# Science Strategy for the Peel-Harvey Estuary

**Peter Rogers, Norm Hall, Fiona Valesini**

**Prepared for the Peel-Harvey Catchment Council**

**July 2010**

Centre for Fish and Fisheries Research

Murdoch University

PEEL-HARVEY CATCHMENT COUNCIL (Inc.)

*People working together for a healthy environment*

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## Executive Summary

This report, "Science Strategy for the Peel-Harvey Estuary", has been commissioned by the Peel-Harvey Catchment Council (PHCC) and prepared by the authors on their behalf. The strategy developed is about a new beginning, a fresh start towards dealing with ongoing but emerging risks for managing the ecosystem health of the Peel-Harvey Estuary. This report focuses on the ecosystem health of the estuary but, like any estuarine system, the inter-relationships between the surrounding catchment and drainage systems, including the rivers and streams and adjoining nearshore marine waters, are inherently inter-twined and thus cannot easily be separated.

Like many estuaries in Western Australia, the Peel-Harvey is changing principally due to the pressures of catchment development, increasing human populations, increasing freshwater extraction, changing water use and drying climate. The predicted effects of climate change, *i.e.* rising sea levels, shifting temperatures, intensification of storm events and reduced freshwater inflows, will continue to impact on the estuarine ecosystem, influenced strongly by nutrient flow from the catchment and changing interface with the marine environment.

The work of Professor Ernest Hodgkin and others in the 1980s and 1990s and ultimately the building of the Dawesville Channel in 1994 were pivotal in recovering the quality of the estuarine waters in the Peel-Harvey and therefore values of the system at that time.

Since the building of the channel, development and population growth in the catchment and usage of the estuary has expanded as the economy and population of Western Australia has continued to grow. Today, Mandurah and the surrounds of the Peel-Harvey Estuary, as one of the state's prime assets, continues to be a destination of considerable attraction, with the population resident in its catchment expected to double in the next ten or so years.

That is about four times the level of activity and population that existed at the time the channel was built.

Evidence is provided suggesting that the quality of the Peel-Harvey Estuary ecosystem is again declining and this is expected to become an issue of political import as ongoing population growth, intensity of catchment use and longer term climate change exert their impacts on the Peel-Harvey Estuary, the catchment and its adjacent riverine and nearshore marine waters.

This report attempts to re-define and provide an appropriate science strategy that monitors long term, ecosystem health for the estuary. It also provides a pathway for the building of predictive capacity to allow managers to cope with changing and different scenarios linked to drivers of ecological change including population growth, development and climate change. Where possible, every attempt should be made to build on existing monitoring strategies and evaluation tools assisted by model development.

In writing this report, issues of governance for the management of estuarine health, reporting and accountability are raised and discussed along with many suggestions for change. This report does not pretend it knows all the answers, nor has it covered every piece of research or issue relevant to the future management of these waters.

Like many complex and often called "wicked problems," there is no immediate quick fix or solution. The community itself has to be a necessary part of the problem identification and its solution. Community empowerment in the facilitation of ongoing adaption of science and corrective actions ensures that values of the Peel-Harvey system and its assets meet their changing expectations over time.

This science strategy has been built around a philosophy of good information, supported by monitoring and science, as the platform for effective decision making through informing the community and enlisting their support in determining priorities for management action.

Fourteen recommendations are proposed, some of which have broader application to the management of all estuaries in Western Australia. These recommendations have been built around issues of monitoring and science; development of models and indices; and community, governance and science partnerships.

The strategy for the Peel-Harvey Estuary is estimated to cost about $14 million in today's costs over a 10 year period. An aligned strategy, which extends to a range of key estuaries in the south-west, has the potential to generate substantial cost-efficiencies as part of a broader program, having similar benefits for the maintenance and improvement of estuarine ecosystem health.

