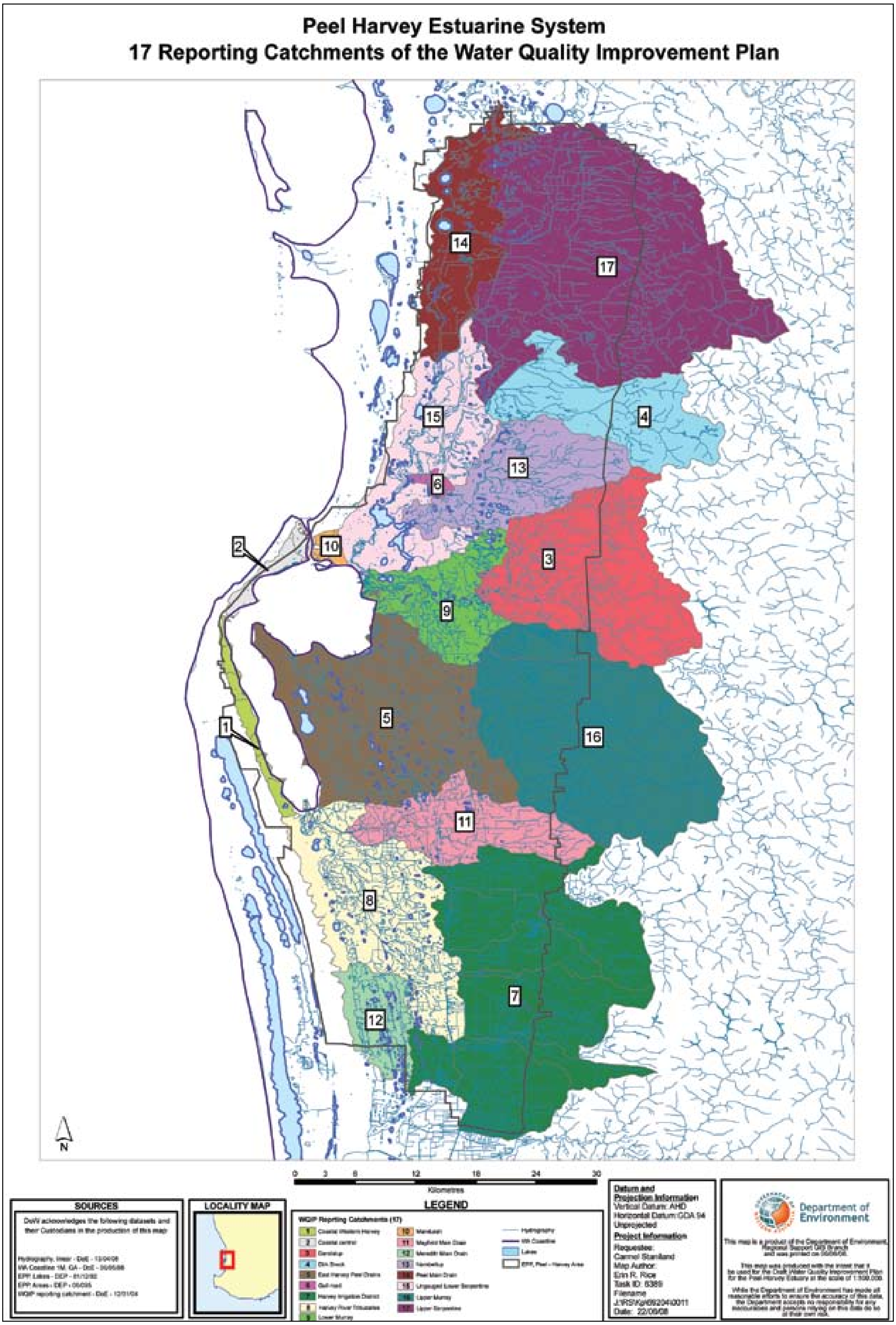


Figure 6: The seventeen reporting catchments of the Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System (courtesy of Department of Water).

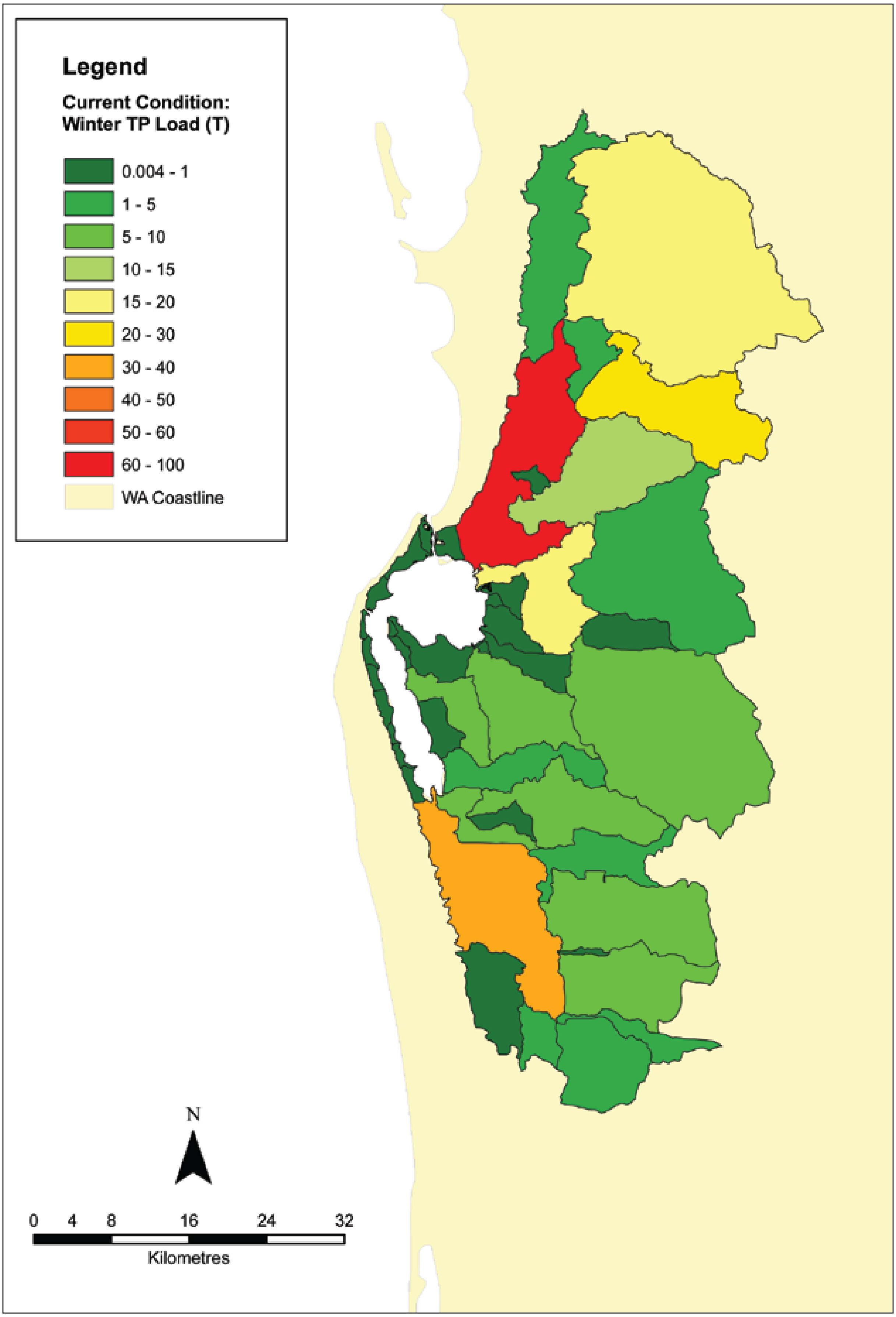


Figure 7: Current condition: Winter total phosphorus loads (T) (courtesy of Department of Water).

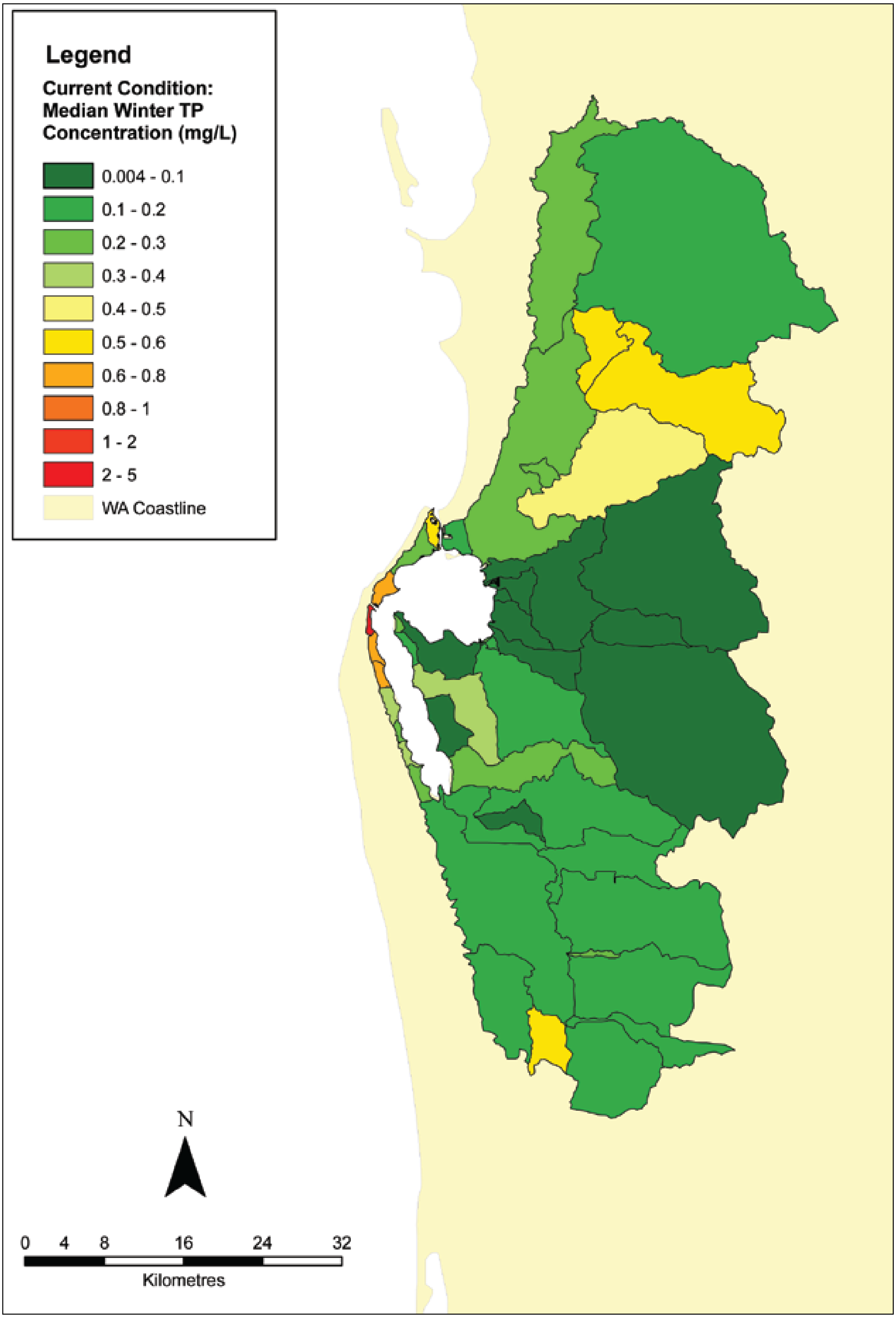


Figure 8: Current condition: Median winter total phosphorus concentration (mg/L) (courtesy of Department of Water).

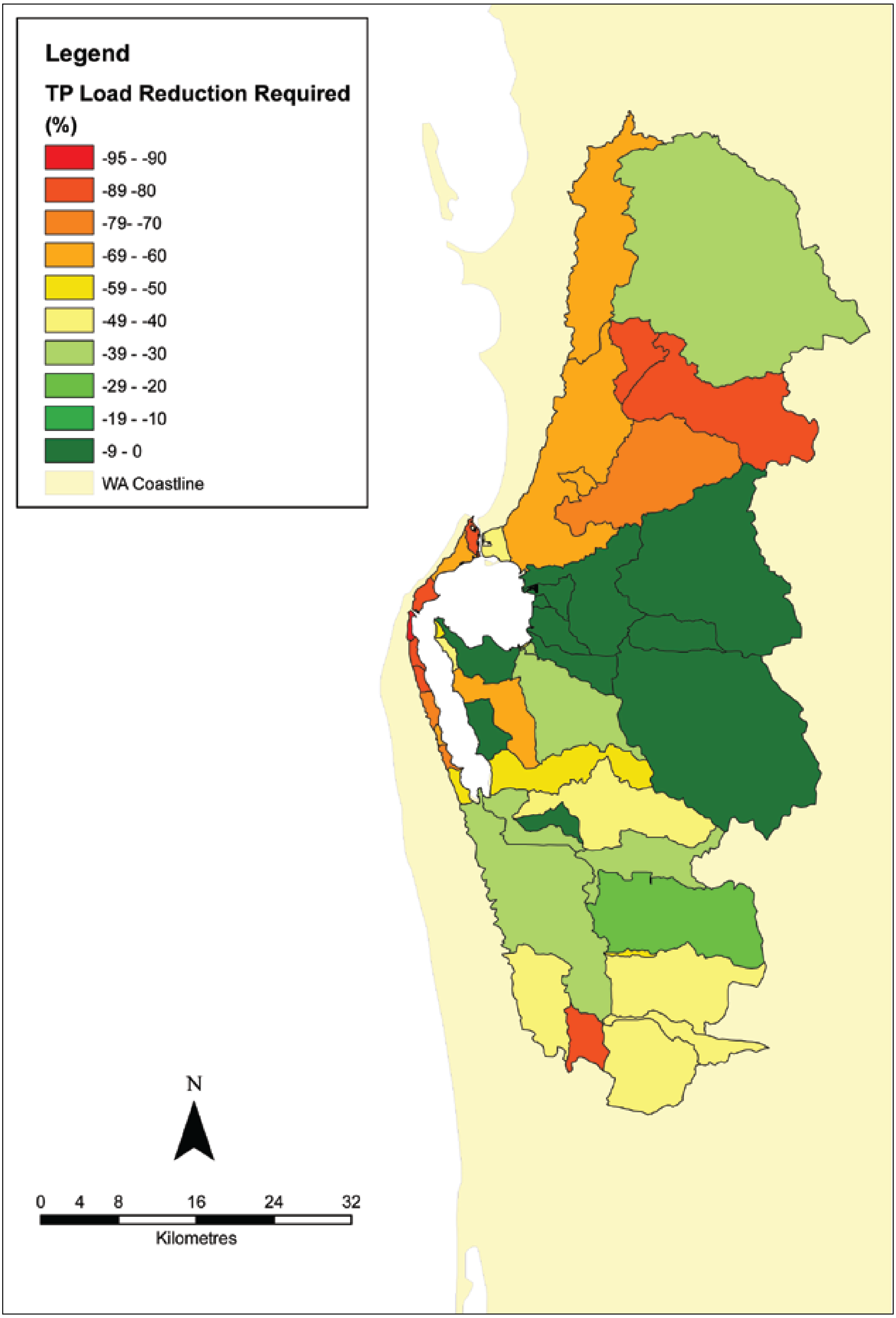


Figure 9: Total phosphorus load reduction required (%) (courtesy of Department of Water).

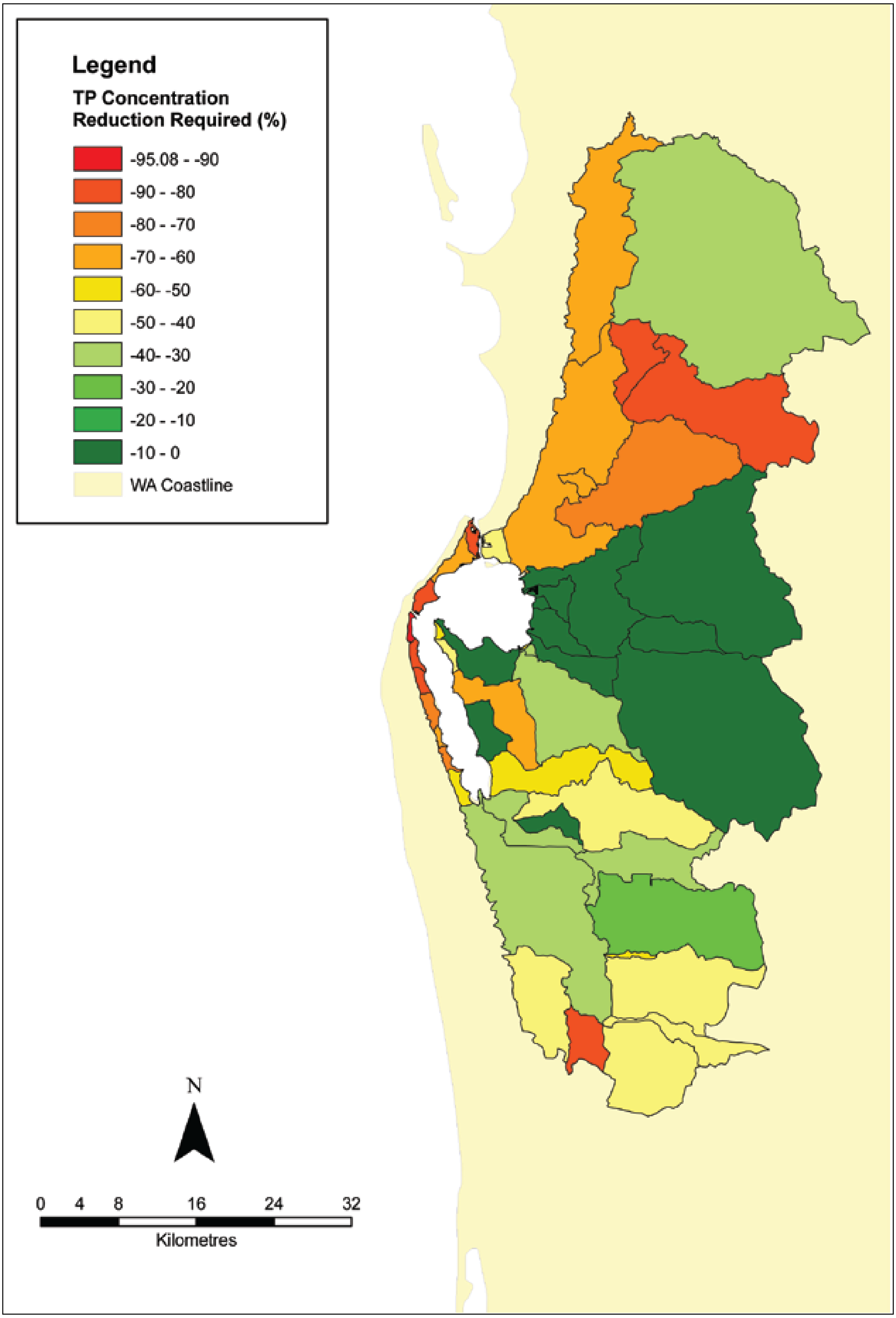


Figure 10: Total phosphorus concentration reduction required (%) (courtesy of Department of Water).

Table 3: Load reduction targets by main catchments and critical reporting catchments (courtesy Christian Zammit)

Catchment	Total Phosphorus load target to estuary (t/pa)	Estimated current Total Phosphorus winter load (t/pa)	Estimated load reductions required to meet 0.1 mg/L (%)
Total Serpentine	21	69	60
Dirk Brook Yangedi			82
Nambeelup Brook			78
Peel Main Drain			66
Ungauged Lower Serpentine			60
Total Murray	16	16	-
Dandalup, Upper and Lower Murray			-
Total Harvey	38	61	40
Coastal Western Harvey			83
Coastal Central			79
East Harvey Peel Drains			47
Grand Total	**75**	**145**	**48**

More detailed results are provided in Appendix B. With current landuse and climate conditions, estimated median winter Total Phosphorus load to the estuary is approximately 145 tonnes or about two times greater than the desired average annual load specified of 75 tonnes in an average year. **Significant reductions are required in the Serpentine and Harvey catchments, from 69 to 21 tonnes and 61 to 38 tonnes or about 60 percent and 40 percent respectively.** The Murray catchment shows that in-stream water quality concentration targets are being met, however considerable reductions must still be achieved to reduce the loads entering estuarine waters. However, during large episodic events as occurred in the Swan River (Swan River Trust, 2000) the Murray River may discharge well over it's target loads. The modelling estimated catchment contributions from areas below the three gauging stations as contributing significantly to phosphorus to the estuary. These include rapidly urbanising areas including catchments to the west, north and east of the estuary where there is rapid transport of nutrients and little chance of assimilation (Zammit *et al*., 2006).

All seventeen reporting catchments are shown in Figure 6, however critical reporting catchments requiring management actions in the Serpentine are Peel Main Drain, Upper Serpentine, Dirk Brook and Nambeelup Brook; and in the Harvey are Coastal West and Coastal Central, East Harvey Peel Drain and parts of Harvey Drains. Table 3 outlines the estimated load reductions required in each of these catchments.