One of the keys to managing the future lies with the better integration of science and its delivery across the silos of government, the tertiary institutions and the community. Fundamental to this is the proposed appointment of a senior scientist with the PHCC to be the integrator, the coordinator of science and the community's independent science champion to deliver effective collaboration, implementation and outcomes for estuarine ecosystem health.

The challenge is to match science with investment and the gradual evolvement of capacity, knowledge and solutions within an adaptive management decision-making pathway that is directly linked to transparent performance measurement and reporting. The pathway must be supported by continuous improvement in modeling and decision support tools that assimilates monitoring data, science and knowledge required to meet management needs. The development of models which integrate data and information within a systems-based framework provide the means for creating effective science-based decision-making tools for the future management of all estuaries in south-western Australia. This will provide a holistic and consistent approach for all estuaries.

One of the main recommendations of the report focuses on better governance supported by legislation. The authors believe there is considerable merit in the newly announced Chief Scientist's working group examining the need for the community to have a greater understanding of ecosystem health in all estuaries in south-western Australia and to determine action required for improving management of those systems. Should this not proceed, the option of a committee enquiry is recommended.

The challenge for the PHCC and others having an interest in this report, is to consider the merits of the case, the arguments presented and build on the proposals through debate and new knowledge. The science strategy should thus be considered as a platform for nurturing the future health of the Peel-Harvey Estuary and for extending those approaches relevant to other estuarine systems.

There are far too many assets at risk, both natural and man-made, to simply ignore the messages in this report. The proposed science strategy provides a practical pathway to moving forward.

## Forward

This science strategy for the Peel-Harvey Estuary has been developed for the PHCC to facilitate science planning, delivery and priority setting for research. The ultimate outcome aims to integrate science with the management objectives for the estuary, enabling the future development of new evaluative and predictive tools to facilitate the Council and other management stakeholders in effectively performing their advice and management functions, and to maintain the health of the estuary into the future.

The report has not been written as a fully referenced scientific paper (although references quoted are provided in full at the end of the report), but one that seeks to address emerging issues, detail risks that impact on the long term health of the estuary and identify some pathways for their resolution. Its use is primarily identified as one of informing the community, engendering debate and ultimately facilitating a greater coordination of science-led community management and investment in managing Western Australia's largest estuarine system, the Peel-Harvey Estuary; an asset having immense value to all Western Australians.

## Summary of Recommendations

***Issues of monitoring and science***

1. The ongoing successful management of the Peel-Harvey Estuary, including satisfying Ramsar obligations, needs to be built on funding, support for monitoring and the coordination of reporting by the PHCC on the following elements.
   i. The Water Quality Improvement Plan (EPA, 2008).
   ii. Total nutrient loads flowing into the estuary, ideally for phosphorous, nitrogen and organic carbon.
   iii. Analysis, performance measurement, reporting and adaption of the strategies employed to reduce nutrient flows into the estuary.
   iv. Key biotic components, including:
      a. Submerged macrophyte (macroalgae and seagrass) and littoral and fringing vegetation cover, composition and biomass throughout the estuary (3 yearly intervals);
      b. Macrophyte wrack cover, composition and biomass throughout the estuary as a proxy for year-to-year variation in macroalgae and seagrass production;
      c. The species composition and proxies for biomass of fish and benthic invertebrate communities (including crabs and prawns) throughout the estuary and its adjacent nearshore marine waters (3 yearly intervals);
      d. Water bird species counts throughout the estuary (3 yearly intervals).
      e. Spatial coverage of other habitat types, such as shallow mudflats, throughout the estuary (every 3 years);
      f. The composition of the phytoplankton communities at nominated sites throughout the estuary (2 weekly);
      g. The growth and reproductive biology of key fish and crustacean species (10 yearly intervals);
      h. Collection of data relevant to human health issues (annually as available).
   v. Nutrient and non-nutrient contaminant loads in estuarine sediments.