2.8 Load allocations to sources of phosphorus

The model was used to estimate sources of phosphorus across the study area (Figure 11). The data can also be presented in load tonnage by reporting catchment (in Appendix B).

As shown in Figure 11 the "current" landuse that delivers the majority of the phosphorus to the estuary (39 percent) is grazing; representing intensive animal, feed lots and grazing areas. The remainder of the source of phosphorus is from Residential (representing urban and rural areas), intense horticultural, cropping, forestry, agricultural, horticultural and industrial. Remedial action should focus on these landuse types that occur in close proximity to waterways.

Other sources of phosphorus in the catchment that cannot be attributed to current landuse are rundown (from past landuse practices that often resulted in over application of phosphorus) and atmospheric inputs (eg dust and rainfall). These were estimated by turning off all other landuses within the modelling. These two sources are grouped together in the figures as atmospheric and rundown, however only trace amounts of phosphorus are delivered to the estuary via atmospheric inputs (Zammit *et al*., 2006).

Sources for the Serpentine, Murray and Harvey river catchments are shown in Figures 12-14.

Diffuse sources are the major contributors to the phosphorus load reaching the estuary and it is possible to have a significant impact by controlling

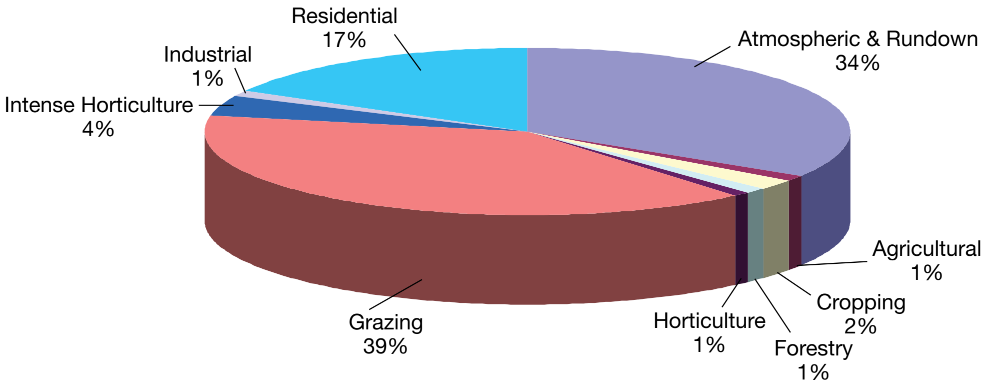


Figure 11: Current sources of phosphorus by landuse type to the Peel Inlet-Harvey Estuarine System for the entire coastal catchment (Zammit *et al*., 2006).

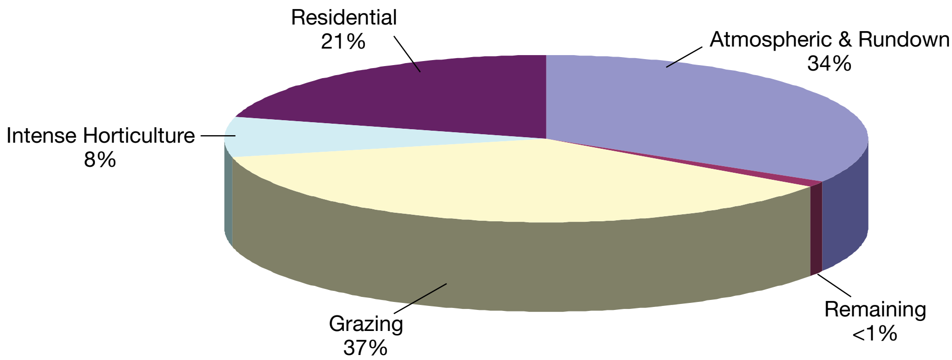


Figure 12: Current sources of phosphorus by landuse type to the Peel Inlet-Harvey Estuarine System for the Serpentine River catchment (Zammit *et al*., 2006).

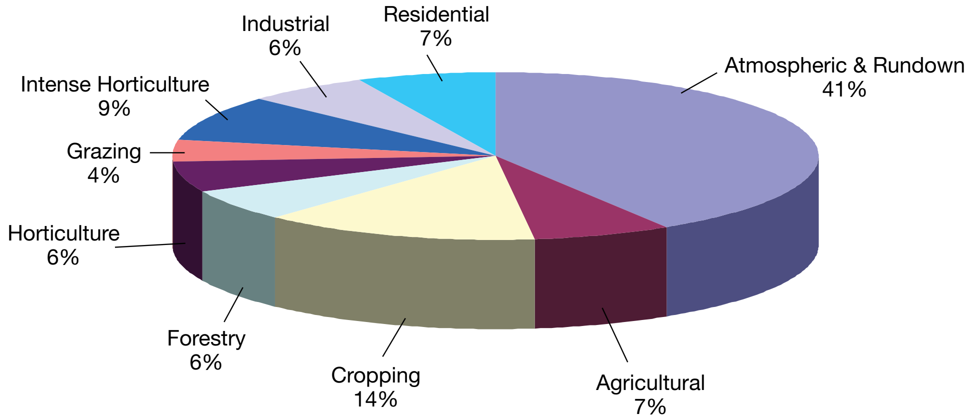


Figure 13: Current sources of phosphorus by landuse type to the Peel Inlet-Harvey Estuarine System for the Murray River catchment (Zammit *et al*., 2006).

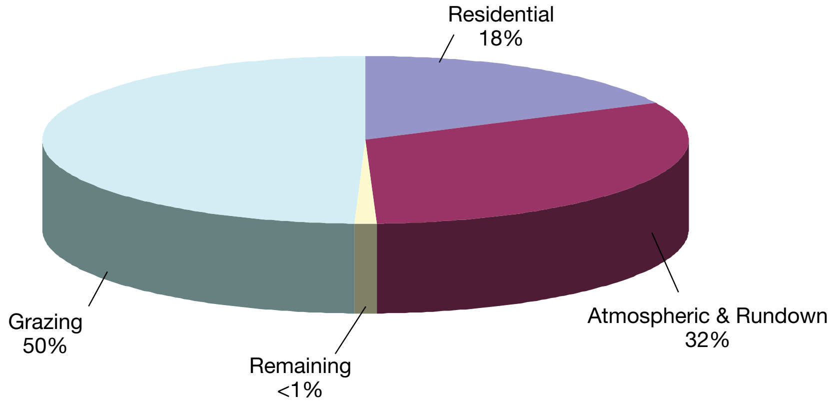


Figure 14: Current sources of phosphorus by landuse type to the Peel Inlet-Harvey Estuarine System for the Harvey River catchment (Zammit *et al*., 2006).

them. Control of diffuse nutrient sources can occur through removal of the source (e.g. by managing fertiliser application to the soil or preventing stock access to a waterbody) or by impeding the transport of nutrients to a waterway (such as by managing soil loss from pasture and cultivated lands). Point sources can be readily identified making it somewhat easier to apply control measures such as removing the nutrient source from the wastewater stream. While they may contribute proportionally less nutrients than diffuse sources, control of point sources may mean that overall loads are lowered in critical sub-catchments.

Internal nutrient sources are those nutrients either generated by in-stream productivity (e.g. through nitrogen-fixation) or through the storage and breakdown of nutrients contributed from external sources (e.g. runoff and groundwater infiltration). The sediments often represent the highest nutrient storage capacity in aquatic systems. In the Swan River chemicals are added to the waterbody to bind phosphorus in sediments making it less readily available to algae. Dredging of nutrient-rich sediments may be undertaken, thereby removing nutrients. The mechanisms of controlling internal nutrient loads may be costly however, and can cause additional environmental harm.

Actions which are designed to reduce at source, such as water sensitive design for land capability, cleaner production and source control such as through codes of practice, are cost-effective and underpin the recommended management measures identified in Section 4.1.

2.9 Decision Support Systems for water quality improvement

Although the relationships between catchment landuse practices and the development of water quality issues within receiving waterways are well known, it is often difficult to modify established landuse practices to restore high water quality values. Modification of landuse practices may take place over many years and changes in the condition of receiving waters will consequently take longer.

Mechanisms are available to support decisions when choosing possible modifications and changes to existing landuse practices in particular areas of a large catchment. One example is a numerical model that synthesises information available for catchment management scenarios, and allows a rapid assessment of appropriate management combinations/scenarios. It can be constructed to allow evaluation of catchment processes (e.g. soil types, hydrological regimes, landuse change) and/or the cost-effectiveness of management options (e.g. soil types, landuse activities, cost of management options). For the Peel-Harvey Catchment, a predictive model has been constructed for catchment processes to predict changes in water quality in estuarine reaches as a result of management actions, at a water shed scale no smaller than 10 hectares. The model has been constructed using LASCAM (Large Scale Catchment Model), a soil and hydrology model, and accounts for nutrient processing in the catchment landscape and within the riverine reaches (Appendix B). This model does not incorporate estuarine nutrient processing (e.g. benthic nutrient cycling).

A second model used in the Peel-Harvey Catchment as part of the CCI program SSPRED (Support System for Phosphorus Reduction Decisions, Appendix C), was used to guide the choice of agricultural Best Management Practices (BMPs) using cost benefit analysis. It uses a nutrient loss risk approach and is based on current known landuses in the catchment. It also allows catchment and waterways managers to undertake basic economic analyses of BMPs that can be employed in the urban and rural areas of the catchment.

In combination, these models allow comprehensive catchment management scenarios to be developed, including predicted changes in estuarine water quality, areas to be targeted with particular land-use practice modifications, and associated costs. The modelling findings are presented in Section 4.1.

The results of the two models were very consistent in terms of calculation of current phosphorus loadings and estimated target reductions. Importantly, the SSPRED model which is based on current landuse practices correlated well with monitored data from the catchment.

The large scale catchment model derived 17 reporting catchments (aggregated from 216 sub-catchments) for the purposes of target setting for water quality (Figure 6). At this stage, it has been developed for predicting phosphorus only.

The implementation plan will require monitoring for attainment of interim water quality and load reduction targets.

3. River Flows

3.1 Existing programs addressing river flows

The estuaries and waterways up to the three primary gauging stations (shown on Figure 4) are dominated by tidal flows particularly since the opening of the Dawesville Channel. Before European settlement, freshwater inflows were intercepted by extensive freshwater/brackish wetlands, which dampened the effect of major storm flows. Many of these wetlands no longer exist and waterways have been extensively converted into agricultural drains. Environmental flows within waterways are important for improvement in stream flow and for protection of in-stream and riparian habitat and biodiversity. The Serpentine and Harvey Rivers were dammed before environmental flow allocations were adopted and the impact of reduced flow is observed in these waterways.

The Plan is designed to achieve environmental flow objectives, detailed in section 3.4, that maintain natural flow variability, protect wetlands and floodplains (mimic natural inundation and drying patterns) and minimise the effect of dams on water quality (mimic natural frequency, duration and seasonal flow).

Environmental Water Requirements (EWR) are descriptions of the water regimes required to maintain or restore ecological processes and protect the defined environmental values (consistent with the National Principles for Provision of Water to the Environment (Water and Rivers Commission, 2000) (ANZECC and ARMCANZ, 1996). In other words EWRs are required to be able to achieve the environmental flow objective. Water regime is a description of the variation of flow rate or water level over time; it may also include a description of water quality. Further research is required to adequately determine EWR's for the Peel Harvey catchment. The current drainage system could be better managed over time to reduce peak instantaneous flows from cleared and developed lands, which will assist in reducing nutrient attenuation and sediment discharges.

3.2 Monitoring and modelling of river flows

The flow and water quality data for the Peel-Harvey Catchment were taken from several sites spread across the main catchments of the Serpentine, Murray, Harvey Rivers (Figure 4). As a result, three different models representing the three main rivers system were calibrated in Zammit *et al.,* 2006.

Because of time constraints and the large size of the catchment (~12 000km^2), 10 gauges were used to calibrate the hydrological model. With further funding, the established load measuring unit (LMU) gauges will be used to assess the validity of the calibration results. The water quality model used the 3 primary LMU sites. The choice of the gauges was driven by their historical importance (e.g. where primary load measurement units are located, see Appendix D) and the quality of the phosphorus data at each location. The sites used for calibrations are presented in Table 4.

Table 4: Calibration sites used in the hydrological model (Zammit *et al.*, 2006)

Context Name (Site Name)	Starting Year [3]	Ending Year
Serpentine		
Serpentine Drain (Dog Hill)	1979	2004
Dirk Brook (Kentish Farm)	1971	2001
Murray		
Murray River (Pinjarra)	1991	2004
Harvey Estuary		
Caris Drain (Greenlands Road)	1991	1996
Coolup Main Drain (Paull Road)	1991	1995
Mayfield Main Drain (Old Bunbury Road)	1991	1996
Mayfield Sub G Drain (Mayfield)	1982	1995
South Coolup Main Drain (Yackaboon)	1990	1996
Mealup Drain (Mealup Road)	1991	1997
Harvey		
Harvey River (Clifton Park)	1982	2004

[3] The starting year and ending year provided corresponds to the hydrological data. The data period covered by the water quality data is given in Appendix D Annex 1.

The linear and log flow charts (Figures 15-17) that were derived show the impact of damming in the reduced flow and variability of Serpentine and Harvey flows, the summer irrigation releases in the Harvey, and summer releases in the Serpentine.

River flow usually enters the estuary for 4-6 months each winter. This generates dynamic waters and usually lowers salinities to near fresh. However, the Dawesville Channel has changed this so that stratification develops between riverine freshwater discharging to the estuary and more saline marine water remaining on the bottom. This condition exacerbates water quality particularly during mid to late spring and early summer and often leads to algal blooms and hypoxia. Later summer and early autumn conditions are often critical periods as saline water becomes warm and occasionally hypoxic, particularly if phytoplankton blooms occur and senesce. Poor water quality at this time can be made worse if rain and cloudy warm conditions occur leading to fish kill incidents.

Eight dams have been constructed in the catchment to allocate significant volumes of water outside the catchment. These dams are managed by Water Corporation and Harvey Water and are used for public water supply or irrigation purposes. They are characterised within the model by a maximum capacity and a starting year, which is presented in Table 5. Because of the unnatural behaviour of the dam releases in terms of water and phosphorus yields, their capacities have been adjusted by the model. At the time of the calibration, no dam release information was available.

The Peel-Harvey coastal plain is largely one huge complex of various wetland types. Many wetlands are located on the eastern side of the Harvey estuary and in the Serpentine catchment. Many lakes are located in the Serpentine catchment and are below the gauging station in the zone of tidal influence. Only one major wetland (Spectacles wetland) is located above a gauging station and thereby was incorporated into the Decision Support System model (DSS). The Spectacles wetland is known for its capacity to treat and remove nutrients. Table 6 lists the major wetlands and lakes used in the DSS model.

Large modifications to surface water hydrology have occurred in the catchments as a direct result of agricultural and urban development where seasonal wetlands once existed. Extensive drainage networks cross the coastal plain and these networks intercept surface and ground waters, to rapidly deliver nutrients and sediments directly to the waterways. This extensive network has major impacts on river flows and water quality in the estuary. It continues to be a matter of great concern to catchment and estuarine managers, and will be addressed in the future Catchment Management Plan. Further research is needed to consider water quality implications in the management of drainage and the need to properly assess, develop and implement drainage best management practices to achieve this aim.

Table 5: Dams in the Peel-Harvey Catchment and their maximum capacity (Zammit *et al*., 2006)

	Completion Year	Maximum capacity (ML)
Serpentine Dam	1961	137,667
South Dandalup	1973	138,011
Conjurup	1994	180
North Dandalup	1994	74,849
Logue Brook	1963	24,590
Samson Brook	1941	7,993
Drakes Brook	1931	2,290
Waroona	1966	14,872

Table 6: Location of the main wetlands used in the DSS model (Zammit *et al*., 2006)

Name	Location
The Spectacles	Upper Serpentine
Black Lake	Lower Serpentine
Goegrup Lake	Lower Serpentine
Yalbanberup Pool	Lower Serpentine
Guanarnup Pool	Lower Serpentine
Lake Mealup	Harvey Estuary
Lake McLarty	Harvey Estuary

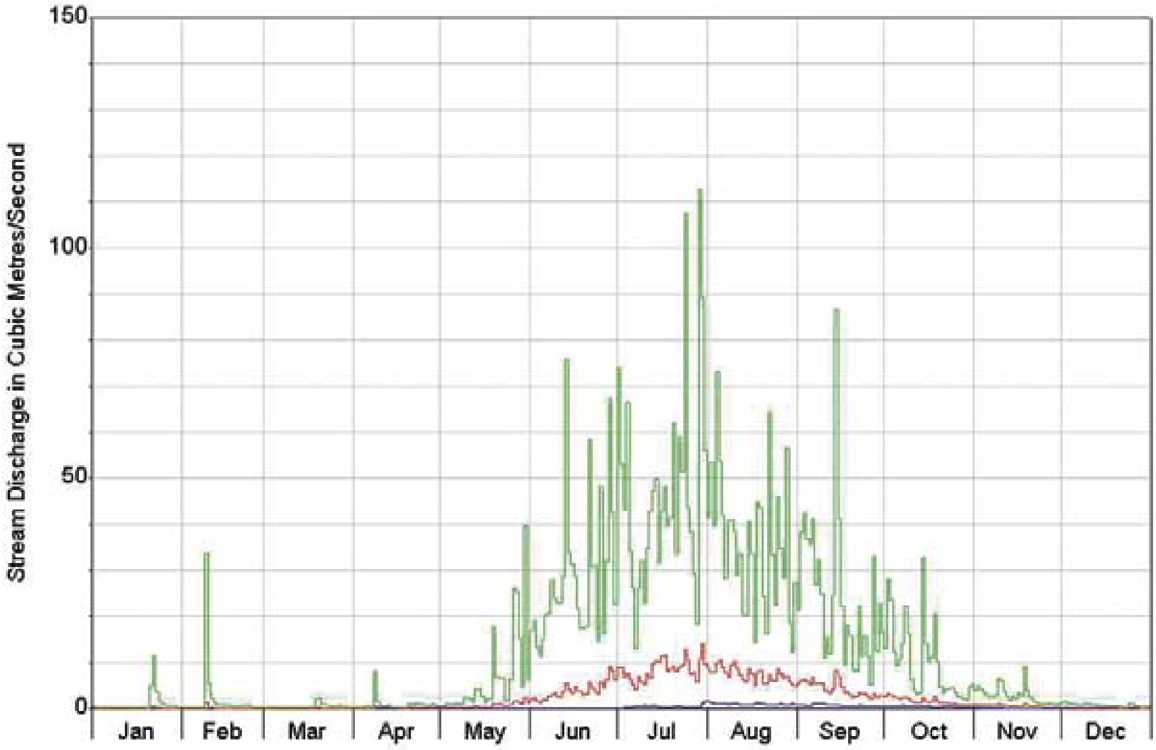


Figure 15a: Linear flow chart for the Serpentine River at the primary LMU site (limit of tidal flushing) Station 614030. Daily maximum (green), daily minimum (blue) and daily mean (red). Period of record 21/02/1979 to 13/06/2005 (courtesy Department of Water).

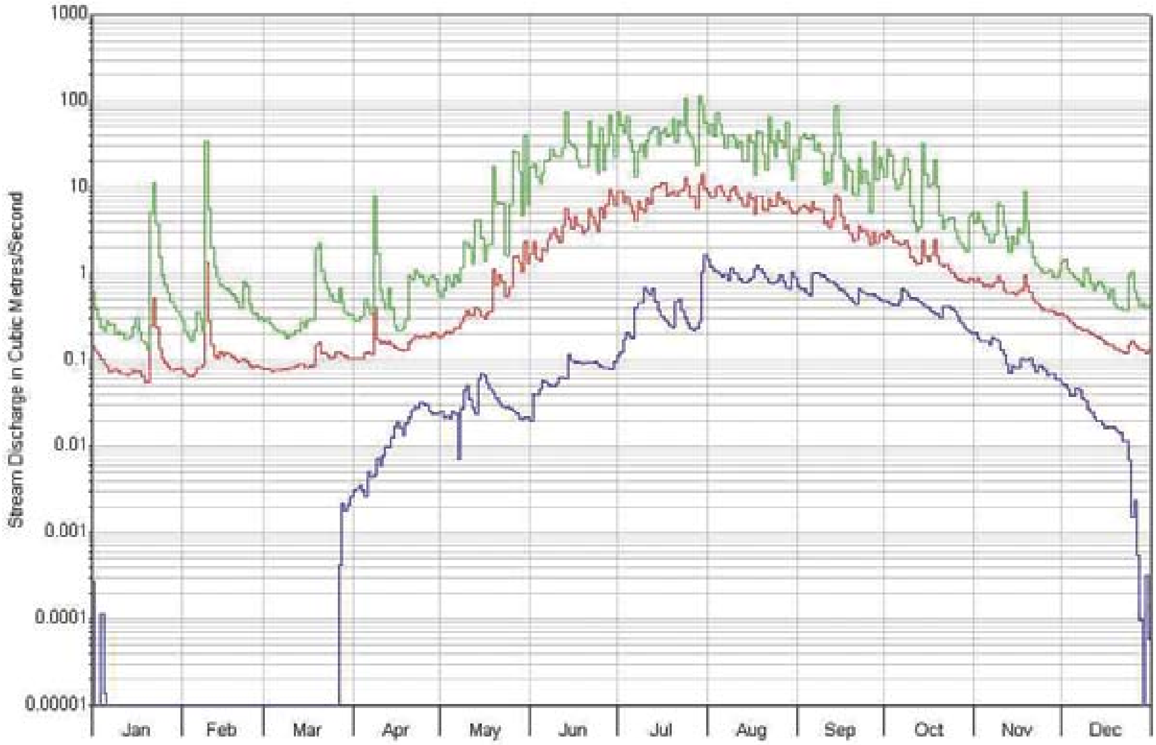


Figure 15b: Log flow chart for the Serpentine River at the primary LMU site (limit of tidal flushing) Station 614030. Daily maximum (green), daily minimum (blue) and daily mean (red). Period of record 21/02/1979 to 13/06/2005 (courtesy Department of Water).

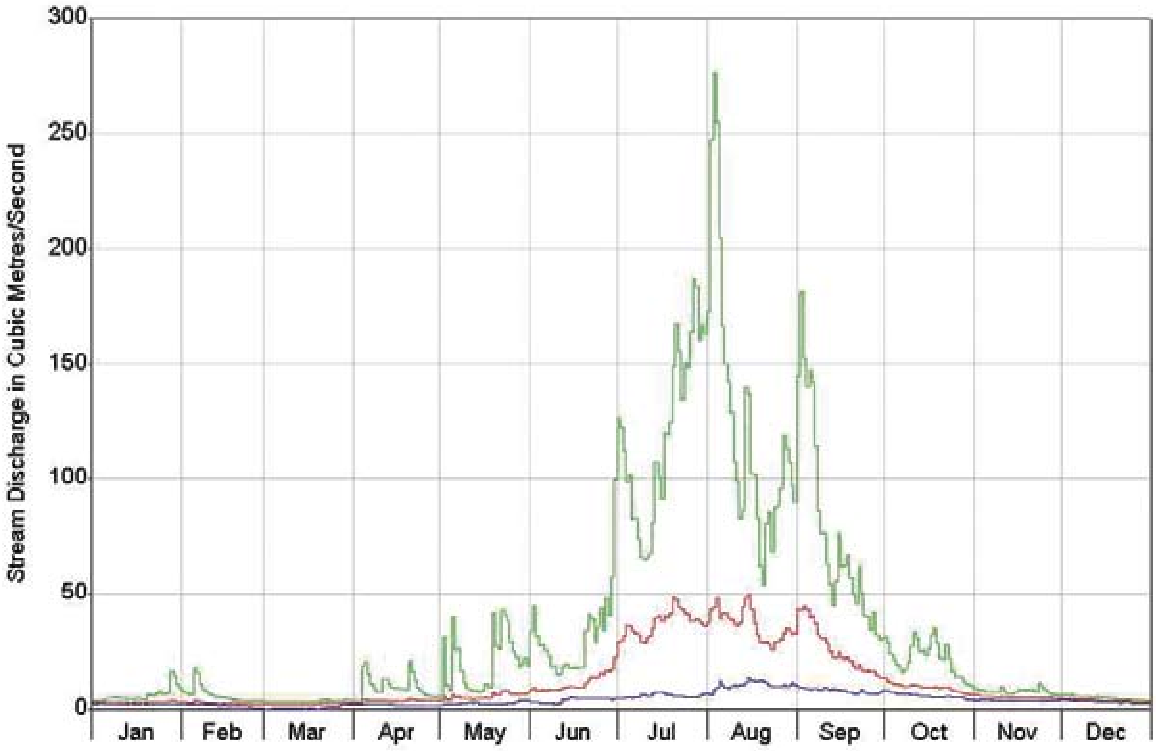


Figure 16a: Linear flow chart for the Murray River at the primary LMU site (limit of tidal flushing) Station 614065. Daily maximum (green), daily minimum (blue) and daily mean (red). Period of record 23/10/1991 to 09/06/2005 (courtesy Department of Water).

Figure 16b: Log flow chart for the Murray River at the primary LMU site (limit of tidal flushing) Station 614065. Daily maximum (green), daily minimum (blue) and daily mean (red). Period of record 23/10/1991 to 09/06/2005 (courtesy Department of Water).

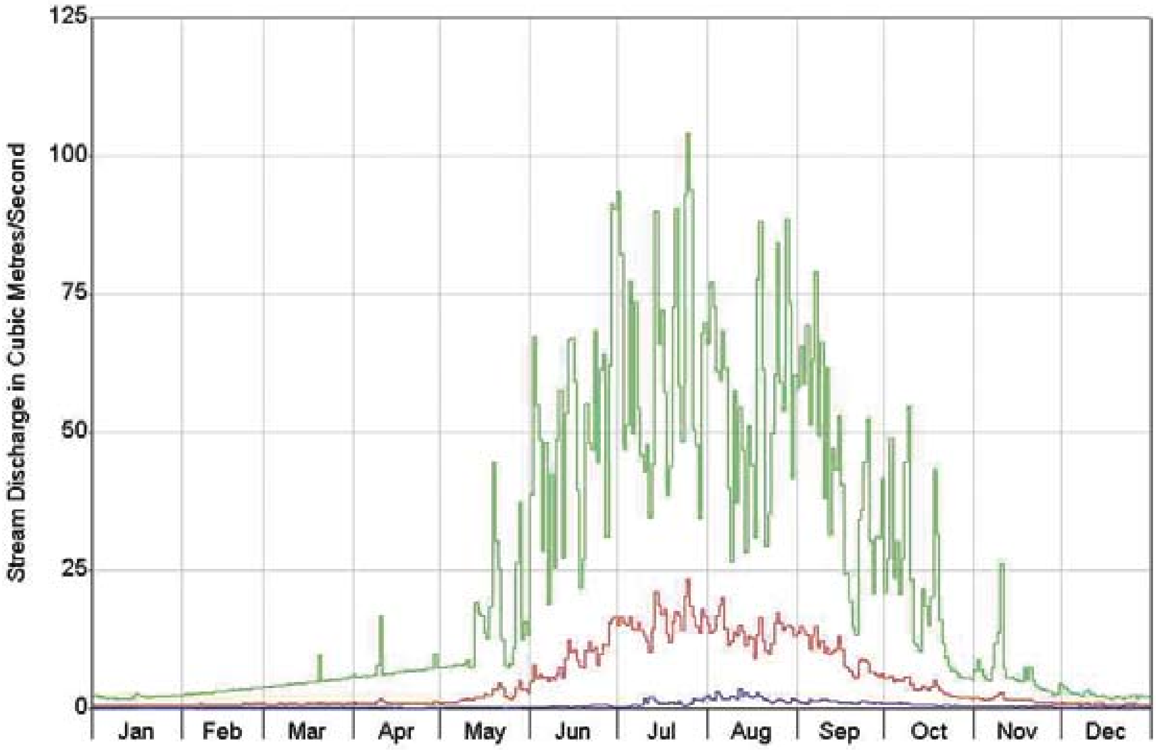


Figure 17a: Linear flow chart for the Harvey River at the primary LMU site (limit of tidal flushing) Station 613052. Daily maximum (green), daily minimum (blue) and daily mean (red). Period of record 04/05/1982 to 27/05/2005 (courtesy Department of Water).

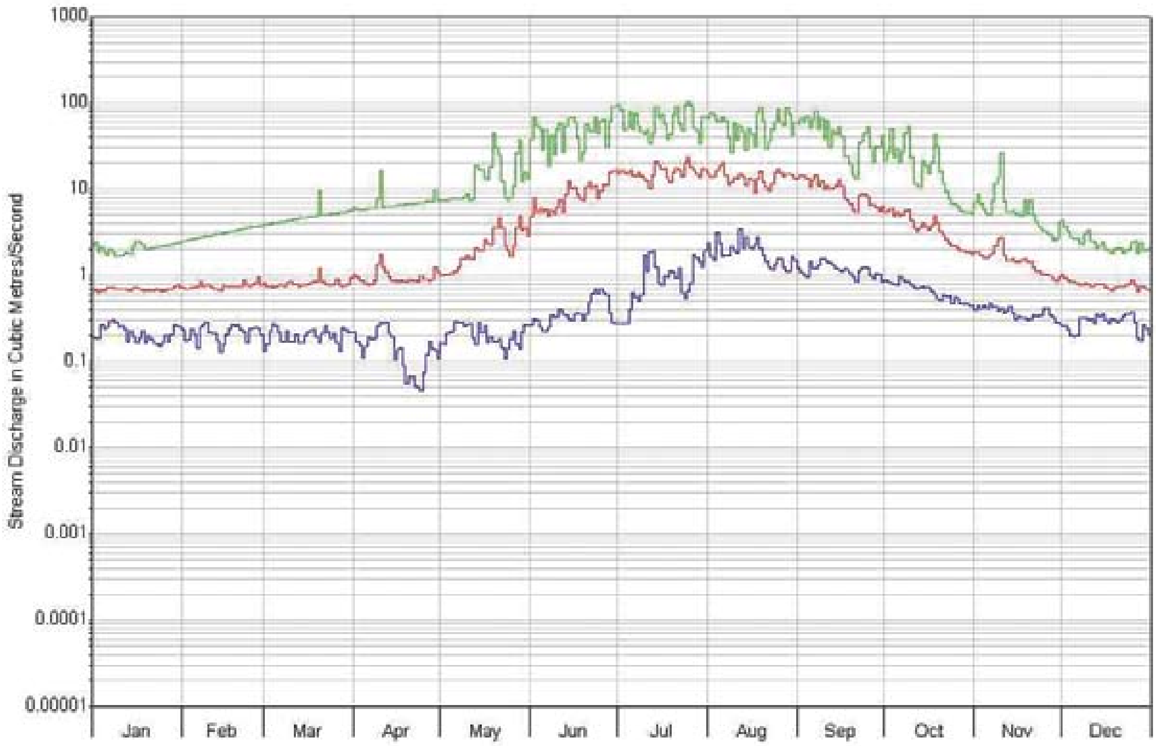


Figure 17b: Log flow chart for the Harvey River at the primary LMU site (limit of tidal flushing) Station 613052. Daily maximum (green), daily minimum (blue) and daily mean (red). Period of record 04/05/1982 to 27/05/2005 (courtesy Department of Water).

3.3 Methodology for setting river flow objectives

The seasonal and annual variability of flow is essential for maintaining healthy aquatic ecosystems. Flows provide habitat, linkages to wetlands, flushing of pollutants, organic matter and sediment, and triggers spawning cues for fish breeding and many other processes. River regulation (dams), abstraction and landuse change have altered the natural pattern of stream flow. These changes have resulted in reductions to quantity of in-stream water and occurrences of small floods as well as extreme changes in the seasonal availability of water (water held over winter and released in summer).

River flows in the Peel-Harvey region are generally seasonal and are much more driven by groundwater than is experienced on the eastern seaboard. Further research needs to be directed to investigations on how to protect high and low flows, maintain habitat inundation of wetlands and floodplains, seasonal flows, and minimise the effects of dams. The '3 day rule' which provides for agricultural properties abutting a drain in certain areas to not exceed 72 hours inundation needs to be reviewed. The Department of Water is working with the Water Corporation to clarify the interpretation and application of the rule and also develop alternative criteria for coastal drainage for consideration and consultation with the Economic Regulation Authority.

Actions over the next few years should focus on developing the knowledge base and decision support tools in consultation with catchment stakeholders to deliver effective flows, whilst minimising risks. Significant changes to the existing flow regime without detailed understanding and good predictive capacity would carry risks, such as upstream migration of the salt wedge and damage to tidal wetlands and benthic primary producers that are in equilibrium with the current flow regime. Actions to address environmental flows and set flow objectives should focus initially on filling key information gaps. Investigations should include hydrological and hydrographic assessments to determine flows sufficient to maintain the life cycle of target species and support viable populations, to determine in-stream assimilation and bio-availability of nutrients, develop decision support tools and assess capacity to deliver the various components of the flow regime. These resource intensive investigations should be undertaken within wider programs of water resource managers.

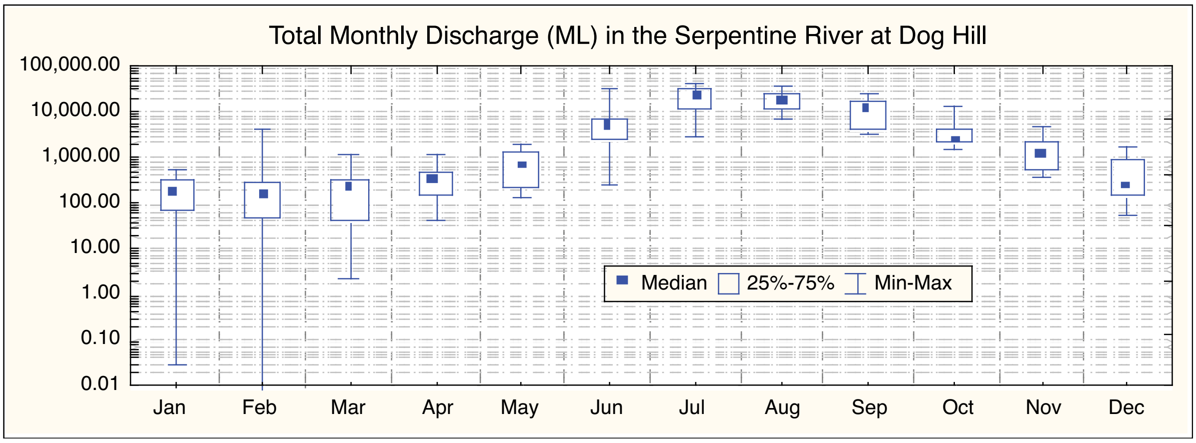
3.4 River flow objectives and flow regimes for estuarine segments

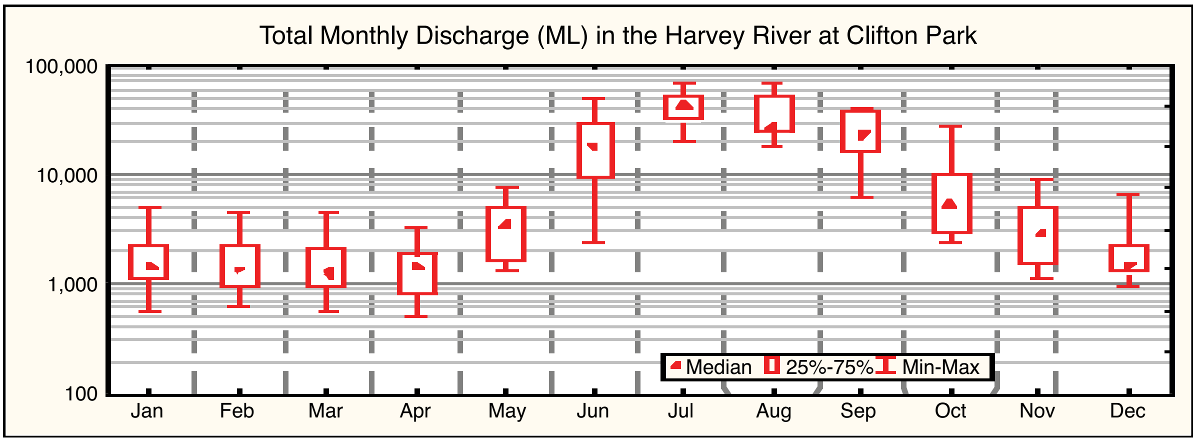
The river flow objective for tidal reaches of Serpentine, Murray and Harvey Rivers is to maintain current flow variability.

The Environmental Protection Authority considers that returning flows to their original state is both impractical and unattainable. With the current drying climate further flow reductions are inevitable.

The Environmental Protection Authority also considers that if studies show that a peak water flow event is needed for the health of the rivers then the Water Corporation should be required to release flows as permitted under their legislation. This is most likely to be triggered by an ecological need of the in-stream flora and fauna.

Finally, aspirational objectives within the catchment include protecting wetlands and floodplains (to mimic natural inundation and drying patterns) and minimising the effect of damming on water quality (to mimic natural frequency, duration and seasonal flow).





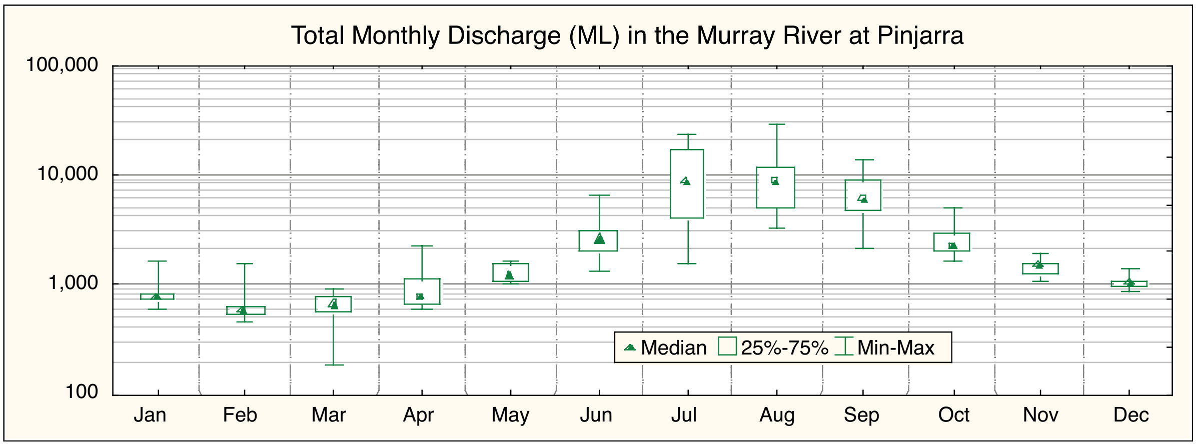


Figure 18: Total monthly discharge in mega litres (ML) into the three primary load measuring units in the Serpentine, Harvey and Murray Rivers from 1990-2004 (courtesy of Christian Zammit).

4. Management Measures and Control Actions

4.1 Management measures to meet phosphorus reductions

The results of the modelling (Zammit *et al*., 2006) and monitoring (Rose, 2003) projects of the CCI program have indicated that excessive nutrients are predominantly derived from diffuse sources. In 2003, nearly 70 percent of the phosphorus discharges came from agricultural activities. However, urban areas that account for only six percent of the landuse by area contribute more than 20 percent of the phosphorus inputs – and this figure is rising, with gardens, lawns and on-site sewerage systems (septic tanks) being the source of this pollution. Phosphorus load discharge from the three river systems is approximately 145 tonnes and a reduction of at least 48 percent is required to meet the 75 tonne target in an average year (Section 2.7), which the LASCAM modelling estimates could take up to 30 years to achieve.

Zammit *et al*. (2006) describes in detail the results of different scenarios of best management practices (BMPs) for each subcatchment of the Peel-Harvey Estuarine System. Neville (2005a) provides cost benefit analysis of Best Management Practices 4.1.1, 4.1.2 and 4.1.6.

The Plan aims to reduce phosphorus loading into the waterways through changes to agricultural and urban practices and landuse planning. The following thirteen Best Management Practices are recommended to achieve phosphorus load reductions that address current and future actions.

4.1.1 Rural Fertiliser Management

Much of the soil of the Peel-Harvey coastal catchment is sandy and has low fertility without fertilisers being applied. Fertilisers high in phosphorus have been applied in the past to maintain production. The highly water soluble 'Superphosphate' has been commonly used and so a high proportion (up to 80 percent) of phosphorus is lost to production with winter rain. Phosphorus is then leached through the coarse sandy soil or is transported in surface water flow via drains where it accumulates in the rivers and eventually the estuaries (Joint Government and Fertiliser Industry Working Party, 2007).

The issue is relevant not only for loss of phosphorus through sandy soils, but also in "heavy" or clayey soils through surface runoff or erosion (despite the soils having a high PRI) (Peel Development Commission, 2006a).

If for sandy soils, a slow release phosphate fertiliser is used, it will dissolve only slowly and is more likely to be taken up by plants or attached to the soil. The timing of fertiliser application is also important. Changing the type of fertiliser (highly soluble to low water soluble/slow release, on agricultural areas would reduce the overall load delivered to the estuary by 13 percent. Through modelling, the Serpentine catchment can be predicted to have an estimated 18 percent drop in phosphorus discharges after switching to a slow release fertiliser (see Table 23 Appendix B (Zammit *et al*., 2006).

The phosphorus loads to the estuary would be reduced by 11 percent when the rate of fertiliser applied is reduced by 20 percent combined with splitting the fertiliser application (ie. 30 percent at start of the season and 70 percent at the end of the season). The Harvey catchment showed the greatest reduction at 22 percent (see Table 26 Appendix B (Zammit *et al.,* 2006).

The Joint Government and Fertiliser Industry Working Party finalised the Fertiliser Action Plan in 2007 for environmentally sensitive areas of the South West of Western Australia, proposing to phase out highly water soluble phosphate fertilisers. A key strategy of the Fertiliser Action Plan is not only requiring the use of low water soluble phosphate fertiliser on low PRI soils (sandy) but also to address the better management of fertilisers on sandy and higher PRI soils (heavy) through extension programs.