2. That the PHCC be sufficiently funded to enable the ongoing appointment of a Senior Scientist to deliver the following outcomes.
   i. The integration of science across the University, Government and broader community sectors and facilitation and co-ordination of a science strategy that addresses current and future risks for the Peel-Harvey Estuary, its catchment and its adjacent riverine and marine waters.
   ii. Provides, with the co-operation of the Western Australian science community and advice from government agencies, reporting on the current and projected status of the ecosystem health of the Peel-Harvey Estuary and its adjacent riverine and nearshore marine waters, and on the performance of catchment management strategies.
   iii. Helps establish priorities for research in the Peel-Harvey Estuary, its adjacent riverine and marine waters and its catchment.
   iv. Facilitates community liaison and communication on the outcomes of research relevant to the objectives of the PHCC.
   v. Facilitates co-investment and funding for monitoring, research and model development and evaluation.
   vi. Maximises the opportunity to build science capacity in the region using PhD programs, relationships with the university sector relevant to estuarine, catchment, riverine and nearshore

marine adaptive research (including restoration) and Commonwealth and State funding programs.

3. New investment in science will be required over a number of years for capacity to be developed to enable reliable prediction of the future status of the estuary. The type and accuracy of data required for quantitative modelling will depend on the questions asked, accuracy required, timing and level of risk acceptable for interpretation. Over time, knowledge and data needs to accumulate towards meeting the objective of evolving longer-term modelling and management requirements. Areas in which knowledge gaps have been identified, and thus which require new research, include the following.
   i. Development of a quantitative food-web to enable an understanding of the trophic pathways for bird and fish populations in the estuary;
   ii. The adoption of remote-sensing technologies to allow mapping of the spatial coverage of submerged macrophytes, accumulations of macrophyte wrack along the shores, littoral and fringing vegetation and shallow mudflats;
   iii. Basic but accurate bathymetry that provides data to build a hydrodynamic and sediment transport model for the estuary, capable of defining future impacts of changing water fluxes from river flows, changes in sea level, storm surges and wind conditions;
   iv. The role of sediments, particularly monosulphidic black oozes (MBOs), in the de-oxygenation of water and the entrapment and release of nutrients;
   v. Estimation of nutrient and sediment fluxes within the estuary, through production of a biogeochemical model based on the hydrologic and sediment transport model that is linked to ocean interchanges and entrance channel modification;
   vi. Detailed sedimentology throughout the estuary, including in coastal waters and land near the estuary entrance, to facilitate more accurate predictive models of longer term climatic change on the estuary and its foreshores. Its basic form should allow scenario testing for assessing various engineering solutions for adaptive management, and be able to cope with various and changing assumptions around climate change predictions;
   vii. Research surveys of recreational fishing be undertaken at least at five-yearly intervals, and that the potential of using fixed video cameras at jetties, shore locations and boat ramps, such as the Department of Fisheries is testing in other locations, should be considered for use in monitoring recreational fishing effort in the Peel-Harvey Estuary in the intervening years.
   viii. Development of multi-metric biotic indices (*e.g.* from fish or benthic invertebrate characteristics) for quantifying year-to-year changes in estuarine health condition;
   ix. A pre-feasibility study involving an expert panel that identifies the contribution to estuarine nutrient loads by various land uses in the catchment, in order to ascertain the practicality of introducing a pricing or taxing arrangement that requires or enables funds to be applied to the future management of the estuary and its associated riverine and nearshore marine waterways.

***Development of models and indices***

4. That the PHCC:
   i. Note that work is funded by the Western Australian Marine Science Institution (WAMSI) and currently progressing to develop a set of qualitative models for supporting the future development of quantitative ecosystem models that will provide decision support tools for the management of the ecosystem health of the Peel-Harvey Estuary;