Fertiliser manufacturers, through the Fertiliser Action Plan, have provided samples of low water soluble fertilisers for agricultural demonstrations. With the availability of low water soluble fertiliser and bauxite residue (see section 4.1.2) the Environmental Protection Authority believes phosphorus loads can be reduced into the estuary. However it is still unclear whether voluntary uptake alone of a changed fertiliser regime will be sufficient to achieve the water quality objective.

4.1.2 Rural Soil Amendment

The sandy soils of the catchment are low in the natural clays and loams that bind onto phosphorus and reduce the rate of leaching. It is possible to add amendments to the soil that help to hang on to the phosphorus.

Soil amendment materials such as bauxite residue applied to the land help to absorb phosphorus and are therefore very effective in reducing leaching into the Peel Inlet-Harvey Estuarine System.

Rivers (1999) states that the ability of the soil conditioner bauxite residue to hold onto phosphorus (the phosphorus retention index (PRI)) is hundreds times greater than naturally occurring soils. Naturally coastal sandy soils hold onto phosphorus so weakly that it is common for most of the fertiliser that is applied to the paddock to have leached over a metre down through the soil profile, away from the establishing annual clover, before the early, three leaf stage of development.

The application of bauxite residue dramatically reduces this leaching, resulting in greater total phosphorus in the soil surface and a greater amount of phosphorus available to plants (Rivers, 1999). Bauxite residue has been given some bad press, but there is no science to support it (Summers *et al.,* 2004).

The Environmental Protection Authority, in 1993, released Bulletin 714 (Environmental Protection Authority, 1993) reporting on the proposal by the Department of Agriculture to the widespread use of bauxite residue in the Peel-Harvey Coastal Plain Catchment. It concluded that the proposal for the use of bauxite residue in the catchment was environmentally acceptable subject to environmental conditions. These conditions were primarily concerned with the implementation of research and monitoring programmes to ensure that only positive environmental benefits resulted from the use of the red mud. These results were then to be used in a Code of Practice specifying the approved processes and protocols for red mud use.

The Meredith Drain catchment area is about 4300 hectares of which 2500 hectares is farmland. It is an agricultural drain discharging into the Harvey Estuary (Environmental Protection Authority, 2000).

Widespread use of bauxite residue started in 1994 with most fields being amended with 20 tonnes per hectare and showed reduced phosphorus concentrations by up to 70 percent in the drain's waters and increased pasture productivity by up to 25 percent (Rivers, 1999). A total of 30 000 tons of bauxite residue was applied. Prior to the development of the Code of Practice (Department of Agriculture, 2000) 80t/ha and up to 200t/ha were applied in small areas. Farmers have been getting good results by simply applying between five to 10 tonnes of bauxite residue per hectare re-applied between 5 to 10 years. Extensive laboratory, field and catchment-scale trials undertaken since 1993 have shown an immediate and marked ability of bauxite residues to reduce leaching of nutrients (Summers, *et al.*, 2004).

A deed of indemnity was signed by the State Government in 1999 to indemnify the manufacturer against any liability for its use as an agricultural soil amendment.

Consultation must now commence with stakeholders to overcome barriers to the use of soil amendments such as bauxite residue. Once barriers are overcome a four-year demonstration program can then commence. If it is shown that after the four year period uptake is low then a regulatory approach may be necessary.

4.1.3 Urban Fertiliser Management

As stated in section 4.1.1 many of the soils of the Peel-Harvey coastal catchment are sandy and have low fertility without fertilisers being applied. When too much fertiliser or highly water soluble fertiliser is applied phosphorus is leached through the coarse sandy soil to the estuary. Loss of phosphorus through runoff and sediment erosion for the heavy soils is an issue for urban users.

The use of a low water soluble domestic fertiliser at reduced rates for domestic gardens will reduce the load to the estuary.

The Fertiliser Action Plan states that, if implemented, it will make alternative low water soluble products available and in particular for urban domestic use a maximum of 1 percent of water soluble phosphorus for lawns and turf and 2.5 percent for general garden use (Joint Government and Fertiliser Industry Working Party, 2007). Regulation at point of sale locations may be the best way to achieve implementation of this Best Management Practice.

Designing gardens so that they contain plants that require less water or fertiliser will also assist. A targeted public education program aimed at promoting environmentally responsible gardening will complement the outcomes of the Fertiliser Action Plan.

4.1.4 Sewage management in existing homes, dwellings and Wastewater Treatment Plants

The poor health of the Murray River has been identified locally as a significant environmental concern and the impact of nutrients and bacteria leaching from conventional septic systems has been identified as a key-contributing factor. Unsewered areas seem to have a big impact (17 percent of winter load) and septics have been identified as one of the primary sources of phosphorus of urban phosphorus export.

Zammit *et al.,* (2006) demonstrated that full connection to the infill sewerage should bring a reduction of 22 percent of the total loading to the estuary. The Murray catchment showed the greatest predicted reduction of 27 percent.

For the Serpentine catchment connection to the infill sewerage would be sufficient to go halfway towards meeting the load reduction targets for two of the reporting subcatchments.

Wastewater Treatment Plants (WWTP) treat sewage and other wastewaters from surrounding homes and industries. If treated wastewater is discharged to the environment loaded with high amounts of phosphorus, groundwater or nearby rivers will be contaminated. In some cases the groundwater below WWTPs of the Peel region flow to the Peel Inlet, the river and the ocean.

The reuse of the wastewater, for example by industry or the introduction of new technologies to reduce the phosphorus concentration, will reduce or eliminate the phosphorus entering the environment and eventually the estuary.

Expediting the infill program for connection and ensuring all current homes are connected to a reticulated sewerage system where available or septic tanks replaced with alternative onsite systems will have a significant positive impact on the health of the rivers and estuary. Requiring, through licensing, that all Peel region WWTPs achieve progressively a zero discharge of phosphorus to the environment within five years will also greatly assist the Plan meet its objectives.

4.1.5 Zero discharge for licensed agricultural premises

Phosphorus discharges from licensed agricultural premises such as turf farms or intensive feedlots, can have a significant impact on the water quality in their local catchment and subsequently the estuarine system.

Eliminating phosphorus can be achieved by processing effluent for compost or re-using the animal effluent as fertiliser over the dry summer months.

Two subcatchments in the Harvey catchment would meet the load reduction target when the previous BMP (full connection to infill sewerage) and this BMP (zero discharge for licensed agricultural premises) are combined.

Reducing the export from the licensed agricultural premises of phosphorus to zero in a subcatchment in the Serpentine catchment (Gull Road) would account for half of its required load reduction (Zammit *et al.,* 2006).

Requiring, through licensing, that all licensed agricultural premises achieve progressively a zero discharge of phosphorus to the environment within five years will, as shown above, have a significant impact on the health of the waterways.

4.1.6 Improve other agricultural practices to reduce phosphorus discharges

a) Perennial pastures

Perennial pastures have deep-rooted systems, stay green later in spring and therefore limit erosion. They have the ability to intercept water and nutrients that have leached below the shallow root system of annual pastures and provide opportunities for immediate water and nutrient uptake when there is un-seasonal weather. Perennial pastures can be significantly more productive than annual systems and use larger amounts of water, which reduces waterlogging and salinity problems (Neville, 2005a) (Neville, 2005b).

Replacing annual pastures with perennial pastures can help in the uptake of phosphorus and other nutrients. Perennial pastures include kikuyu, paspalum, couch, rhodes and veldt grass.

Establishing an extension, demonstration and incentive program to promote the uptake of perennial pastures for suitable land uses will assist in adoption of this measure.

b) Effluent management

Animal effluents generally contain high concentrations of nutrients and bacteria and therefore respresent a significant risk to water quality if not handled correctly (URS, 2005).

When handled correctly, animal effluents are an excellent nutrient source, and should be regarded as a resource and recycled on farm or stored appropriately for use off site (Neville, 2005b).

Requiring effective effluent management practices to achieve progressively zero discharge of phosphorus to the environment within five years with effective auditing and enforcement will, as stated by Zammit *et al.* (2006), significantly reduce the total load of phosphorus to the Peel-Harvey estuary.

c) Better managing irrigation systems

Some of the most productive agricultural landuses are irrigated farming systems. In Peel-Harvey these include irrigated annual and perennial horticulture as well as significant areas of irrigated pasture and fodder for dairy farming. Irrigated farming systems are generally more intensive than dryland systems and are therefore subject to higher nutrient levels. Water-borne nutrient export from agricultural properties is a major cause for concern in the Peel-Harvey catchment (Neville, 2005b).

Shifting to a more efficient irrigation regime can reduce nutrient loss and there is the potential to stop summer phosphorus losses and also improve losses in winter (Neville, 2005b).

4.1.7 Reafforestation of agricultural lands

Modelling results show that a well-targeted reafforestation program could improve the health of the estuary with big phosphorus reductions to be made in the upper Serpentine and small areas of the Harvey (Zammit *et al*., 2006).

Reafforestation can involve the utilisation of agricultural land solely for timber production, broadly referred to as farm forestry, or combining with agriculture to produce agroforestry.

Identification of strategic areas for reafforestation of agricultural lands and funding incentives for this will greatly improve the uptake of this measure.

4.1.8 All new development to be connected to reticulated sewerage or Alternative Treatment Unit

Septic tank systems are one of the primary and significant sources of phosphorus in urban and peri-urban areas.

All homes and properties in new urban developments should continue to be connected to reticulated sewerage. All new homes in new non-urban development should also be connected to reticulated sewerage or an acceptable alternative treatment unit (ATU).

4.1.9 Urban Soil Amendment

Many areas in the coastal catchment of the Peel-Harvey have sandy soils (low PRI) with low ability to retain moisture, nutrients and trace elements. Urban development may diminish the capacity of soil to support plant growth, through processes such as the removal of topsoil and soil compaction.

Soil amendment or remediation is a technique used to create fertile topsoil by increasing the soils' ability to retain moisture and nutrients before they infiltrate through to the groundwater. Soil remediation involves adding an agent to the soil to improve its structure, water holding capacity and nutrient recycling capacity capacity (ie high phosphorus binding).

Potential amendment/remediation agents include bauxite residue, compost, organic rich soils, loam soils, natural clay and crushed limestone. Chapter 7 of the Stormwater Management Manual for Western Australia (Department of Environment, 2004b) also discusses suitable amendment agents.

After further research into the effectiveness, rates and handling of soil amendments in urban situations is carried out, then existing policies should be amended to reflect the requirement for all new developments to remediate soil in accordance with the Water Sensitive Urban Design (WSUD) Technical Guidelines.

4.1.10 Incorporating measures into Local Planning Policies, strategies, planning conditions and State policies

A key aspect of the successful implementation of this Plan will be the adoption by local and state government of the best management practices/ measures listed in this Plan.

Decision-making authorities need to take a lead role in implementing best management practices. Incorporating these into local planning policies, strategies and planning conditions will ensure BMP implementation. Government and community need to work cooperatively towards reaching the targets of the Plan in reducing phosphorus to the estuary.

4.1.11 Water Sensitive Urban Design

Most areas proposed for future development within the Peel region have significant water resource management issues. There is an identified need for an increased focus on total water cycle management and WSUD to improve the management of stormwater, particularly nutrients, and increase the efficiency of the use of water (Peel Development Commission, 2006a).

Key aims are to reduce nutrient runoff and peak flows from suburbs to protect downstream waterways and wetlands, and groundwater. It can involve the use of features that incorporate stormwater into parks and public open space to retain first flush events onsite. In many cases, such features can be designed as part of streetscapes, bush or park landscaping and add to the amenity of a neighbourhood.

The technical guidelines and the Local Planning Policy prepared by the Peel Development Commission were recently completed in consultation with local government officers for planning and future development proposals.

This measure requires all new development approvals and strategic landuse planning to incorporate water sensitive urban design according to local planning policies and the Peel-Harvey Coastal Catchment Water Sensitive Urban Design Technical Guidelines (Appendix E) (Peel Development Commission, 2006b) (Peel Development Commission, 2006a).

4.1.12 Drainage Reform

This measure targets the coastal catchment drainage system of the Peel region, ie the catchments' waterways that have been constructed or significantly modified from natural channels. There are 1015 kilometres of waterways that make up the Mundijong, Waroona and Harvey District Drainage Districts (Del Marco, 2007).

Management of the drains to reduce in-channel sediment movement and increase vegetation will provide significant reductions in phosphorus entering the estuary. Del Marco (2007) states that of the 870 tonnes of phosphorus that enters the drains on an annual basis, 140 make it to the estuary (ie. 730 tonnes is retained in the sediment and vegetation).

Implementation of this measure is recommended through the delivery of the Peel Harvey Catchment Council's Drainage Reform Plan (Del Marco, 2007) and the Department of Water's Coastal Drainage Discussion Paper (Department of Water, 2008). These plans set out BMPs for drainage system management.

The ultimate goal of drainage management in the Peel region is to have on-ground management of waterway corridors that meets water conveyance and sediment management objectives (Del Marco, 2007).

4.1.13 Wetland and Waterway protection and revegetation

Wetland and waterway protection and revegetation is an additional measure from the draft Plan.

Restoring and preserving the natural functions of wetlands, rivers and other waterways is a high priority for all future development. This measure refers to all waterways and wetlands not covered by the previous 12 measures.

Wetlands may greatly influence the water quality of rivers and streams by removing pollutants such as sediments, nutrients, organic and inorganic matter and some pathogens. Runoff and drainage water which pass through such wetlands are essentially 'filtered'. This improvement in water quality comes from the wetland's ability to retain nutrients such as nitrogen and phosphorus, to intercept other pollutants, and to trap sediment and reduce suspended solids (Environmental Protection Authority, 2004b).

However, the capacity of a wetland to trap pollutants is not infinite. This natural capacity is reduced by the need to ensure better water quality is maintained in the wetland to protect the environmental values and beneficial uses within the wetland itself (Environmental Protection Authority, 2004b).

The maintenance and protection of waterway buffers and their riparian vegetation can be achieved through fencing of waterways for stock exclusion and repairing and revegetating where necessary to increase shade, trap nutrients and sediment and stabilise stream banks.

Nutrient enrichment of rivers stimulates primary production - sometimes aquatic plant growth, but more commonly excessive algal growth. This is especially the case when nutrient enrichment is combined with lack of shade (e.g. through loss of riparian vegetation), as high light intensity and warmer water also stimulate production of algae etc (Lovett, *et al.,* 2007).

Neville (2005a) states that combining varying levels of riparian management (fencing, revegetation etc) over different stream sizes with varying levels of adoption (35%-100%) could bring about a 12% reduction of the total phosphorus export to the estuary.

This measure recommends identifying and protecting the remaining wetlands and natural waterways including fencing and revegetating where necessary.

Table 7 sets out the Environmental Protection Authority's recommended actions and Table 8 sets out the implementation measures of these actions.

4.2 River flow objectives

Until these objectives are properly defined, water resource managers will focus on maintaining the existing flow regimes in the Serpentine, Murray and Harvey catchments. Scientific investigations are required into altered nutrient and sediment loads and transport, changes in channel morphology, floodplains and wetlands, and impacts on riparian and aquatic habitats and fauna.

4.3 Minimising the impacts of future urban growth on water quality and environmental flow

Catchment-based modelling (Zammit *et al*., 2005) was used to estimate the potential impacts of landuse changes under the Peel and Metropolitan Region Schemes (PRS and MRS). The main landuse changes include new urban areas between Mandurah and Pinjarra as well as the Northern Serpentine Catchment, where small landholdings can mean denser stocking rates of horses and more intensive fertiliser applications. The impacts were found to be dramatic, with an overall increase in 20 percent phosphorus export to the estuary but significant localised increases in areas next to the estuary.

The model predicts the load and concentration increase is caused by increased fertiliser application and/or reduction of flow. Reduction of flow also compounds problems with high concentrations. As expected, areas under development pressures show the largest impacts. The load from the Murray increases tenfold, while concentrations in areas west of the Harvey Estuary double or triple in most cases.

Table 7: Recommended Actions of Best Management Practices for the Peel-Harvey Water Quality Improvement Plan

Best Management Practices (BMP)		Recommended on the ground action	Technical References for further information on implementing the BMP
1	Rural fertiliser management	• Use low water soluble/slow release fertiliser applied to sandy textured soils, applied at minimum of 25 percent reduction from current use. • Conduct regular soil and/or tissue testing and dose to required needs. • Apply fertiliser at the break of season when there is some green cover, preferably in split applications (ie. 30 percent at start of the season and 70 percent at the end of the season). • Application of fertilisers in spring when nutrient requirements are greatest. • Maintain buffer between fertiliser application and watercourses. • Accurately calibrate your fertiliser spreaders. • Use soil testing to make fertiliser decision and if possible use nutrient budgeting to assist. • Apply RedCoat Super (bauxite residue coated granules of super, effective for two years (currently not on market) on sandy soils (between 6-45 percent P reduction).	(Neville, 2005b) (Department of Agriculture and Food, 2006) (Joint Government and Fertiliser Industry Working Party, 2007) (Swan River Trust, 2006)
2	Rural soil amendment	• Applied to soil surface without mixing in at 10 tonnes per hectare to sandy textured soils in agricultural areas, applied every five years on sandy textured soils with PRI (Phosphorus Retention Index) <15 with an upper rate of 25t/ha for current agricultural practices. Application rates will vary according to intended landuse, soil type, soil pH and soil organic carbon level. • Ensure 10 metre buffer of untreated ground between areas of red mud and remnant vegetation. • Not to be applied to wetlands or major drainage structures. • Care must be taken to minimise dust during all stages of distribution.	(Neville, 2005b) (Rivers, 1999) (Environmental Protection Authority, 2000) (Environmental Protection Authority, 1993) Ministerial Statement 339 - 4 February 1994
3	Urban fertiliser management	• Use low water soluble fertiliser applied to sandy textured soils, applied sparingly to gardens and turf. • Minimise lawn areas or plant an alternative lawn. • Fertilise only when symptoms of nutrient deficiency occur eg. yellowing. • If fertiliser is needed use a complete lawn fertiliser containing a nitrogen, phosphorus and potassium. • Establish public education program on environmentally responsible gardening, including the use of native plants, reduced lawn, low water use, mulching etc.	www.sercul.org.au

Best Management Practices (BMP)		Recommended on the ground action	Technical References for further information on implementing the BMP
4	Sewage management in existing homes, dwellings and Wastewater Treatment Plants	• Required within two years of sewer passing the property for existing houses.	
5	Zero discharge for licensed agricultural premises	• Staged approach to zero offsite discharge (currently must meet 0.1 mg/L), to address set-up costs for licences.	(Department of Environment, 2005)
6.	Other agricultural practices a. Perennial pastures b. Effluent management c. Irrigation management	• Replacing annual with perennial pastures in grazing areas. – apply kikuyu and paspalum to wet depressions and drainage line; – couch suited to medium to higher land; – rhodes and veldt grasses on dry sands; Follow Department of Agriculture and Food establishment recommendations. Ongoing returns for this BMP are expected to be $60 per hectare.	(Neville, 2005a) (Neville, 2005b) (URS, 2005)
		• Effective effluent management can include a range of options, such as collection, conveyance, treatment, storage and reuse of solid and liquid wastes to achieve zero offsite discharge.	(Department of Agriculture and Food, 2006) (Neville, 2005b) (Department of Environment, 2005)
		• Better managing irrigation systems – Irrigation system design including whole farm planning, using a qualified irrigation system designer and applying on better soils to retain nutrients; – Efficient irrigation systems including water use efficiency and minimising run-off; – Irrigation scheduling including monitoring soil moisture to help determine crop requirements; and – presence of a recycling system. Installation of improved irrigations systems can sometimes be a costly exercise, however, retro-fitting of specific management methods such as automatic gates and values can be cheaper.	(Neville, 2005a) (Department of Agriculture and Food, 2006) (Neville, 2005b) (URS, 2005)

Best Management Practices (BMP)		Recommended on the ground action	Technical References for further information on implementing the BMP
7	Reafforestation of agricultural lands	• Strategic reafforestation of agricultural land to produce: – farm forestry; or – agroforestry. Can be applied for example as shelter belts and alley farming.	Treenotes Series (Department of Agriculture and Food) (Zammit *et al*., 2006) (Peel Development Commission, 2006a)
8	All new development to be connected to reticulated sewerage or an Alternative Treatment Unit (ATU)	• Connection to reticulated sewerage to apply to all new urban developments. • Connection to reticulated sewerage or ATU to apply to non-urban development. • Build into approvals conditions by decision-making authorities for all new subdivisions and new homes to be connected to reticulated sewerage.	(Government of Western Australia, 1992b)
9	Urban soil amendment	• All new urban developments in areas with sandy soils to undergo soil remediation/amendment at the estate scale. • At the lot scale blending or applying a layer of higher PRI soil 0-50cm beneath the finished ground level can provide increased phosphorus retention. • Soil amendment materials such as bauxite residue may be used. • Remediate soil in accordance with Peel-Harvey Coastal Catchment Water Sensitive Urban Design Technical Guidelines. • Take care to maintain soil permeability.	(Peel Development Commission, 2006b) (Peel Development Commission, 2006a) (Department of Environment, 2004b)
10	Incorporating measures into local planning policies, strategies, planning conditions and State policies	• Decision-making authorities to take lead role in incorporating best management practices including water sensitive urban design principles, criteria and outcomes in its strategic landuse planning, policies, structure plans and subdivision conditions.	(Peel Development Commission, 2006a) (Peel Development Commission, 2006b)
11	Water Sensitive Urban Design (WSUD)	• Compliance with Environmental Quality Criteria in local planning policy. • Compliance with stormwater management policies. • Application of water sensitive urban design treatment trains. • Preparation of water management strategies. • Soil amendment. • Total phosphorus and total nitrogen import and export criteria. • Minimum percentage area of deep-rooted perennial vegetation. • Building and landscaping covenants. • Construction and building site management.	(Peel Development Commission, 2006a) (Peel Development Commission, 2006b) (Department of Environment, 2004b)

	Best Management Practices (BMP)	Recommended on the ground action	Technical References for further information on implementing the BMP
12	Drainage reform	• Modification to drainage management practices to reduce in-channel sediment movement as opportunities arise (ie. revegetation and fencing for stock exclusion). • Drainage should be managed as a water resource as part of the total water cycle with the dual objectives of optimising stormwater runoff and reducing nutrient flows into the rivers and streams.	(Peel Development Commission, 2006a) (Department of Water, 2008) (Department of Environment, 2004b) (Environmental Protection Authority, 2004a) (Del Marco, 2007)
13	Wetland and waterway protection and revegetation	• Fencing waterways and wetlands for stock exclusion. • Revegetation of degraded areas with local native vegetation. • Repairing riparian vegetation with the outcome to increase shade, trap nutrients and sediment and stabilise streambanks. • Offstream watering and stream crossings.	(Pond, 2005) (West Australian Planning Commission, 2006) (Water and Rivers Commission, 1999) (Water and Rivers Commission, 2002) (Atyeo and Thackway, 2008) (Peel Development Commission, 2006a) (Lovett *et al.,* 2007) (URS, 2007)

A major objective of the Plan is to find the best mix of practical and reasonable actions, to be applied across the Peel-Harvey Catchment, to meet the target of less than 75 tonnes of total phosphorus load in an average year. The proposed actions are a mix of voluntary and regulatory measures. The mix selected may possibly change over time if, for instance, either landuses change following further development approvals or if longer term monitoring reveals that water quality is not improving. Appropriateness of a measure is also dependant on soil type.

The Environmental Protection Authority has set a longer term target of 75 tonnes to be monitored over 10 years after full implementation and the management actions adapted as appropriate. It has reasonable confidence, based on the LASCAM and SSPRED modelling, that if appropriate fertiliser and soils amendments are commercially available and the highest adoption rates are achieved — with environmental planning controls placed on new developments, provision of incentives where public benefits accrue on private lands, and a staged approach to regulation if warranted — this target can be attained in 30 years after full implementation.

However due to run down in soil stores and in stream and estuarine sediments (the latter which have not been modelled to date), it may take some further years for the estuarine waters to be visibly cleaner and healthier.

Even at 100 percent adoption of these management actions, a rate considered by catchment partners to be unrealistic, the LASCAM modelling estimated that not all reporting catchments would meet their required P reductions, notably in the parts of the Serpentine and Harvey catchments. For these reporting catchments, the following actions are recommended at higher application rates (based on Tables 26-38 in Zammit *et al.,* 2006):

- strategic parts of Harvey Irrigation District: 10-30 percent reafforestation;
- Some Harvey Coastal Catchments: infill connection/replacement of septics, soil amendment, 50 percent agricultural fertilizer reduction and low water soluble phosphorus fertiliser (higher than the modelled allocation rates) , and dairy effluent management; and
- parts of Serpentine: infill connection/replacement of septics, soil amendment on sandy textured soils, 50 percent agricultural fertiliser reduction and low water soluble phosphorus fertiliser, some reafforestation.

Measures which should be implemented through primarily mandatory measures are soil amendment for new urban areas where soils with a low Phosphorus Retention Index (<15) exist; full connection to reticulated sewerage within two years of provision; implementation of water sensitive urban design for nutrient retention in new urban areas; and use of low water soluble fertiliser on Public Open Space.

Particularly for diffuse source contributors, this Plan notes further enabling measures that will be required to encourage wide adoption of management actions across the Peel-Harvey Catchment. These include the availability of a viable low water soluble phosphorus fertiliser and soil amendment for low PRI soils; an incentives package, and a long term extension program provided to local government officers and land managers, by State agencies.

Table 8: Recommended Actions for implementation of the Plan.

	Best Management Practice (BMP)	EPA Recommended Action
1	Rural fertiliser management	• Implement the Fertiliser Action Plan to phase out the use of the high water soluble phosphate fertilisers. • Ensure a management entity has responsibility to oversee the implementation of the Fertiliser Action Plan. • Establish a four-year demonstration program for low water soluble phosphorus fertilisers and extension program for best practice farm fertiliser management. Extension program for better fertiliser management will extend to heavy soils as well as sandy soils. • Establish an exception and accreditation scheme.
2	Rural soil amendment	• Engage with stakeholders on overcoming barriers to the use of soil amendments such as bauxite residue. • Amend EP Act licensing to allow the use of waste product soil amendments. • Establish a four-year extension program on the use of soil amendments covering the specifics of soil type, soil testing etc in rural areas to encourage uptake of soil amendments on farms. • Establish incentive packages for rural landowners. • If, after the four-year extension program, uptake is considered low, consider appropriate regulatory measures.
3	Urban fertiliser management	• Implement the Fertiliser Action Plan's recommendation to phase out high water soluble phosphate fertiliser and to make bagged fertiliser for lawn and garden only available to the maximum of 1 percent and 2.5 percent water soluble phosphorus respectively. • Develop a targeted public education program to promote environmentally responsible gardening, including the use of fertilisers, native plants, reduced lawn, low water use, mulching etc. (eg Peel Urban Sustainability Initiative).
4	Sewage management in existing homes, dwellings and Wastewater Treatment Plants	• Enforce full connection of all existing homes to reticulated sewerage within two years of sewerage system passing the property. • Expedite current infill program in the Peel coastal catchment, in particular sensitive areas adjacent to waterways and wetlands. • Bring forward plans to infill Peel coastal catchment suburbs outside of current program. • Establish incentive and public education program designed to encourage the upgrading of septic systems to nutrient reduction technologies or Alternative Treatment Units (ATUs) where reticulated sewerage is not available. • Through licensing, Wastewater Treatment Plants in the Peel region must achieve progressively zero discharge of phosphorus to the environment within five years.

	Best Management Practice (BMP)	EPA Recommended Action
5	Zero discharge for licensed agricultural premises	• Through licensing, practices of all licensed agricultural premises in the Peel region to achieve progressively zero discharge of phosphorus to the environment within five years.
6a	Perennial pastures	• Establish a three year targeted extension and demonstration program to promote the replacement of annual pastures with perennial pastures. • Establish an incentive program.
6b	Effluent management	• Require effective effluent management practices to achieve progressively zero discharge of phosphorus to the environment within five years. • Audit and enforce licence conditions in regard to effluent management in dairies and piggeries.
6c	Irrigation management	• Initiate a scoping and feasibility study to reuse effluent in irrigation practices. • Develop an extension program for improving water quality outcomes in sandy soils and to control sediment runoff in heavy soils. • Encourage the irrigation industry to engage in the Irrigation Modernisation Planning Assistance Program to increase the efficiency of their irrigation distribution system.
7	Reafforestation of agricultural lands	• Identify strategic areas for reafforestation of agricultural land and develop subsequent financial incentives for revegetation projects.
8	All new development to be connected to reticulated sewerage or ATU	• All new homes in new urban development to continue current mandatory practice that they must be connected to reticulated sewerage. • All new homes in new non-urban development to be connected to reticulated sewerage or ATU. • Amend where necessary and continue to implement and more actively enforce State Planning Policy (SPP) for the Peel-Harvey.
9	Urban soil amendment	• Engage a university, perhaps through doctorate studies, to research the effectiveness, application rate and methodology of handling soil amendments in urban development. • All new development to remediate soil in accordance with Peel-Harvey Coastal Catchment Water Sensitive Urban Design Technical Guidelines. • Regulate, either through strengthening existing policy (EPP or SPP) or new regulations, to require the use of soil amendments in urban development approvals.
10	Incorporating measures into local planning policies, strategies, planning conditions and State policies	• Local government to incorporate the relevant recommended actions and measures into local planning policies, strategies and planning conditions. • Other decision-making authorities also to take a lead role in incorporating best management practices including water sensitive urban design principles, criteria and outcomes in its strategic landuse planning, policies, structure plans and subdivision conditions in accordance with the State Planning Policy (Peel-Harvey) (SPP) and the Environmental Protection (Peel-Harvey) Policy (EPP). • Government to amend, where necessary, the SPP and EPP to reflect the Plan's recommendations.

	Best Management Practice (BMP)	EPA Recommended Action
11	Water Sensitive Urban Design (WSUD)	• All new development approvals to incorporate WSUD. • Strategic landuse planning to incorporate WSUD. • Develop capacity building program (eg New Waterways Program). • Develop performance based codes for new urban drainage. • All local governments to adopt WSUD Technical Guidelines and Local Planning Policy.
12	Drainage reform	• Implement the recommendations of the Drainage Reform Plan, Peel-Harvey Coastal Catchment and the Department of Water's Coastal Drainage Discussion Paper. Some examples of priority recommendations include: o Survey the capacity of the gazetted drainage system and critical waterway reaches. o Commence trial preparation of at least one Sub-catchment Drainage Management Plan. o Establish Healthy Peel Drains for Clean Water Scheme – including incentive program for drainage BMPs. o Implement Urban Stormwater Retrofitting project. o Develop agreed processes and guidelines for reviewing and revising existing rural drainage design manuals and operating and maintenance practices. o Assess and collate information and data for coastal (rural) drainage BMP techniques. o Develop and trial a drainage management framework for coastal drainage systems.
13	Wetland and waterway protection and revegetation (new measure)	• Identify and protect remaining wetlands and natural waterways and revegetate degraded areas. • Establish or continue existing (eg Healthy Wetland Habitats) incentive programs for fencing for stock exclusion and revegetating degraded waterways and wetlands on private and public land.
Other recommendations throughout the Plan		
Costings and timelines (s6.1)		• Western Australian government agencies to agree on indicative costings and timelines to implement the recommended measures and actions of this Plan within six months of publication of this final Plan.
Modelling strategy (S5.1)		• Implement a modeling strategy through the continuation of the Decision Support System model.
Monitoring, reporting and review (S5.2, 5.3, 5.4, 6.1 & 6.2)		• Establish an effective governance framework including the establishment of a management body to oversee implementation of the Plan's recommendations. • Establish monitoring and reporting to the community (eg report cards) of the Plan's implementation. • Implement the recommended Water Quality Monitoring Strategy in the catchment and estuary. • Implement a review of the Plan within ten years, commencing year eight.
Catchment management plan (S6.1)		• Deliver the 1989 Ministerial condition by developing a comprehensive catchment management plan.
Community education for the Plan's implementation (S6.1)		• Establish educational publications and awareness training on the Plan's implementation.

Climate change and growth are accounted for as all new developments will be subject to more stringent conditions relating to soil amendment, fertiliser type and timing, connection to sewerage or alternative on-site systems, and point source licences. The Environmental Protection Authority therefore considers that 1) there should be no need to make further adjustments to proposed best management practices and control actions, and 2) the total maximum phosphorus loads can be attained. However, if in the event that further adjustments are required then the adaptive management strategy sets out procedures to be followed.

The Plan recommends control actions relating to use of soil amendment and fertiliser type and timing, to be applied at the approvals and referrals stage and consistent with the guidelines set out in the Local Planning Policy for the Peel Harvey Estuarine System (Peel Development Commission, 2006b).

A planning framework proposed for urban catchment management has been provided in Appendix E (Peel Development Commission, 2006b). Key nutrient reduction activities for urban landscapes recommended in the proposed planning framework are to:

- retain and restore existing elements of the natural drainage system, including waterway, wetland and groundwater features and processes, and integrate these elements into the urban landscape, possibly through a multiple use corridor;
- minimise pollutant inputs contributed via runoff and leaching through implementation of appropriate nonstructural source controls (e.g. urban design, regulation and organisation, maintenance and behavioural techniques) and structural controls;
- infiltrate rainfall as high in the catchment as possible to minimise runoff - use multiple low cost ‘in-system’ management measures to reduce runoff volumes and peak flows (e.g. maximise infiltration from leaky pipes and stormwater pits installed above pollutant retentive material); and
- maximise water use efficiency, reduce potable water demand and maximise the re-use of harvested water from impermeable surfaces.

All development proposals should aim to:

- maintain at least 20 percent of the subject land with deep rooted perennial vegetation;
- develop building and landscape covenants to include design criteria such as soakwells, water tanks with plumbing to toilets and laundries, runoff from impermeable surfaces to lawns and gardens, plant drought tolerant and low-nutrient demanding landscapes within the front setback area, and amend soil beneath lawn and landscaped areas to maximise phosphorus capture; and
- connect to deep sewerage where available or to nutrient stripped on-site systems where not (Peel Development Commission, 2006b).

4.4 Use of market-based instruments

Options for resourcing improvements to water quality favour market-based approaches as they are seen as efficient and effective mechanisms for raising revenue and achieving complex environmental objectives. Possible schemes include tradeable permits, NRM auctions and offsets.

A trading scheme requires one party to be able to address the pollution reduction more cost-effectively than another party. Within the Peel-Harvey Catchment point sources contribute less than five percent of phosphorus exports, however opportunities may still exist for trades between urban and agricultural sources as a means to jointly involve urban and rural communities in addressing nutrient issues in partnership.

The Bush Tender scheme operating in Victoria is an example where landholders bid for contracts to manage remnant vegetation. A similar scheme could also be used to target stream bank and biodiversity management.

Offset schemes allow regulated sources to achieve pollution abatement through sponsoring alternative actions for abatement from other, often diffuse sources. This could be achieved by investing in revegetation or rehabilitation of waterways, wetlands and drains. This measure has merit for upstream actions in the Peel–Harvey Catchment that may offset impacts arising from intensification of landuses in close proximity to sensitive receiving waters.

A review of implementation measures that influence uptake of nutrient reducing actions was based on a farmer attitudinal survey and bio-economic modelling undertaken for the Department of Agriculture and Food in the Peel-Harvey Catchment (URS, 2005). The report recommended investment strategies that can deliver nutrient reductions at least cost and deliver maximum benefits to the landholder. This will require a high level of direct and up-front government support to match the public to private benefit mix. It could include a product stewardship scheme with manufacturers and importers such as for fertiliser to ensure those enterprises hold responsibility for appropriate use of their products. This might be developed to promote the future sale and use of low water soluble fertilisers in susceptible areas through ongoing education, skills and group development.

4.5 Use of economic incentives

Education based approaches to encourage voluntary adoption of best management practices in the Peel-Harvey Catchment have not been successful as a pollution control and additional mechanisms are needed. A farm survey undertaken as part of the Peel-Harvey CCI program suggested a market of relatively 'traditional' landholders who are comfortable with what they are doing (Lavell *et al.,* 2004). Many landholders are small operators where farming is not the primary source of income and who are not looking to optimise returns on their properties or are likely to be risk averse. These mechanisms must work with existing landholders and existing land uses. Mechanisms to enhance adoption of nutrient reducing actions with low set-up costs such as farm visits or free soil testing, or change or reduction in fertiliser types can provide accepted private benefits. However the catchment based modelling estimated that appropriate fertiliser management on its own will not meet the Peel-Harvey Catchment phosphorus reduction targets.

With the shift towards whole of water and nutrient cycle management, the resources required for water quality improvement are significant. The cost of retrofitting or re-designing existing practices will involve a substantial level of financial investment where public benefits can out weigh private development costs.

Decision making authorities can potentially reduce phosphorus loss risk to waterways by determining nutrient surplus and nutrient use efficiency. High surplus landuse could be located further away from susceptible receiving waters, where high efficiency land users (i.e. individual operators) may have more flexibility in location than poor efficiency individuals. The approach of using nutrient surpluses as a tool to influence management outcomes has been used previously, for example, the MINAS (Mineral Accounting System) system in the Netherlands.

Whilst a range of best management practices is available to address the causes of nutrient pollution, most investment to date has been directed towards symptoms. The SSPRED model was developed to estimate costs and benefits of implementing conventional best management practices to improve on current phosphorus reductions of around four percent. A conservatively staged implementation of best management practices indicated that a further phosphorus reductions of 38 percent was possible (Neville, 2006). Over a 20-year period, the net cost of these practices would result in a significant net benefit to land managers. Cost barriers to the adoption of the selected agricultural best management practices appear limited and bring the current low adoption levels into question. The modelling showed that the staged implementation would however not meet phosphorus load reduction targets in the Peel-Harvey catchments in total.

If best management practices are not adopted widely or don't become effective within 10 years it will be difficult to justify ongoing investment in them. And if ongoing monitoring of ambient water quality and adoption rates are not showing gains after 10 years, then management measures would need to be modified or applied more rigorously with monitoring of effects at the highly sensitive small scale.

An incentives based program developed by the Department of Agriculture and Food called Farming for the Future (F4F) links current recommended practices in nutrient reduction to a system of recognition or certification compatible with quality assurance schemes, market and regulatory requirements (under section 122A of the *Environmental Protection Act 1986*). The F4F process verifies the practices with known science at the farm and landscape scale and has potential to link with NRM processes.

4.6 Institutional and organisational reforms

A key purpose of the Plan is to guide investment in actions to reduce the phosphorus input to estuarine waters, and identify the most cost-effective management actions to improve water quality in a timely manner.

Significant improvements are required in the following areas: landuse planning to occur in a holistic way and in full consideration of environmental outcomes; clear and adequately funded institutional arrangements for overall statutory policy, compliance and regulatory enforcement, operational planning and service delivery; integrated catchment and waterways management initiatives. These actions will need to be undertaken by community, all levels of government and natural resource management bodies.

Governance arrangements for the Plan are currently being considered by the State government. The Environmental Protection Authority recommends governance arrangements should be reviewed to incorporate implementation of the Plan's recommendations once the Plan has been finalised and government has made appropriate decisions. These arrangements may include an implementing body supported by working groups from all levels of government, key environment, conservation and resource management agencies, NRM groups and community representatives. The broad scope of the responsibilities may include:

- facilitate and coordinate ongoing environmental management between Government, industry and the community to achieve a set of water quality and land management outcomes covering the Peel-Harvey;
- develop an integrated Catchment Management Plan which would incorporate measurable environmental quality objectives and criteria;
- achieve behavioural change and environmental improvement, through coordination, implementation, monitoring and public reporting of performance;
- adapt management actions to achieve and maintain the environmental quality objectives as the knowledge base improves (for example, consider statutory or other management options); and
- better integrate landuse and water planning, in particular within the Peel Region Scheme.

All levels of government will have important roles in implementing the Plan:

- local governments are able to regulate water and nutrient sensitive urban design through local planning schemes and planning policies and decisions;
- State governments can establish and support governance and institutional arrangements, introduce appropriate landuse controls and establish incentives frameworks and offsets programs to achieve water quality outcomes; and
- the Australian Government can provide financial support, principally through the regional Natural Resource Management Program to, for example, help maintain adaptive management capacity and implement incentives. It may also give priority to relevant projects under Caring for our Country, the Community Water Grants programme and other environmental funding programs.

4.7 Regulatory reforms for improved water quality and environmental flows

Licensed discharges may be considered as nutrient point sources to the Peel-Harvey Estuarine System. A review of licensed discharges in the catchment was undertaken by Department of Environment (2005) and is provided in Appendix F. Key points made in the review are provided below.

An interim load limit of 1 kg/ha/y for phosphorus for each licensed premise was adopted by the Department of Environment in 2004, based on EPA Bulletin 363. Bulletin 363 states:

'The average application rate for nutrients in broad-scale agriculture is approximately 9 kg/ha/y of phosphorus. Of the 9 kg applied, an average of 0.95 kg/cleared ha/y is lost to the environment.'

As stated in the review this interim limit achieves a number of positive outcomes including:

- the setting of the 1 kg/ha/y export limit of phosphorus from the properties listed in Appendix E has been incorporated into the LASCAM modeling and has influenced how licensees manage and control on-site nutrient sources; several premises have demonstrated that consideration is now being given to the impact that their wastes are having off site;
- premises that have been previously discharging phosphorus at levels in excess of the above limit are now aware of their requirements to improve water quality; and
- if license limits are not complied with, the licensees will be in breach of their environmental license, which carries substantial penalties and appropriate enforcement action can be initiated.

Future nutrient reductions from licensed discharges are anticipated through use of the new regulations for the management of unauthorised discharges (*Environmental Protection (Unauthorised Discharge) Regulations 2004*. The unauthorised discharge regulations do not include the discharge of waste that the Department of Environment and Conservation currently licenses through the *Environmental Protection Regulations 1987*. These regulations will allow the Department to target poor environmental performers and premises that are not currently operating at best practice. As recommended in the Department of Environment (2005) review another set of regulations is needed to bridge the gap between the Unauthorised Discharge Regulations and the Environmental Protection Regulations. The Department of Environment and Conservation is currently considering the way forward in regulating nutrient rich wastewater. As stated in the recommended Best Management Practice No. 6(b) a zero discharge of phosphorus for all other agricultural practices involving effluent management is required within five years.