ii. Note that the funding of a modelling workshop to define the type of quantitative model required to meet future management needs of the Peel-Harvey Estuary has been approved by WAMSI. The work on both this and the above initiative is planned to be completed by early 2011 (refer to section 6.1).
iii. Endorse the merits of the proposed strategy for development of the ecosystem health indices and predictive models as described in Chapter 6.
iv. Subject to the outcomes of (ii) above, the priority is for the funding of the development of a coupled hydrodynamic, biogeochemical and ecological model, which can be used as a risk-based decision tool by providing predictions of estuarine physical and ecological status arising from current and future population and climate change scenarios. This model should also account for spatial and seasonal shifts in the physico-chemical characteristics of the Peel-Harvey Estuary, as required. The key to building this model is its construction in modular form that allows each component to be built independently and integrated as needed, or as resources allow. The construction of this model could be undertaken by a range of agencies, with the correct governance arrangements. The ownership, coordination and integration of such a tool by the PHCC will be a key driver for its successful completion and utilisation.

5. Independent of the coupled model referred to above, it is plausible to fund, at lower cost, the development of estuarine health indices, including identification of their main environmental drivers, and provide the resultant information in forms that (i) are easily understood and accessed by the community and (ii) are appropriate for rigorous surveys of ecosystem status. Such an approach could be used to provide a comparative assessment of the ecosystem health of key south-western Australian estuaries over a time series. However, compared to the coupled model, its predictive capacity is limited.

***Community, governance and science partnerships***

6. Management of estuaries needs to be adaptive and have an effective governance and accountability framework that engages a partnership between the community and governments in understanding not only the future risks for estuaries, their catchments and adjacent riverine and nearshore marine waters, but also in the mitigation strategies to effectively manage complex natural resource issues. The community must be empowered through effective reporting and engagement to bring overall management performance to account, politically and through legislation.

7. To facilitate an understanding of the effectiveness of existing management programs for reducing nutrient loadings into the Peel-Harvey Estuary, the Auditor General should be requested, via the Environmental Protection Authority (EPA), to undertake a performance audit of the progress of actions proposed by that agency under its Water Quality Improvement Plan (November 2008). This review would effectively establish a benchmark for future audits and reporting. One of the audit outcomes needs to determine a cost effective means of agency performance reporting on a regular basis, including the prospect of ongoing audits every five years.

8. That the PHCC work with the Minister for Water and the Minister for Environment to seek:
   i. the establishment of a new reporting framework to require Natural Resource Management (NRM) agencies, Local Government and relevant authorities to report to a single agency charged with providing annually a report on the ecosystem health status of the Peel-Harvey Estuary. This agency would also be responsible for describing the current and predicted impacts on the estuary

and its catchment from climate change and anthropogenic activities, and separately on the progress and success of mitigation strategies to reduce risks to the health of this ecosystem.

ii. the immediate development of an interim reporting format for assessing the ecosystem health status of the Peel-Harvey Estuary within the context of south-western Australia, covering at least the Swan-Canning Estuary, the Leschenault Estuary, the Vasse region, Hardy Inlet, Wilson Inlet and Oyster Harbour.

iii. the requirement, by legislation, of relevant Government agencies to report to a single agency on the performance of their functions and programs relevant to the ongoing management of the Peel-Harvey Estuary, its catchment and its adjacent riverine and nearshore marine waterways. Importantly, this should include as relevant, programs such as the Water Quality Improvement Plan (EPA, 2008) and the Monitoring Requirements for the Peel-Yalgorup Ramsar Site (Hale, 2008).

9. The objectives of the PHCC should change to reflect stewardship responsibilities not only for the catchment, but also for the ongoing ecosystem health of the Peel-Harvey Estuary and its waterways, including its adjacent riverine and nearshore marine areas.

10. That the PHCC is sufficiently funded so that its core responsibilities can be undertaken without continually detracting from its role caused by the requirement to seek funds from various sources to ensure its ongoing operations.

11. That the Departments of Water and Environment and Conservation, in consultation with the State's NRM regions, catchment councils and EPA, explore the principles outlined in the Swan and Canning Rivers Management Act 2006 to determine how a similar but more general Act (or modification of the Waterways Conservation Act 1976) could be modelled to provide legislation relevant to the management of the State's other key estuaries and their catchments.