The Environmental Protection Authority will be reviewing the *Environmental Protection (Peel Inlet – Harvey Estuary) Policy 1992* in the near future to take into account where appropriate the Plan's recommendations.

4.8 Current legislation relating to water quality within the Peel-Harvey Coastal Catchment

This section identifies current legislation relating to water quality within the Peel-Harvey coastal catchment. This list however is not exhaustive.

The *Environmental Protection Act 1986* (the Act) and associated *Environmental Protection Regulations 1987* (EP Regulations) is the key tool that can be used to manage or deal with any premises that operates in the Peel coastal catchment. The Department of Environment and Conservation can and will take action when there is a breach of the Act or EP Regulations (ie a discharge that was of a magnitude that resulted in pollution) that is in line with its Enforcement and Prosecution Policy: May 2008 (Department of Environment and Conservation, 2008).

In 2004 the *Environmental Protection (Unauthorised Discharge) Regulations 2004* (UDRs) were gazetted. These regulations make it an offence to discharge certain materials into the environment. The materials prohibited are identified in Schedule 1 of the UDRs. The materials that are now covered under the UDRs that are relevant to this framework are animal wastes, animal oils and food waste. The UDRs do not include discharges of waste that the Department of Environment and Conservation currently licences through the Act and associated EP Regulations.

The UDRs provide the ability to target poor environmental performers and premises that are not currently operating at best practice with regards to discharges to the environment (Department of Environment, 2005).

In 1992 two Environmental Protection Policies (EPPs) relevant to the Peel-Harvey coastal catchment, the *Environmental Protection (Peel-Harvey Estuary) Policy 1992* as outlined in detail in section 2.3 and the *Environmental Protection (Swan Coastal Plain Lakes) Policy 1992* (Lakes EPP) were gazetted. The Lakes EPP sets out to protect lakes depicted on Miscellaneous Plan 1815 on the Swan Coastal Plain from filling, draining, mining, excavating and drainage.

Environmental Protection Policies are prepared under Part III of the *Environmental Protection Act 1986* and have "the force of law as though they have been enacted as part of this Act", on and from the day on which the policy is published in the *Western Australian Government Gazette.* The Act is binding on the Crown. Accordingly, the wider community as well as all government departments and agencies are required under law to comply with both the Act and EPPs prepared under the Act.

Legislation proclaimed on 8 July 2004 *(Environmental Protection (Clearing of Native Vegetation) Regulations 2004* protects all native vegetation in Western Australia. Clearing native vegetation is prohibited, unless a clearing permit is granted by the Department of Environment and Conservation, or the clearing is for an exempt purpose.

The *State Planning Policy 2: Environment and Natural Resources* defines the principles and considerations that represent good and responsible planning in terms of environment and natural resource issues within the framework of the 1997 State Planning Strategy (Western Australian Planning Commission, 1997).

The *State Planning Policy 2.1 Peel-Harvey Coastal Plain Catchment* as detailed in section 2.3 ensures that land use changes within the Peel-Harvey estuarine system likely to cause environmental damage to the estuary are brought under planning control and prevented.

The *Rights in Water and Irrigation Act 1914* was amended in 1984 to give the Water Authority the power to prohibit drainage works that were likely to affect the water in a watercourse, wetland or underground water source (Department of Water, 2008).

The *Soil and Land Conservation Regulations 1992* provides the Commissioner of Soil and Land Conservation with the responsibility for assessing and approving drainage. Under Regulation 6 it specifically includes any drainage in the Peel–Harvey Catchment and therefore has an impact on the Mundijong, Waroona and Harvey Drainage Districts (Department of Water, 2008).

5. Monitoring and Modelling

5.1 Water Quality Modelling Strategy

Although the Murray River currently meets the Water Quality Objectives it will still need to be modelled to observe possible changes in water quality if conditions change. Previous modelling has shown that phosphorus loads from the Murray River could be doubled and the median concentrations could increase by eight times if the Peel Region Scheme was applied and the current rainfall pattern remained. Therefore it is proposed modelling should be based on all three catchments.

Water quality modelling should be reviewed and if necessary revised after five years and publicly reported. The revised modelling should be continuous as information and science change. Information should be additive over time. The experience learnt from current modelling is that it takes years to develop communication, understanding and appreciation of how powerful modelling can be, between the various agencies and the community.

In order to provide managers with the best possible information and predictive modelling results, it is necessary to fund monitoring and continuous modelling for the life of the Plan. Hence two types of programs are needed to be run during this period:

- Discharge and water quality monitoring; and
- Modelling data. This program will focus on keeping up to date all the datasets used by the predictive tools. In particular it will focus on updating:
  - Rainfall (yearly basis)
  - Landuse information (two yearly basis)
  - Point source information (two yearly basis)
  - Inventory and location of management measures and control actions (yearly); and
  - Nutrient survey (five yearly)

The discharge and water quality monitoring program will permit the predictive tools to assimilate the latest monitoring data during the life of the Plan. This will correct any major discrepancies between predictions and observations at the different monitoring points on the catchment during the life of the Plan. The results from the predictive tools will then be used to optimise the monitoring network by identification of the proper scale at which to measure the different management actions.

The modelling data program will have several benefits. Firstly, it will keep the landuse information up to date. As the Peel Harvey catchment is under intense urbanisation pressure eg, City of Mandurah indicated that its population will treble by 2010, it will be important to keep track of the landuse change over the catchment. This necessity is outlined by the modelling result of the implementation of the Peel Regional Scheme and the Metropolitan Regional Scheme. Secondly it will help keep track of the different interventions happening on the catchment. As a result, modelling and monitoring may be tailored to focus on some particular subcatchment to show the benefit of a particular treatment. Thirdly, by updating the nutrient survey, it will help to quantify the uptake of all the behavioural change aspects of the Plan. It will also give managers an indication of the efficiency of these type of control actions. Fourthly, by the predictive tools being endorsed by the different agencies a more integrated nutrient management approach could be established.

The proposed strategy will then have several benefits for the Plan:

- it will allow a revision of the predictive tool on a regular basis. This will enable the Plan's recommendations to be adjusted to allow for climate change information, in a semi real time scenario;
- it will permit the revision of the time frame associated with the Plan's loads and flow targets at the bottom of each reporting catchment;
- it will assist the implementation of different management actions. Adaptive management action could be decided after yearly review of the monitoring and modelling results; and
- it will provide a transparent public review process with greater community participation and uptake of the Plan and its objective.

However, the aim of the Plan is the protection of the receiving water body. As such it is important to note that a full estuarine modelling exercise needs to be funded. A proper estuarine modelling exercise needs to be considered for at least three years and should encompass the effect of the Dawesville Channel on the water and nutrient movement in the estuary. There is a nutrient store in the sediments of the estuary and an estuarine model may provide valuable information about the rate of depletion and immobilisation of this pool of nutrients. This exercise will have the aim of coupling the catchment and estuarine model to determine what action needs to be done and where on the catchment to meet a specific estuarine water quality target.

The Department of Agriculture and Food, as part of its commitment to interim projects funded under the CCI program, developed a number of tools including a web based geographical information system to monitor adoption rates of best management practices. The web interface, given appropriate login privileges, allows users to add and update BMP information, with catchment wide reporting of adoption levels of different BMPs possible. Similar monitoring projects being developed by peak NRM groups could utilise and build on these developments.

In addition, Department of Agriculture and Food developed field based tools to capture BMP adoption and nutrient balance data, and the SSPRED model to estimate the costs and benefits of implementing BMPs at a range of scales from the Plan's reporting catchment to subcatchment. The SSPRED model uses a risk based framework considering soil type, landuse type and nutrient surplus, and integrates this with information on the costs and effectiveness of different BMPs to develop scenarios.

The Environmental Protection Authority considers that the task of defining the catchment-based performance targets with SMART (simple, measurable, appropriate, representative and timebound) indicators will be one of the first tasks in implementation of the Plan.

The revised model must be developed with participation with all relevant agencies, community groups and landcare organisations. These organisations must work together ensuring data flows easily between parties and is of a high standard.

5.2 Water Quality Monitoring Strategy

This section outlines a strategy for water quality monitoring for the estuarine system and relevant parts of the Peel-Harvey catchment, consistent with the National Water Quality Management Strategy's Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC and ARMCANZ, 2000) and the State Water Quality Management Strategy No 6 (Government of Western Australia, 2004). Water quality monitoring is required under environmental conditions for the Peel Inlet and Harvey Estuary Management Strategy (1989-1991) as outlined in section 2.3.

In November 2003 a water quality monitoring program (WQMP) (Rose, 2003) (Appendix D) was developed through CCI funding to complement this Plan. The Water Quality Monitoring Strategy outlined below will summarize the actions proposed for the current and future implementation of the WQMP, with the major monitoring objectives being to:

- establish a catchment monitoring network that would measure nutrient loads entering the estuary, in particular phosphorus loads, with a known degree of confidence or accuracy;
- monitor and assess the effectiveness of management measures and control actions;
- monitor and assess the achievement or maintenance of draft river flow objectives;
- provide baseline data for load trend detection over several years time and changes in phosphorus loads to the estuarine system; and
- measure flow, nutrients and suspended sediments to help validate and calibrate the catchment decision support system.

5.2.1 Catchment Monitoring

Sampling Sites

Three primary LMUs were identified that could measure loads coming from the three major tributaries of the Peel-Harvey, the Serpentine, Murray and Harvey Rivers. These tributaries already had flow gauging sites established (Dog Hill – Serpentine River, Pinjarra Weir – Murray River, Clifton Park – Harvey River), that were in relatively good condition (Table 9, Figure 19). However, they needed to be refurbished. All three primary LMUs have now been refurbished and are fully operational. These have been running since August 2004. It must be noted that these three LMUs are located at the lowest point on each of the rivers where "freshwater" loads can be measured.

A multi-criteria analysis was undertaken that scored values for the range of criteria necessary for effective site location and network establishment. The result of the analysis identified ten highly ranked sites that could be established (Table 9). These are referred to as secondary LMUs. Eight out of the top ten secondary LMUs have been established and have been operating since March 2006. The last two secondary LMU sites, Caris Main Drain and South Dandalup River – Patterson Road have not yet been established but will be when adequate resources are available. The last two LMUs provide very little additional information to overall load estimates but if built would provide better spatial coverage of the catchment.

The LMU network does not permit small scale measurements to identify efficiency of BMPS. The aim of the LMU network is to measure loads coming from the catchments. As a result they are placed at the bottom of the catchment. An LMU network satisfying measurement of BMP efficiency would require LMUs on first order stream or drain.

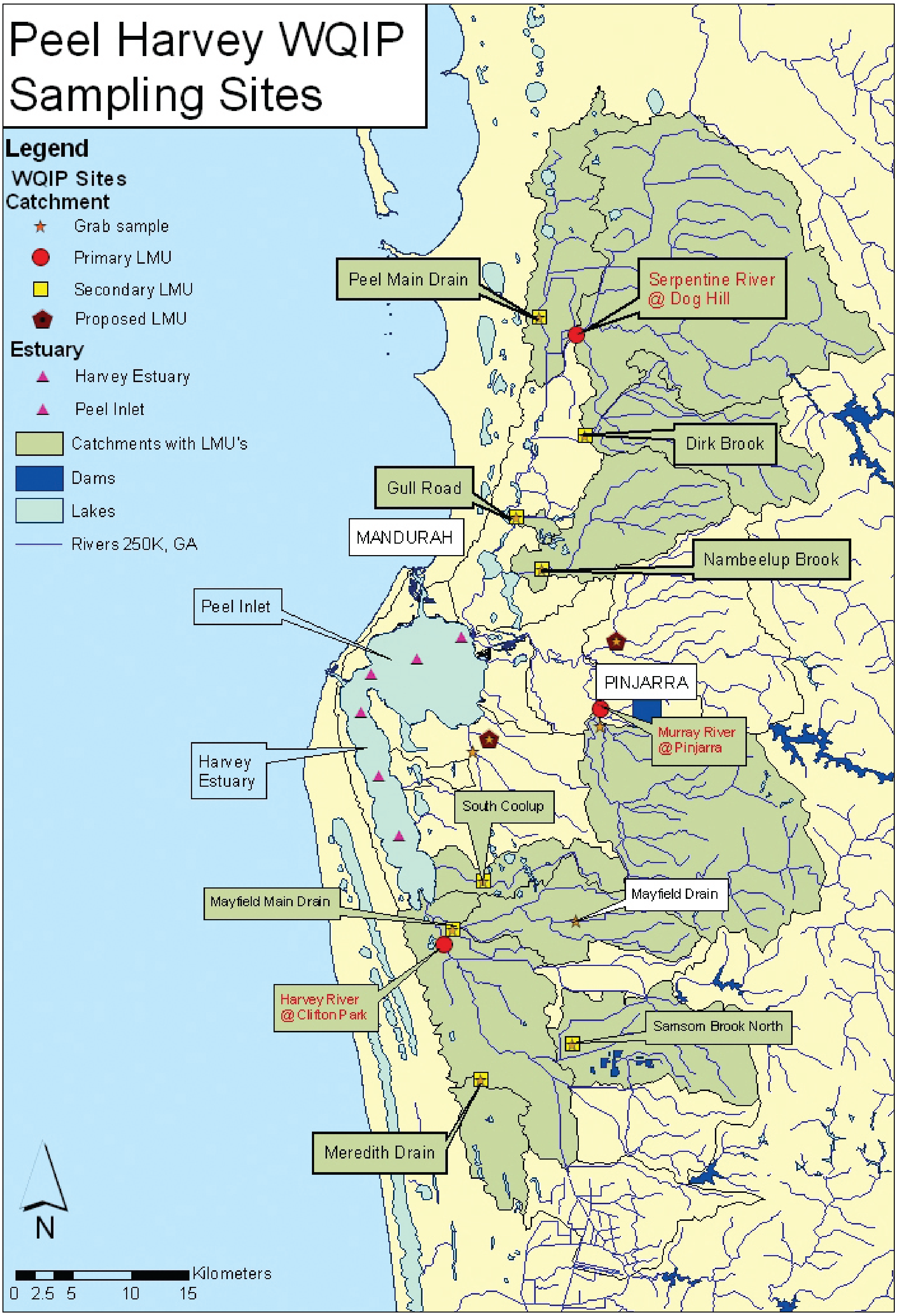


Figure 19: Monitoring sites for the catchment, primary and secondary LMU sites, grab sampling sites, proposed secondary LMU sites (Caris and South Dandalup) and estuarine sampling sites (Courtesy Department of Water).

Table 9: Primary and Secondary LMUs for the Peel-Harvey catchment (courtesy of Department of Water)

Primary LMUs	Gauging station number	Catchment size (km^2)
Serpentine River – Dog Hill	614030	1,128
Murray River – Pinjarra Weir	614065	7,180
Harvey River – Clifton Park	613052	1,185
Ten highest ranked secondary LMUs		
1. Nambeelup Brook	614063	115
2. Karnup Road – Peel Main Drain	614121	121
3. Gull Road Drain	614120	7
4. Dirk Brook – Yangedi swamp	614094	138
5. Meredith Drain	613053	49
6. Coolup South Main Drain (Yackaboon)	613027	32
7. Mayfield Main Drain	613031	112
8. Samson Brook North	613014	19
9. Caris Main Drain	Not registered – decommissioned	23
10. South Dandalup River – Patterson Road	Not registered	670

Now that 11 sites have been established, effort has been directed at running them to obtain at least three years of data. This will improve flow control structures, improve flow rating curves that predict flow volumes at various heights of flow and improve the recording of flow information and reporting such that verified data could be imported into data bases every six months. An assessment of flow ratings at all sites has been done which identified at what flow stage and rating curves are least accurate, eg for low, medium or flood flows. This has indicated which priority sites will need flow measurements over the next few years so that more accurate water flow estimates can be made.

Catchment Sampling Regime

Currently the three primary LMUs are run annually under an optimised software program called PlaNet. This program allows the best sampling frequency to be undertaken that optimises information while minimising the cost of taking too many samples with little information gained. More details on how PlaNet works is outlined in Appendix D (Rose, 2003).

Three secondary LMUs are run annually based on current funding arrangements. A different suite of LMUs are run every different year. See Table 10. After all primary and secondary LMU sites have been run for three years a good set of baseline load estimates will be provided with known error. Flow data is run continuously regardless of nutrient sampling so that critical flow data is always collected. This will allow some general nutrient load estimates to be made. All sites have a gauging station. Dissolved fractions and complex organic forms of nutrients ie Dissolved Organic Nitrogen and Total Organic Carbon etc, are now taken every two weeks at LMU sites sampled for that year. These measurements will help refine the DSS model and help to provide good quality assurance.

Table 10: Current sampling schedule for LMUs over three Years beginning in the Winter of 2006 (courtesy Department of Water).

Site	Year One	Year Two	Year Three
Primary LMUs			
1. Dog Hill – Serpentine River	√	√	√
2. Pinjarra Weir – Murray River	√	√	√
3. Clifton Park – Harvey River	√	√	√
Secondary LMUs			
1. Karnup Rd Bridge (Peel Main Drain)		√	
2. Dirk Brook	(√)	(√)	(√)
3. Nambeelup Brook	√		
4. Gull Rd		√	
5. South Coolup MD			√
6. Mayfield MD		√	
7. Samson Brook North – Sommers Road			√
8. Meredith MD	√		
TOTAL	**5 sites**	**6**	**5**

To improve on the current sampling regime it is proposed that 11 LMUs are sampled and that at least three to five LMUs are "optimised" to sample according to the latest flow regimes and provide data with pre-established accuracy and precision based on PlaNet simulations. A further two more LMU sites will be developed to better cover all relevant sub-catchments eg South Dandalup River at Patterson Road and Caris Main Drain in the southern Peel. Complementing this will be an evaluation of flow rating curves and control structures at all existing LMU sites and to embark on a long-term capital improvement program for any structures needing replacement or installation. Flow-rating measurements will also be undertaken to improve flow-rating curves. Together, this will improve flow estimates making load estimates more accurate.

Effort will also need to be made that will improve flow and nutrient sampling in tidal areas, some 25-30 percent of the Peel-Harvey coastal catchment. This information will help improve estimates of nutrient loads entering the estuary.

Sampling analysis plans for the LMU network are nearing completion. These outline the precise sampling method, sampling frequency and analytes sampled for each LMU. It is proposed that existing catchment grab sampling that measures nutrient concentrations at 15 streams to complement this new network be rationalised and refined to complement the LMU sampling regime. The grab sampling regime can take nutrient fractions at the same sites as the LMUs and in turn help calibrate and improve the usefulness of a catchment DSS model. Table 11 shows the proposed analytes for measurement.

5.2.2 Estuarine Water Quality Monitoring

Comprehensive estuarine water quality monitoring programs have existed between the late 1970s and 1999, in part to address the Ministerial conditions but to also help describe the ecological conditions of the system until remedial action like constructing the Dawesville Channel was undertaken. The last five years of these programs have concentrated on monitoring water quality changes caused by the Channel. The program however, has since been reduced to a monthly sampling regime at six sites (Figure 19) that does not measure water quality aspects important to public health, waterways management and recreational use. Phytoplankton is taken three monthly. Limited physical and phytoplankton parameters are also taken monthly at the lower tidal reaches of the Serpentine and Murray Rivers.

Estuarine monitoring is essential to track performance and measure water quality targets, assess the effectiveness of the Plan and NRM initiatives. River flow enters the estuary 4-6 months in the year, therefore a weekly monitoring program for six months would need to be established to sample this period frequently enough in order to describe critical water quality conditions (Department of Water, 2006).

Proposed strategy

The objective of this strategy will be to operate a regular water quality and biological monitoring program to address public health surveillance, resource target and performance measures. This program will be operated for a minimum of ten years in order to provide, at the minimum, a baseline benchmark for comparing water quality trends. Based on the nutrient concentrations and load estimates entering the estuarine system, it will report regularly on how effective catchment management activities are in meeting any load targets, water nutrient concentrations and other objectives stated in statutory legislation (eg EPPs), Ministerial conditions and this Plan. The strategy will provide regular monitoring in the tidal reaches of the major tributaries to help understand and provide answers that can address deteriorating water quality, scums and fish kills in these regions of the system.

More specificially:

1. Conduct water quality sampling for nutrients and phytoplankton weekly between October and April, ie for 6 months, reduced to fortnightly between April and September. This could be increased to weekly all year if significant funding becomes available. See Table 12 for parameters.
2. Phytoplankton sampling will provide the basis for early warning public health surveillance (as such there will be a need to be a service agreement with the Phytoplankton Ecology Unit to process samples within sufficient time to provide advice to the Department of Health and other authorities with health responsibilities).
3. Conduct seasonal macroalgae and seagrass field surveys that include 2x yearly synchronised with aerial photographic runs to allow development of future photographic survey techniques. This seasonal survey work should evaluate the value of incorporating three weekly surveys during the most active growing season between mid-spring and early summer.

Table 11: Proposed analytes for measurement as part of the water quality monitoring program in the catchment (courtesy of Department of Water).

ANALYTE	COMMENTS
Total Phosphorus (TP)	Collect now and in future
Filterable Reactive Phosphorus (FRP)	Collect now and in future
Total Nitrogen (TN)	Collect now and in future
Ammonia (NH3) (actually ammonium in water)	Collect now and in future
Nitrate-Nitrites (NOx)	Collect now and in future
Total Suspended Solids (TSS)	Collect now and in future
Total Dissolved Solids (TDS)	Collect now and in future
pH (or total acidity – alkalinity)	Collect now and in future
Conductivity – salinity	Collect now and in future
Dissolved Organic Carbon (DOC)	Collect in future
Dissolved Organic Nitrogen (DON)	Collect in future
Miscellaneous compounds such as tannins and mineral complexes	Collect in future

Table 12: Water Quality Parameters for the estuary (courtesy Department of Water)

Parameter - analyte	Comment
1. Phytoplankton	Cell density and taxa identification, integrated and at depth on request or investigation
2. Chlorophyll a	Integrated and scums
3. Total phosphorus	Measure of organic and inorganic nutrient
4. Filterable Reactive Phosphorus	Essential plant nutrient
5. Total nitrogen	Measure of organic and inorganic nutrient
6. Ammonia or ammonium	Essential plant nutrient and indicator of organic decomposition
7. Nitrate-nitrite	Essential plant nutrient and essential compound in denitrification & N cycle processes
8. Total alkalinity/Total titratable acidity	TA – TTA, essential measure of potential acidity
9. BOD	Biological Oxygen Demand (microbial demand)
10. COD	Chemical Oxygen Demand (chemical reactions requiring oxygen)
11. Salinity	Measure of dissolved salt in water (ocean ca 36ppt)
12. Conductivity when relevant	Measure of salts in water
13. Turbidity (NTUs or TSS)	Measure of water clarity that affects plant growth/productivity and insolation of water
14. Secchi depth	Basic measure of light penetration for plant growth and measure of suspended material and sediments in water
15. Light penetration	Depth that sunlight reaches into water body
16. pH	Measure in log scale of H+ concentration or water acidity-alkalinity (ie basicidity)
17. Temperature	Measure in Celsius of thermal heat
18. Tidal state	Flood-Ebb tides indicating water levels and local currents
19. Seas	Degree of roughness or turbulence from wind and currents

4. Process investigations lasting between 24 to 48 hours should be evaluated and undertaken to study metal, nutrient and biological fluxes during certain events or poor water quality periods. Work should be focussed on evaluating how fluxes change, how this will affect future water quality and if management options exist. For example, studying diel nutrient and metal fluxes when hypoxic conditions are chronic during the summer and seeing if any intervention techniques are feasible or necessary and how these fluxes may affect aquatic animal health.
5. Conduct nutrient limitation bioassays for phytoplankton, on a weekly to seasonal basis.
6. Seasonal benthic and zooplankton surveys should be conducted to link water quality and macrophyte conditions with invertebrate communities to determine trophic health and productivity as well as for the general estuarine health of the Peel-Harvey estuarine system.
7. Bird and fish surveys should also be conducted to link these communities with estuarine environmental health and to monitor changes relevant to recreational and commercial fishing as well for international treaty obligations.
8. Sampling analysis plans including data management; analysis framework and reporting will be prepared for operation of the estuarine monitoring program.
9. Encourage and develop an estuarine modelling capacity that is predictive and management oriented and can use estuarine and catchment water quality monitoring data for verification and calibration.
10. Develop and fortify the link and information requirements between the Plan, estuarine environmental-nutrient targets and catchment – landuse activities.

5.2.3 Effectiveness of management measures and control actions

The Water Quality Monitoring Strategy will monitor and assess the effectiveness of management measures and control actions through evidence of a trend towards reduction of total phosphorus and the eventual achievement of total phosphorus targets at the LMU sites. Section 2.7 describes the phosphorus load reductions required by the DSS for entering the estuary. Table 3, section 2.7 shows the required reductions for the main catchments from the point of delivery to the estuary. As monitoring will be at the proposed LMU sites then Table 12 shows the individual reductions required at each LMU. The overall load reduction required at the LMU sites is approximately 25 tonnes. The amount of reduction required at the LMUs is less than the point of delivery to the estuary (70 tonnes) since they are higher up in the catchment. Monitoring will be used to locate the most problematic sub-catchments and areas where improved catchment management would reduce nutrient export. The allowable Phosphorus target to estuary is 75 tonnes and the total allowable phosphorus to three primary gauging stations is 56 tonnes.

The trends of the Phosphorus concentration and loads of the streams at the LMUs will be recorded

Table 13: Total Phosphorus Load Targets at Load Measuring Units (LMU) instrumented catchments (courtesy of Department of Water)

Load reduction Target based on Winter median					
Catchment	**LMU site**	**Current load**	**Load Reduction %**	**Load Reduction (T)**	**Load Target (T)**
Murray	Pinjarra Weir	8.172	0.00	0	8.172
Harvey	South Coolup	1.667	-15.97	0.266	1.401
	Samson North Drain	7.37	-28.57	2.106	5.264
	Mayfield Drain	6.315	-18.03	1.139	5.176
	Clifton Park	24.785	-13.04	3.233	21.552
	Meredith	0.689	-43.18	0.298	0.391
Serpentine	Peel Main Drain	4.301	-65.87	2.833	1.468
	Dog Hill	17.258	-38.27	6.605	10.653
	Dirk Brook	4.857	-46.52	2.26	2.597
	Nambeelup Brook	9.468	-58.16	5.506	3.962
	Gull Road	0.688	-60.00	0.413	0.275
	Total load reduction at LMU's			**24.659**	

and assessed to ensure the trend is decreasing. Load Reductions have been calculated at each of the 11 LMU sites and assessed against the targets. The reductions in Table 13 are made on the assumption that the climate is the same as that during the period 1990-2004 and that landuse does not change post 2003.

Work has been undertaken by State agencies to collect and analyse nutrient samples at the Meredith Main Drain LMU to monitor the effects of red mud applications in the sub-catchment. Samples at Meredith are taken six hourly and collected every 2-3 weeks and analysed for total phosphorus. Grab samples were also taken as part of a fortnightly catchment sampling run and analysed for

Table 14: Indicators and values for Water Quality in the Peel-Harvey Estuarine System

Region	Management objective	Resource condition	
		Indicator	Target
Lower estuarine reaches Serpentine River Lower estuarine reaches Murray River	Reduce nutrients feeding phytoplankton blooms in estuarine reaches of the rivers	Phosphorus	Total phosphorus (Winter Median Target) 0.1mg/L
Lower estuarine reaches Serpentine River Lower estuarine reaches Murray River	Reduce frequency of potentially toxic phytoplankton blooms (e.g. cyanobacteria and dinoflagellates)	Phytoplankton cell counts; number of recorded blooms (measured in Serpentine only); chlorophyll a (currently not measured)	Phytoplankton less than 20,000 cells/mL; Reduced bloom and eliminate nuisance and toxic algal blooms; Chlorophyll a 10µg/L (currently not measured)
Lower estuarine reaches Serpentine River Lower estuarine reaches Murray River	Reduce spatial extent and frequency of hypoxic/anoxic events	Dissolved oxygen (DO) in surface waters; in bottom waters when surface achieved	Dissolved Oxygen 5 mg/L, frequency and extent (currently not measured)
Lower estuarine reaches Serpentine River Lower estuarine reaches Murray River	Reduce spatial extent and frequency of fish kill events	Fish kill events	Zero
Peel Inlet Harvey Estuary	Reduce nutrients feeding phytoplankton blooms in the Peel Inlet and Harvey Estuary	Phosphorus	Total phosphorus 75 tonnes/pa [30 µg/L, long term] difficult to attain in 25 years
Peel Inlet Harvey Estuary	Maintain levels of phytophankton within levels acceptable to community	Chlorophyll a	Chlorophyll a [3 µg/L, long term]
Peel Inlet Harvey Estuary	Maintain levels of dissolved oxygen to support a healthy and resilient ecosystem	Dissolved oxygen	[70-80% saturation]
Peel Inlet Harvey Estuary	Minimise appearance of toxic algae for example, *Lyngbya* spp., in the Peel Inlet and Harvey Estuary	Toxic algae presence	No increase in Distribution, Density, Measure toxicity

subspecies TN, TKN, Nox, NH3-N /NH4-N & TP & PO4-P. There currently is no flow rating review or surveys being undertaken (Rose, 2003).

The Environmental Protection Authority considered a range of indicators and targets by riverine and estuarine segments, see Table 14.

5.2.4 Monitoring of river flow objectives

The river flow objectives are to maintain current flows in all rivers. See Figure 18 for current flows (1990-2004).

After all LMU sites have been established effort will be directed at improving flow control structures, improving flow rating curves that predict flow volumes at various heights of flow and improving the recording of flow information and reporting such that verified data can be imported into data bases every six months. An assessment of flow ratings at all sites has been done identifying at what flow stage and rating curves are least accurate, eg for low, medium or flood flows. This has indicated what sites will need flow measurements over the next few years so that more accurate water flow estimates can be made.

Once the LMU sites have been improved, river flows can be monitored and reported as described in section 3.4 as to whether the river flow objectives are being maintained.

5.3 Monitoring implementation of the Plan

The intent is to measure attainment of water quality improvement and efficacy of specific management actions. It will also provide feedback to modelling to improve its accuracy as a management tool. The monitoring and evaluation plan employs indicators and targets that are sensitive enough for measuring in-stream concentrations and flows and therefore loads. These include phosphorus concentrations in catchment and estuarine waterways, and can be extended to include dissolved oxygen concentration in bottom waters of the riverine tidal reaches, the number of fish kills observed in the riverine tidal reaches per year, the number of harmful algal blooms recorded in the riverine tidal reaches per year, and access surveys for primary and secondary recreation in estuarine waterways throughout the year.

Key attributes of the program to monitor and evaluate effectiveness and uptake of current best practices should be: small scale, high priority catchment, and high risk area, high level of implementation, control paired catchments, before and after monitoring opportunities.

The monitoring program should include monitoring for: system-wide water and nutrient balance, estuarine ecosystem health, and organisms that have the potential to cause nuisance to the public. The agencies required to bring about implementation should be jointly responsible for obtaining the funding necessary to ensure full implementation.

5.4 Adaptive Management Strategy

The Adaptive Management Strategy is an iterative process. It closes the cycle from information gathering and evaluating, modelling for reduction targets using improved management practices, monitoring for trends in water quality condition and uptake of best management practices, to further review and modification of management practices.

The strategy will continue for the life of the final Plan and will be based on:

- regular reviews of the management measures and control actions;
- additional information derived from expanded monitoring at appropriate small scales, including the effectiveness of management measures and control actions;
- continuous improvements in predictive modelling as the science improves;
- attitudinal surveys at 1, 5 and 10 years as described in section 6.1; and
- any intra-term review of the Water Quality Objectives, phosphorus load targets and/or river flow objectives.

Ongoing monitoring and assessments will guide the continuous improvement and refinement of the management effort in the short to medium term.

The Environmental Protection Authority has reasonable confidence based on the known science that if; appropriate fertiliser and soils amendments are commercially available and the highest adoption rates are achieved—with environmental planning controls placed on new developments, provision of incentives where public benefits accrue on private lands, and a staged approach to regulation if warranted the water quality target can be achieved.

6. Reporting and Review

6.1 Reporting implementation of the Plan

In implementing the Plan, progress towards attainment of phosphorus reduction targets will be monitored and reviewed, and adapted if necessary to help meet water quality targets.

It is possible, if funded, that reporting will focus on the following components:

- the health of waterways in the catchment and estuary, which would involve regularly measuring the total phosphorus, total nitrogen, phytoplankton abundance or levels of chlorophyll-*a*, oxygen, algal growth, fish deaths, clarity of water and bacteriological levels. The limited baseline data means that trend monitoring will be conducted in the first decade. Table 13 shows the proposed indicators for the catchment and estuary;
- performance based indicators, which will look at the extent to which the recommended actions have been implemented; for example; looking at how much low water soluble fertiliser or soil additives are being used on rural and urban properties; how many existing homes have connected to sewerage; percentage of new and existing urban lots and developments implementing water sensitive urban design; farmers with leaking effluent ponds etc.;
- potential "real time" indicators related to bottom end water quality may include the percentage of farmers and urban land holders changing their attitudes and recognising that they are part of the water quality problem and solution through attitudinal surveys at 1, 5 or 10 years; and
- appropriate indicators should be developed by the proposed Peel Harvey Water Quality Improvement Council as its first major task to implement this Plan.

The findings should be reported publicly in an annual 'scorecard' approach similar to that of the Cockburn Sound Management Council or Moreton Bay 'Healthy Rivers' water quality program to provide performance feedback for the community.

It will combine with and utilise existing and new databases, such as that being developed by the Department of Agriculture and Food to track BMP adoption rates. There will be an annual scorecard for each of the catchments outlining the priority BMPs for each catchment. Figure 20 shows a 2005 Cockburn Sound Report Card.

It is recommended that improved working partnerships between government and community to coordinate and implement these plans, with strong linkages to the NRM processes should be achieved through an appropriate implementing body.

The Peel-Harvey Catchment will also be the focus of a future Catchment Management Plan, as this is a requirement in the 1989 environmental conditions for the Peel Inlet-Harvey Estuary Management Strategy.

There will be financial implications associated with the implementation of this Plan that have not been reported here. These will need to be addressed through appropriate parts of Government along with the clarification of the roles and responsibilities for implementation.

All levels of government, Local, State and Australian, will have important roles in implementing the Plan. The Australian Government may also give priority to relevant projects under Caring for our Country, the Community Water Grants programme and other environmental funding programs as the Peel-Harvey coastal catchment is considered one of the country's top ten water quality hotspots.

The Environmental Protection Authority recommends that Western Australian government agencies agree on indicative costings and timelines to implement the recommended measures and actions of this Plan within six months of publication of this final Plan.

6.2 The Plan's review

In addition to annual monitoring and review, there should be a formal review of the Plan within 10 years.

The Plan is recommended to have a life of 10 years and continue to have effect until reviewed with the review commencing in year eight of the plan. The review will also include the formal review of the interim water quality objectives and load targets. Monitoring throughout the ten year period will be maintained to investigate and evaluate trends and attainment of improved water quality in the estuary, and will be reported annually in community scorecards.

Report Card 2005

Subject: Ecosystem Health in Areas of a High Level of Protection (Broader area of Cockburn Sound)

	Environmental Quality Indicators	*Management Response	Comments
Physical and Chemical Measures	• Chlorophyll 'a' • Light Attenuation • Dissolved Oxygen • Temperature • Salinity • pH	M M M M M M	**Chlorophyll 'a' met the guideline.** Elevated levels were recorded for Jervoise Bay and Mangles Bay. **Light attenuation met the guideline.** Key areas of concern were around the north of the area and Jervoise Bay. **All sites met the guideline for dissolved oxygen, temperature and salinity.** **pH was reported for the first time in 2005 and all sites met the guideline.**
Indirect Biological Measures	*Algal Growth Potential* • Periphyton	R	Periphyton growth has been discontinued based on scientific advice. A new measure for algal growth potential is yet to be developed.
Direct Biological Measures	*Phytoplankton Biomass (Activity)* • Chlorophyll 'a' *Seagrass* • Shoot density • Depth limits	M I M	**All sites met the guideline.** **Most seagrass sites met the standard.** Seagrass shoot density failed to meet the standard at Mangles Bay.
Toxicants in Water	*Metals and Metalloids* *Non-metallic Inorganics* • Organics • Pesticides • Herbicides and Fungicides • Surfactants • Hydrocarbons • Miscellaneous/Others	M	For the range of water toxicants monitored to date (April 2003), levels are either below the guidelines or below normal laboratory detection limits. **These parameters were not intended to be sampled on an annual basis.**
Toxicants in Sediments	*Organometallics (e.g. TBT)* *Metals and Metalloids* *Organics*	R M	No TBT sediment data were available in 2005 to determine whether the guideline was met. The CSMC has initiated a study which will assess TBT in Cockburn Sound against the environmental criteria. This research will be completed at the end of 2005 and will be available for the 2006 Report Cards. In addition, Report Cards will be updated on the website as the data become available. Preliminary data provided to the CSMC indicate that the TBT standard may have been exceeded in some areas of Cockburn Sound. It should be noted that the application of TBT in Australia has been banned and the use of TBT is currently being phased out in other countries. Sampling for metals, metalloids and organics in sediment was not undertaken in the high protection area in 2005. Results reported here are based on 2001 monitoring and suggest levels are either below the guidelines or below laboratory detection limits.

LEGEND *Management Response:

- M **Monitor** – Below guideline; continue monitoring.
- I **Investigate** – Above guideline; investigate and where necessary, take precautionary action.
- A **Action Required** – Above Standard; initiate management response.
- R **Research** – Additional information required to establish state of the Sound and/or criteria.
- Below normal laboratory detection limits.

This Report Card provides a broad assessment of Cockburn Sound and indicates the overall management response required.

Figure 20: Example of a report card (courtesy Cockburn Sound Management Council).

7. References

ANZECC and ARMCANZ (1996). "National Principles for Provision of Water for Ecosystems." *Sustainable Land and Water Resources Management Committee Subcommittee on Water Resources, Occasional Paper SWR No 3 July 1996. Task Force on Water Reform, Commonwealth of Australia*.

ANZECC and ARMCANZ (2000). "Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra."

Atyes, C. and Thackway, R. (2008). "A field manual for describing and mapping revegetation activities in Australia." Bureau of Rural Sciences, Canberra.

Bradby, K. (1997). *Peel-Harvey: The Decline and Rescue of an Ecosystem*. Greening the Catchment Taskforce (Inc.)

Brearley, A. (2005). *Ernest Hodgkin's Swanland, Estuaries and Coastal Lagoons of South-western Australia, University of Western Australian Press*.

Del Marco, A. (2007) *Drainage Reform Plan Peel-Harvey Coastal Catchment Volume One and Two: A report by Ironbark Environmental for the Peel Harvey Catchment Council, Mandurah, Western Australia.*

Department of Agriculture (2000). *Code of Practice for the Distribution and Application of the Alkaloam (Bauxite Residue) for Broad-acre Agriculture and Horticulture in the Peel-Harvey Coastal Plain Catchment,* Department of Agriculture, Western Australia.

Department of Agriculture (2006). "Targeted assistance to intensive agricultural activities in the Peel-Harvey Coastal Plain Catchment, Final Report." Appendix G.

Department of Environment (2004a) *Regional workshops conducted throughout the coastal catchment to define environmental values*.

Department of Environment (2004b). "Stormwater Management Manual for Western Australia, February 2004."

Department of Environment (2005). "Environmental Regulation Framework for the Peel-Harvey Catchment. Discussion Paper - Working Draft. Department of Environment, Regional Operations Division, Kwinana-Peel Region in consultation with Peel Harvey Catchment Council, January 2005." Appendix F.

Department of Environment and Conservation (2008). Enforcement and Prosecution Policy.

Department of Water (2006). "Estuarine Water Quality Monitoring - Peel Harvey Estuary, Projects for WQIP - CCI Peel-Harvey." *unpublished internal document*.

Department of Water (2008) *Coastal Drainage Discussion Paper.*

Environmental Protection Authority (1988). "Peel Inlet and Harvey Estuary Management Strategy, Environmental Review and Management Programme Stage 2, Report and Recommendations of the Environmental Protection Authority. Part I & II." *EPA Bulletin 363*.

Environmental Protection Authority (1993). Widespread use of bauxite residue, Peel-Harvey Coastal Plain Catchment: *Western Australian Department of Agriculture: report and recommendations of the Environmental Protection Authority. Bulletin 714*. Perth, W.A.

Environmental Protection Authority (2000). *Widespread use of bauxite residue, Peel-Harvey Coastal Plain Catchment - extension of approval time limit: Agriculture Western Australia: Section 46 report and recommendations of the Environmental Protection Authority. Bulletin 982*. Perth, W.A.

Environmental Protection Authority (2003). "Peel Inlet and Harvey Estuary System Management Strategy: Progress and Compliance by the Proponents with Environmental Conditions set by the Minister for the Environment in 1989, 1991 and 1993." *Advice of the Environmental Protection Authority EPA Bulletin 1087, January 2003*.

Environmental Protection Authority (2004a). "Drainage Management, Swan-Canning Catchment, Bulletin 1131, May 2004."

Environmental Protection Authority (2004b) "Environmental Protection of Wetlands. Position Statement No. 4."

Environmental Protection Authority (2006). "Communication Strategy for the Peel-Harvey Water Quality Improvement Plan, March 2006." *EPA internal document*.

Environmental Protection Authority (2007). "State of the Environment Report, Western Australia, 2007."

Environment Australia (2002). "The Framework for Marine and Estuarine Water Quality Protection." Appendix I.

Gibson, N. (2001). "Decline of the riverine trees of the Harvey River delta following the opening of the Dawesville Channel." *Journal of the Royal Society of Western Australia* 84: 116-117.

Government of Western Australia (1992a). "Environmental Protection (Peel Inlet-Harvey Estuary) Policy 1992." *Government Gazette Perth, 11 December 1992, pp 5968-5975*.