12. It is necessary to secure long-term funding to underpin a monitoring program that measures and reports on the current and predicted ecosystem health of the Peel-Harvey Estuary. The PHCC should consider the science strategy and develop the business case for the adoption and funding (where necessary) of the ongoing and proposed new monitoring and research, as summarised in Appendix 1 in this report. This science strategy will require a long-term funding commitment of about $14 million, in today's dollars, over a 10 year period.

13. The pathway to gaining security around future funding for monitoring, evaluation and reporting on the current and future predicted ecosystem health of the Peel-Harvey Estuary requires appropriate problem recognition, community support and political action.

14. One possible pathway is for the community to seek a formal, independent, Government-lead inquiry, with appropriate terms of reference, that examines the current status of the State's significant estuaries with respect to their funding, legislative and governance arrangements and their programs for monitoring, evaluating and reporting ecosystem health status. The inquiry needs to take into account the current and future risks for these estuaries from the impacts of climate change, population growth, freshwater extraction and catchment development. The inquiry, as a minimum, ought to focus on the Swan-Canning Estuary, the Peel-Harvey Estuary, the Leschenault Estuary, the Vasse region, Hardy Inlet, Wilson Inlet and Oyster Harbour, and their relevant catchments.

# Chapter 1 Introduction

## 1.1 Terms of Reference

The PHCC (PHCC) commissioned the Centre for Fish and Fisheries Research (CFFR) at Murdoch University to develop a science strategy for the Peel-Harvey Estuary. The strategy aims to underpin the ongoing management programs undertaken by the PHCC, state government agencies and local communities. This work commenced in October 2009 and was completed in July 2010.

The project has developed a science pathway so that the scope of future investments in research and monitoring is sufficiently integrated to allow the further development and extension of ecosystem health indices and quantitative/qualitative ecosystem models for the estuary to provide reliable decision-support tools required for management. This integration of science linked to management objectives for the estuary is central to the development of evaluation and predictive tools to enable the PHCC and other management stakeholders, including the Environmental Protection Authority (EPA) and the Department of Water (DoW), to effectively perform their advice and management functions, and to maintain the health of the estuary into the future.

The project builds on past and current research across a range of fields and identifies gaps in our current scientific knowledge and the data required to develop ecosystem-based decision-support tools for the estuary. In particular, this work was informed by the PHCC's Monitoring and Evaluation Guide for the Peel-Yalgorup Ramsar Site (PYRS; Hale 2008) and the Ecological Character Description for the PYRS (Hale and Butcher, 2007), especially with regard to the primary determinants of ecological character.

The study also drew on work progressed by the CFFR at Murdoch University in the development of indicators for estuarine health and monitoring programs already developed by management agencies and researchers, within the context of their respective objectives.

This study has two objectives:

1. To define a program of research required to enable a coupled ecosystem model/decision-support tool to be developed for the Peel-Harvey Estuary.

2. To determine potential partnerships, pathways and funding strategies for objective 1 to be progressed.

## 1.2 Scope of Report

In preparing this report, the authors examined available literature and undertook a workshop with key stakeholders in November 2009, which is reported later in this chapter.

The report has deliberately been kept concise and is structured to assist the reader who is not a scientist. An executive summary and list of recommendations is found at the front of the report. Each of the recommendations and contextual comments are provided in Chapter 2 for those readers who are interested in the summary conclusions rather than the detail of both background and science.

For those not familiar with the Peel-Harvey Estuary, an easy to read description of the estuary and its ecological health status is found in Chapter 3. The emerging issues and risks for the longer term health status of the estuary are reported in Chapter 4, drawing from information offered by attendees at the workshop held in November 2009 and subsequent "feedback" of a draft report provided to the PHCC executive in June 2010. The emerging issues canvassed in this chapter focus on what are considered by the authors to be the significant issues at an estuary wide scale.

Chapter 5 discusses "Priorities for Future Research, Monitoring and Policy Development", providing comment on actions required to address the emerging and significant issues considered to be impacting on the future health of the estuary. This chapter goes beyond the needs of science and touches upon requirements for effective compliance and governance as essential ingredients to ensure that management outcomes deliver, on an ongoing basis, a level of estuarine health that is acceptable to the community.

The concept of ecosystem health, and similar terms such as ecosystem status, integrity, quality or condition, are widely employed by environmental managers and politicians despite continuing debate surrounding their definitions, let alone how best to measure the qualities that such terms represent. Each of these terms, which are used interchangeably in the current document, is based on an evaluation of the extent to which an ecosystem deviates from a "best" attainable (or acceptable) state. The best attainable state of an ecosystem is driven, in part, by community values, which may shift over time. For these reasons, the community needs to be actively involved in defining values for the assets and acceptable limits of change for indicators of ecosystem health. An assessment of ecosystem health should be holistic and consider the extent to which (i) appropriate environmental conditions are maintained, (ii) appropriate species, populations and communities are present and (iii) ecological processes and interactions are occurring at appropriate rates and scales (Rapport *et al.* 1998).

The monitoring of estuarine ecosystem health is not an easy task due to temporal and spatial difficulties of interpretation and the numerous drivers impacting on ecological values, many of which are anthropogenic in their character. Chapter 6 defines the essential data requirements for monitoring the ecosystem health of the Peel-Harvey Estuary, and the additional data needs that are required for the development of a predictive coupled ecosystem model for managers. The modelling approaches also draw upon some of the learning's in other jurisdictions in Chapter 7, noting the task of developing an integrated model brings with it significant challenges and costs.

The issues of funding, the sourcing of those funds and who should pay are always fundamental challenges for changing science and management priorities. These aspects are explored in subsection 5.9 and Chapters 2 and 8 and, in consequence, will create the impetus for community discussion and political debate on the merits of proceeding with the proposals raised by this report, which are commented further upon in Chapter 2. Estimates of the costs provided in Appendix 1 are indicative, noting the scoping of the work is being undertaken at a high level. The ultimate costs will very much depend on the level of complexity built into the various decision modules of the coupled model and the rate of development of that model.

### 1.3 Workshop Approach/Methodology

A workshop was held on the 23rd November 2009 in the boardroom of the Marine Operations Centre, 107 Breakwater Parade, Mandurah Ocean Marina. A total of 32 persons attended representing managers, researchers and community members actively engaged in some aspect of the Peel-Harvey Estuary or its catchment. Representatives attended from the Departments of Agriculture and Food, Water, Environment and Conservation, Fisheries, Planning and Transport and the Peel Development Authority, City of Mandurah, Shire of Pinjarra, Murdoch University and Curtin University. Community members also attended, including those from the PHCC and commercial and recreational fishing representatives.

The day's program comprised two parts, a morning seminar session presenting recent insights into the past and current health status of the Peel-Harvey Estuary, likely issues arising from climate change impacts, the use of biotic indicators for measuring trends in ecosystem health and current perspectives on ecosystem modeling.

The afternoon session work-shopped the identification of key management and science questions relevant to the future management of the estuary, the research needs and tools required. The workshop also scoped future research and monitoring needs to meet the information requirements of various management agencies and to monitor the impact of their decisions on the ongoing health of the estuary. Potential sources of funding were listed.

The aim of this workshop was to seek information and participation from various Natural Resource Management (NRM) agencies, local government and interest groups from the community in the development of management "led" evaluation tools for the Peel-Harvey Estuary. The outcomes of this workshop were used by the researchers to develop a report framework and draft science strategy for the PHCC.

The draft report was submitted in June 2010 to enable the clients (the PHCC) and the authors to test the veracity of the report and obtain feedback on relevance and appropriateness of its findings prior to completion of the final report and submission to the Council.