Government of Western Australia (1992b). "Statement of Planning Policy No. 2, The Peel-Harvey Coastal Plain Catchment." *Government Gazette 21 February 1992*.

Government of Western Australia (2004). "State Water Quality Management Strategy No. 6: Implementation Framework for Western Australia for the Australian and New Zealand Guidelines for Fresh and Marine Water Quality and Water Quality Monitoring and Reporting (Guidelines Nos. 4 & 7: National Water Quality Management Strategy), Report No SWQ 6."

Jakowyna, B.N. (2000). *Nutrients in tributary inflows to the Peel-Harvey estuarine system, Western Australia : status and trend*. Perth, W.A., Water and Rivers Commission, Aquatic Science Branch.

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 the South West, Western Australia." *A report to the Western Australian Minister for the Environment, 2 March 2007*.

Kinhill Engineers Pty Ltd (1988). "Peel Inlet and Harvey Estuary Management Strategy Environmental Review and Management Programme - Stage 2. Department of Agriculture and Department of Marine and Harbours, Western Australia."

Land Assessment Pty Ltd (2005). "Peel-Harvey Catchment Natural Resource Management Plan." *prepared for the Peel-Harvey Catchment Council Inc., March 2005*.

Lavell, K., Summers, R., Weaver, D., Clarke, M., Grant, J. and Neville, S. (2004). "An audit of the uptake of agricultural nutrient management practices in the Peel Harvey catchment." *International River Symposium, Brisbane, 2004*.

Lovett, S., Price, P. and Edgar, B. (eds) (2007) "Salt, Nutrient, Sediment and Interactions: Findings from the National River Contaminants Program, Land & Water Australia, 2007."

Neville, S.D. (2005a). "SSPRED: The Support System for Phosphorus Reduction Decisions - BMP Scenarios Report." *Report to Agriculture Western Australia, Ecotones & Associates, Denmark WA.* Appendix C.

Neville, S.D. (2005b). "SSPRED: The Support System for Phosphorus Reduction Decisions - Model Framework Development Report." *Report to Agriculture Western Australia, Ecotones & Associates, Denmark WA.* Appendix C.

Neville, S.D. (2006). "SSPRED: The Support System for Phosphorus Reduction Decisions - LASCAM Scenario Report." *Report to Peel-Harvey Catchment Council, Ecotones & Associates, Denmark WA.* Appendix C.

Peel Development Commission (2002). *Peel Sustainable Development Strategy 2020,Developed through local consultation, November 2002*.

Peel Development Commission (2006a). "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.* Appendix E.

Peel Development Commission (2006b). "Peel-Harvey WSUD Local Planning Policy, Final. A model local planning policy to assist Local Government to determine strategic and statutory proposals within the EPP Policy Area of the Peel-Harvey Coastal Catchment." *Delivered through the Federal Government's Coastal Catchment Initiative. October 2006.* Appendix E.

Peel-Harvey Study Group (1985). *Peel Inlet and Harvey Estuary Management Strategy: Environmental Review and Management Programme, Stage 1. Western Australia. Department of Conservation and Land Management*. Perth, W.A., Department of Conservation and Land Management.

Pond, B. (2005). "Stock Exclusion from Waterways in the Peel-Harvey Coastal Plain Catchment, Final Progress Report, Coastal Catchment Initiative Project, Milestone covering Stages Ten (10) and Eleven (11) in Section F (Table 1) of the Schedule in the contract agreement have been completed and approved." Appendix H.

Rivers, M. (1999). "The Use of Bauxite Residue as a Soil Amendment in the Peel-Harvey Coastal Plain Catchment - Environmental Monitoring Report, August 1999." *Miscellaneous Publication 39/99, Agriculture Western Australia*.

Rose, T. (2003). "Water Quality Monitoring Programme for the Peel-Harvey Coastal Catchment - A guiding document with strategies for establishing a monitoring network capable of accurately measuring nutrient loads." *Prepared for the Coastal Catchment Initiative - Environment Australia. Water Quality Monitoring Program and Infrastructure Project for the Peel-Harvey. November 2003.* Appendix D.

Smith, K., Allison, R., Hammond, M. and Weir, K. (2005) "The impact on fish species in the Serpentine River by a fish kill event on the 23 February 2004."

South West Catchments Council (2005). "South West Regional Strategy for Natural Resource Management, April 2005."

Summers, R.N., Van Gool, D., Guise, N. R., Heady, G. J. and Allen, T. (1999). "The phosphorus content in the run-off from coastal catchment of the Peel-Inlet and Harvey Estuary and its associations with land characteristics." *Agriculture, Ecosystems and Environment, 73: 271-279*.

Summers, R., Rivers, M. and Clarke, M. (2004). "The use of bauxite residue to control diffuse phosphorus pollution in Western Australia - a win-win-win outcome." *Department of Agriculture Western Australia*.

Swan River Trust (2000). "'Summer Surprise' the Swan River blue-green algal bloom." *River Science Issue 2, September 2000, WA*.

Swan River Trust (2006). "Draft Healthy Rivers Action Plan." *A Draft Action Plan for improving water quality in the Swan Canning river system*.

URS (2005). "Implementation Measures that Support, Influence, Encourage or Require Uptake of Best Management Practices for Nutrient Management." *Prepared for the Department of Agriculture, Waroona. October 2005*.

URS (2007) "State of Play: Peel-Harvey Eastern Estuary Catchment Environmental Assessment." *Prepared for the Department of Water.*

Water and Rivers Commission (1999). "Revegetation: Revegetating riparian zones in South-West Western Australia." *Water and Rivers Commission River Restoration Report No. RR4.*

Water and Rivers Commission (2000). "Environmental Water Provisions Policy for Western Australia." *Statewide Policy No. 5*.

Water and Rivers Commission (2002) "Foreshore Policy No. 1 – Identifying the Foreshore Area."

Water and Rivers Commission (2004). "Condition Statement for the Peel Harvey Estuarine System, South-Western Australia." *Water Resources Management Series. Water and Rivers Commission unpublished report*.

Western Australian Planning Commission (1997) "State Planning Strategy", Perth, WA.

Western Australian Planning Commission (2006) "State Planning Policy 2.9 Water Resources." Government Gazette 19 December 2006.

Zammit, C. and Summers, R. (2005). "Modelling Catchment Processes in the Peel-Harvey Basin." *3rd WA State Coastal Conference 15 November 2005*.

Zammit C., Bussemaker, P. and Hall, J. (2006). "Establishment of a Decision Support System for Water Quality Improvement and Protection of the Peel Inlet and Harvey Estuary." *Department of Environment, NRM and Salinity Division, Aquatic Sciences Branch.* Appendix B.

Appendix A

Reasonable assurance

Statement of Reasonable Assurance

The modelling done for meeting the target for improved water quality from phosphorus reduction (by both LASCAM and SSPRED models) predicts that the target would be met after 30 years at 100 percent uptake of the management practices modelled. The Environmental Protection Authority has a high degree of confidence that if the Water Quality Improvement Plan (the Plan) is fully implemented the Plan's targets will be achieved.

The relationship between time and phosphorous reduction is unknown because, inter alia, uptake rates of Best Management Practices (BMP) are not known. However, it is unlikely to be linear: hence a simple interpolation for a 10 years time frame would be meaningless.

The Plan is based on adaptive management. That is, implementing best management practices progressively (depending on resources) but reviewing after 10 years to determine whether the Plan is on track. It is an informed estimate that it would take at least 10 years for this large, complex natural system to respond sufficiently so that the BMP 'signal' could be separated from existing 'noise'.

In 10 years time, data from monitoring phosphorus reduction compared with the base case of no additional implementation of the BMPs in the Plan will enable a judgment to be made whether or not the Plan is on track.

Uncertainty

Two response components must be considered, namely response rate of the natural system (run down lag time) and in adoption rates (rate of behavioural change in a risk-averse community).

To adequately address the run down lag time with the LASCAM model would require a new modelling exercise for which new information is required. For example the modellers would have to move from subcatchment scale to farm scale and will need to know how to assign the reductions among farms and landuses; and the non-linear interactions between physical components requires re-calculation of each BMP or uptake rate.

LASCAM is like a 'snapshot' and currently works at a scale larger than 10 ha, with a 15 year climate scenario (1990-2004) and landuses current at 2003.

There is also large uncertainty on the matter of adoption rates of recommended BMPs as predicting these in a voluntary climate without incentives package and a degree of inertia in this community is difficult. The LASCAM model demonstrates that, even at the modelled rate of 100% with the recommended BMPs, a number of subcatchments could not meet their reduction targets. There also remains the unanswered question of equity, of defining who does what and where, based on principles that are fair and reasonable.

The uptake rates could be modelled in SSPRED, and done quite quickly if only as a catchment overview (SSPRED includes a simple and easy front end to allow scenario generation using various combinations of BMPs in various locations). Note however that the SSPRED report prepared by Neville, 2006 (Appendix C) prepared a more comprehensive view of the modelling at a range of scales, and taking into account where the most cost effective delivery of different BMPs would occur.

There is large uncertainty surrounding climate change, and the catchment is experiencing unprecedented urban growth and landuse intensification. Both models devised mechanisms to deal with these uncertainties.

Also, the modeling did not extend to the estuary and instream processes, given the limited availability of estuarine data and resources. However, the modellers feel confident that for the assumptions stated, the models can provide a reasonable estimate of load reductions for a range of reasonable BMPS, at a reasonable scale.

Conservatism has been built into the modelling, and calibrations made against monitored nutrient and streamflow data. The derivation of phosphorus load targets based on a winter median, daily time approach possibly underestimates the total maximum load allocations.

Appendix B

Establishment of a Decision Support System for the Water Quality Improvement and Protection of the Peel Inlet and Harvey Estuary

Department of Environment, NRM and Salinity Division, Aquatic Science Branch, March 2006

Report by C. Zammit, P. Bussemaker and J. Hall.

This project involved establishing a Decision Support System which was used to test potential scenarios for any impact on the water quality of inflows to the Peel Inlet-Harvey estuarine system. The catchment was split into 17 subcatchments for the purpose of reporting to the Plan. Each scenario was tested for its impact on the median winter load and the median winter concentration of Total Phosphorus. Furthermore, Load Reduction Targets were developed using the Decision Support System, based on the Swan-Canning Cleanup Program median winter concentration target of 0.1 mg/L of Total Phosphorus. The aim was to find a suitable scenario which would meet the Load Reduction Targets and reduce median winter concentrations of Total Phosphorus.

(Report on attached CD-ROM)

Appendix C

The Support System for Phosphorus Reduction Decisions (SSPRED)

- **Model Framework Development Report. Report to Agriculture Western Australia**
- **BMP Scenarios Report. Report to Agriculture Western Australia**
- **LASCAM Scenario Report. Report to Peel-Harvey Catchment Council**

Ecotones and Associates, September 2005 and March 2006

Reports By Simon D. Neville

These reports have been produced to develop, test and implement point and non-point source Best Management Practices for the control of nutrient export in the Peel-Harvey Catchment.

Model Framework Development Report

This report has been produced to adapt an existing Excel-based Best Management Practice evaluation model (SlowCoach) to Peel-Harvey Catchment identifying the data and model requirements to adapt this model. The resulting model has been named the “Support System for Phosphorus Reduction Decisions” or SSPRED. This clearly identifies its role in management – a decision support tool for decisions on Phosphorus reductions.

BMP Scenarios Report

This report has been produced to Develop Landuse Nutrient and Best Management Practice (BMP) Models. It runs BMP model scenarios to determine the most cost effective set of actions to achieve anticipated water quality targets in rural catchments.

LASCAM Scenario Report

This report has been produced as part of a contract for the Peel-Harvey Catchment Council to extend a suite of projects as a number of additional scenarios needed clarification with respect to the lower Murray and the upper Serpentine. Additional work was required to indicate costs of BMP scenarios developed for the Peel-Harvey subcatchment by the Department of Environment using a Large Scale Catchment Model (LASCAM).

This report developed estimates of BMP implementation costs/benefits for the additional actions:

- Point Source Management (removal)
- Septic Tank Management (connection to sewer)
- Soil Remediation (application of Alkaloam).
- High level fertiliser reductions (25%, 50%, 75% and 90%)

It also ran additional SSPRED BMP model scenarios to estimate the indicative costs of actions necessary achieve anticipated water quality targets in CCI catchments (the LASCAM scenario).

(Reports on attached CD-ROM)

Appendix D

Water Quality Monitoring Programme for the Peel-Harvey Coastal Catchment. A guiding document with strategies for establishing a monitoring network capable of accurately measuring nutrient loads, November 2003

Report by Dr Tom Rose and the Aquatic Sciences Branch of the WA Department of Environment, November 2003.

This document outlines a strategy to develop a water quality monitoring program for the coastal catchment of the Peel-Harvey estuarine system that can measure nutrient loads from a monitoring network established in the following two years. This document has a strong nutrient focus, however, a robust load measuring network will be able to be adapted to measuring other water quality parameters in the future, if need arises. The network that will be established from this program will provide good catchment monitoring data to answer questions of performance required by State Ministerial Conditions and the 1992 Peel-Harvey Environmental Protection Policy. The document outlines what is needed to measure water quality and flow so that load calculations and trend analyses are computed with known precision.

(Report on attached CD-ROM)

Appendix E

Peel-Harvey Water Sensitive Urban Design

- **Peel-Harvey WSUD Local Planning Policy, A model local planning policy to assist Local Government to determine strategic and statutory proposals within the EPP Policy Area of the Peel-Harvey Coastal Catchment**
- **Peel-Harvey Coastal Catchment Water Sensitive Urban Design Technical Guidelines**

Delivered through the Federal Government's Coastal Catchment Initiative by the Peel Development Commission, October 2006.

Peel-Harvey WSUD Local Planning Policy

This policy provides a planning framework for Local Government, which aims to integrate catchment management objectives as set out in the Peel-Harvey Water Quality Improvement Plan into Local Government strategic planning and statutory decision making. The framework will assist the integration of land and water resource planning in urban landscapes, through the implementation of Water Sensitive Urban Design (WSUD) principles and practices.

The policy identifies broad policy objectives against which strategic and statutory proposals can be assessed. It will be supported by the Peel-Harvey WSUD Technical Guidelines which will provide more detail on design details, implementation methodologies and assessment tools.

This policy is an interim tool to assist Local Government to achieve landuse planning outcomes consistent with the objectives of the Environmental Protection (Peel Inlet - Harvey Estuary) Policy 1992 (Peel-Harvey EPP) and the Peel-Harvey Water Quality Improvement Plan.

It is envisaged that each Local Government will customise this Model policy to suit its own requirements, however it is expected that key areas, such as the objectives, principles and implementation framework will be retained.

Peel-Harvey WSUD Technical Guidelines

This document has been developed to support implementation of the Peel-Harvey Water Sensitive Urban Design Local Planning Policy and the objectives of the Peel-Harvey Water Quality Improvement.

This Technical Guideline is not intended to be an exhaustive catalogue of WSUD elements, but rather has been prepared to provide local government, developers and consultants with an insight into the importance of site characteristics with respect to the selection of individual WSUD elements in the 'build-up' and design of appropriate combinations of structural and non-structural practices or treatment trains.

This document provides guidance on the application of WSUD for the soil-hydrological conditions prominent throughout the Peel-Harvey region.

(Reports on attached CD-ROM)

Appendix F

Environmental Regulation Framework for the Peel-Harvey Catchment Discussion Paper – Working Draft

Report by Department of Environment, Regional Operations Division, Kwinana-Peel region in consultation with Peel Harvey Catchment Council, January 2005.

The objective of this project was to develop innovative measures to regulate both point and diffuse sources of nutrient contamination. The existing licensed premises were identified and areas of a potentially high risk of nutrient discharge (diffuse sources) were identified using Department of Agriculture and Food datasets. The Decision Support System model then determined the target loads from those sources that would achieve the desired water quality in the receiving waters.

(Report on attached CD-ROM)

Appendix G

Targeted Assistance to Intensive Agricultural Industries

By Department of Agriculture, Albany, March 2006.

This report on the "Targeted Assistance to Intensive Agricultural Industries" summarises the Coastal Catchment Initiative project and identifies opportunities to address gaps in BMP research for point sources, development and implementation, and opportunities for other voluntary, regulatory, economic and market-based measures to support uptake of point source BMPs.

(Report on attached CD-ROM)

Appendix H

Stock Exclusion from Waterways in the Peel-Harvey Coastal Plain Catchment

Report by Bob Pond, May 2005.

The "Stock Exclusion from Waterways in the Peel-Harvey Coastal Plain Catchment" project is a component of the overall Coastal Catchment Initiative to reduce phosphorus (and other nutrients) entering tributaries of the Peel-Harvey.

The aim of this project was to improve water quality in the Peel-Harvey system by reducing diffuse source nutrients and sediment from entering drains and natural waterways by fencing and excluding the grazing of stock in and adjacent to sensitive tributaries.

This project worked with landholders and waterway managers to achieve increased stock exclusion in key locations in the Peel Harvey Coastal Catchment, particularly the Serpentine River catchment. The project involved a combination of provision of fencing subsidies to landholders and waterway managers. Binding agreements for stock exclusion or limited access were sought where considered appropriate. Community consultation to inform and develop landholder and waterway manager support was undertaken and wherever possible riparian restoration of native vegetation was supported and encouraged to achieve biodiversity gains above and beyond the primary intention of nutrient reduction. All landowners have undertaken a commitment to revegetate their project in conjunction with the fencing. Where the fencing has been completed, 95 percent of the landowners committed to undertake revegetation works in the 2005 season.

In consultation with landcare groups, landcare managers, individual farmers and the Steering Committee, a Management Agreement and Statutory Declaration were drawn up to meet the needs of this project. Each landowner was consulted in reference to the conditions of the Management Agreement before funds were released.

(Report on attached CD-ROM)

Appendix I

The Framework for Marine and Estuarine Water Quality Protection

Report by the Australian Government, 2002.

1. A water quality improvement plan will as a minimum:
   a. delineate the marine and estuarine waters to which the plan applies and the catchment which contributes pollutants to those waters;
   b. identify the environmental values of those marine and estuarine waters;
   c. set out the water quality issues, pollutants of concern, and water quality objectives for those waters, and:
      - the estimated total maximum pollutant loads to achieve and maintain the water quality objectives, and how this differs from the current estimated pollutant loads (assumptions used for the basis of these estimates shall be detailed);
      - the estimated constituent point and diffuse source allocations of the total maximum pollutant loads (including from marine activities eg. aquaculture);
      - the estimated point source allocations to each licensed point source, and the allocations to non-point sources of contaminants, including atmospheric deposition or natural background sources;
      - the margin of safety used in establishing the total maximum pollutant load which accounts for uncertainty, including that associated with estimating pollutant loads, water quality monitoring, ecosystem processes and modelling;
      - how decision support systems will be developed and applied to appraise the likelihood of success of the plan, and the degree and timeliness of reductions in pollutant loads, including provision for future growth which accounts for reasonably foreseeable increases in pollutant loads (eg. approved industrial point sources, urban expansion); and
      - seasonal variation in pollutant load inputs, such that the water quality objectives will be met all year round.

   d. set out the river flow objectives for those waters, having regard for ecological and geomorphic processes relating to, but not limited to:
      - protecting natural low flows;
      - protecting important rises in water levels;
      - maintaining wetland and floodplain inundation;
      - maintaining natural flow variability; and
      - maintaining or rehabilitating estuarine processes and habitats.

   e. estimate the time required to attain and maintain water quality and river flow objectives, and the basis to those estimates;

   f. describe the control actions and/or management measures which will be implemented to ensure:
      - discharges of pollutants to coastal waters are less than the total maximum pollutant loads, for all sources irrespective of category or land use activity; and
      - environmental flow provisions will achieve the identified river flow objectives.

   g. set out a timeline, including interim targets and milestones, for implementing the control actions and/or management measures and attainment of water quality and river flow objectives, including a schedule for revising the regulatory and management arrangements, as appropriate;

h. identify accountabilities for implementing the various source control measures, as well as strategies for the maintenance of effort over time;

i. identify strategies for adaptive environmental management, recognising the implications to environmental monitoring programs of management interventions over time;

j. set out the processes for monitoring and/or modelling and reporting on the effectiveness of the control actions and/or management measures, and whether pollutant loads and environmental water provisions are being met;

k. provide time lines and costs for plan implementation;

l. identify opportunities for market based approaches to implement the plan;

m. provide for the periodic review of water quality objectives, total maximum pollutant loads, river flow objectives and environmental water provisions;

n. set out the means for public involvement and public reporting; and

o. identify the process and timing for revising the plan.

2. As an Appendix to the water quality improvement plan, the plan will also contain:

   a. legal advice stating and describing the jurisdiction's statutory capacity to implement the plan and commitments for legislative reform, as appropriate;

   b. the programs and funding committed by the jurisdiction to implementing the plan; and

   c. a "reasonable assurance" ie. a high degree of confidence that projected reductions in the total pollutant load and attainment of environmental water provisions will be achieved. The grounds to the "reasonable assurance" should be substantiated.

Further detail of the framework can be found at the webpage: http://www.environment.gov.au/coasts/pollution/cci/framework/pubs/framework.pdf