## Chapter 2 Science Strategy for the Peel-Harvey Estuary

This chapter summarises the findings of this report, drawing upon the information presented in the following chapters and the collective experience of the authors and numerous contributors to this report. The recommendations presented are unlikely to be the final word on either the science strategy or the actions required for its delivery due to the multifaceted complexity of the issues before the PHCC and the numerous parties involved and affected.

This chapter sets down the recommendations of this report and provides contextual comments to allow the reader to more effectively interpret this report. The themes outlined in this report focus on an understanding of the basic science and monitoring required for the Peel-Harvey catchment, rivers and particularly the estuary, through the development of indices and models, and enabled by improving the partnership between the community, government and science providers.

***Issues of monitoring and science***

**Recommendation**

1. The ongoing successful management of the Peel-Harvey Estuary, including satisfying Ramsar obligations, needs to be built on funding, support for monitoring and the coordination of reporting by the PHCC on the following elements.
    i. The Water Quality Improvement Plan (EPA, 2008).
    ii. Total nutrient loads flowing into the estuary, ideally for phosphorous, nitrogen and organic carbon.
    iii. Analysis, performance measurement, reporting and adaption of the strategies employed to reduce nutrient flows into the estuary.
    iv. Key biotic components, including:
        a. Submerged macrophyte (macroalgae and seagrass) and littoral and fringing vegetation cover, composition and biomass throughout the estuary (3 yearly intervals);
        b. Macrophyte wrack cover, composition and biomass throughout the estuary as a proxy for year-to-year variation in macroalgae and seagrass production;
        c. The species composition and proxies for biomass of fish and benthic invertebrate communities (including crabs and prawns) throughout the estuary and its adjacent nearshore marine waters (3 yearly intervals);
        d. Water bird species counts throughout the estuary (3 yearly intervals).
        e. Spatial coverage of other habitat types, such as shallow mudflats, throughout the estuary (every 3 years);
        f. The composition of the phytoplankton communities at nominated sites throughout the estuary (2 weekly);
        g. The growth and reproductive biology of key fish and crustacean species (10 yearly intervals);
        h. Collection of data relevant to human health issues (annually as available).
    v. Nutrient and non-nutrient contaminant loads in estuarine sediments.

***Comment***

*Chapters 5 and 6 in particular provide considerable comment on elements around monitoring and reporting relevant to this recommendation.*

*Appendix 1 provides a snapshot but comprehensive view of existing monitoring programs under the WQIP and other management and research projects, those proposed by the PHCC in their Monitoring and Evaluation Guide for the PYRS (Hale, 2008) and those proposed by this report. The comparative difference between each of these identifies the existing monitoring gaps that are required to be filled to place ecosystem health measurement and future prediction on a solid platform.*

*Proposed measurement of the key biotic components is intentionally structured to enable the identification of their longer term trends in response to shifts in estuarine conditions. Without regular assessment, longer term trends are difficult to interpret and separate from year to year variance.*

*All of this data is relevant to compiling and reporting the proposed indices of estuarine health, as well as the coupled model.*

*The core elements for an effective estuarine health monitoring and evaluation program must include physical as well as some biological components. The key monitoring elements are listed in order of priority in the above recommendation.*

*As outlined in the comments for recommendation 8, in the absence of a single reporting body covering all elements of ecosystem and management performance reporting impacting on the Peel-Harvey system, it is suggested that the PHCC performs this function.*

**Recommendation**

2. That the PHCC be sufficiently funded to enable the ongoing appointment of a Senior Scientist to deliver the following outcomes.
    i. The integration of science across the University, Government and broader community sectors and facilitation and co-ordination of a science strategy that addresses current and future risks for the Peel-Harvey Estuary, its catchment and its adjacent riverine and marine waters.
    ii. Provides, with the co-operation of the Western Australian science community and advice from government agencies, reporting on the current and projected status of the ecosystem health of the Peel-Harvey Estuary and its adjacent riverine and nearshore marine waters, and on the performance of catchment management strategies.
    iii. Helps establish priorities for research in the Peel-Harvey Estuary, its adjacent riverine and marine waters and its catchment.
    iv. Facilitates community liaison and communication on the outcomes of research relevant to the objectives of the PHCC.
    v. Facilitates co-investment and funding for monitoring, research and model development and evaluation.
    vi. Maximises the opportunity to build science capacity in the region using PhD programs, relationships with the university sector relevant to estuarine, catchment, riverine and nearshore marine adaptive research (including restoration) and Commonwealth and State funding programs.

***Comment***

*A significant component and a driving success factor for the ultimate delivery and construction of the Dawesville Channel in 1994 was the work of Professor Ernest Hodgkin. This scientist was an eminent leader who facilitated the co-ordination and delivery of the collaborative science required across the University and Government sectors necessary to provide the Government and Ministers of the day, the case and confidence to proceed with the Dawesville solution.*

*The value of this independent science leadership facilitated at the time through the EPA was pivotal.*

*With population growth, the solutions of the 1990s are becoming less relevant (refer Chapter 4).*

*A great deal of new science is required to manage future risks for the environmental and ecosystem health of the estuary, rivers and nearshore marine waters. Population and associated development growth along with climate change are significant drivers for changing the condition of these aquatic systems.*

*Collaborative partnerships with the University sector through co-investment, research partnerships, post-graduate research training, joint monitoring programs and collaborations that facilitate learning from other overseas estuarine and riverine restoration programs, can only be to the benefit of the PHCC and its charter. Such partnerships potentially have the capacity to reduce research costs to State Government as the immediate funder. Building science capacity facilitates new knowledge and creation of new solutions. It makes business sense.*

*Coordination of planning, priority setting for science, attraction of funds and the management, delivery and communication of outcomes to stakeholders is key to cost effective delivery of the relevant science and information.*

*A scientist charged with the responsibility for leading the delivery of such a research program needs to be able to provide independent science focussed advice, free of government agency directive but capable of providing leadership within the field. The employment of a senior scientist within the PHCC could fulfil such a role and effectively be the voice of the community science champion. In other jurisdictions, a similar role has been provided by the University sector.*

**Recommendation**

3. New investment in science will be required over a number of years for capacity to be developed to enable reliable prediction of the future status of the estuary. The type and accuracy of data required for quantitative modelling will depend on the questions asked, accuracy required, timing and level of risk acceptable for interpretation. Over time, knowledge and data needs to accumulate towards meeting the objective of evolving longer-term modelling and management requirements. Areas in which knowledge gaps have been identified, and thus which require new research, include the following.
    i. Development of a quantitative food-web to enable an understanding of the trophic pathways for bird and fish populations in the estuary;
    ii. The adoption of remote-sensing technologies to allow mapping of the spatial coverage of submerged macrophytes, accumulations of macrophyte wrack along the shores, littoral and fringing vegetation and shallow mudflats;

iii. Basic but accurate bathymetry that provides data to build a hydrodynamic and sediment transport model for the estuary, capable of defining future impacts of changing water fluxes from river flows, changes in sea level, storm surges and wind conditions;
iv. The role of sediments, particularly monosulphidic black oozes (MBOs), in the de-oxygenation of water and the entrapment and release of nutrients;
v. Estimation of nutrient and sediment fluxes within the estuary, through production of a biogeochemical model based on the hydrologic and sediment transport model that is linked to ocean interchanges and entrance channel modification;
vi. Detailed sedimentology throughout the estuary, including in coastal waters and land near the estuary entrance, to facilitate more accurate predictive models of longer term climatic change on the estuary and its foreshores. Its basic form should allow scenario testing for assessing various engineering solutions for adaptive management, and be able to cope with various and changing assumptions around climate change predictions;
vii. Research surveys of recreational fishing be undertaken at least at five-yearly intervals, and that the potential of using fixed video cameras at jetties, shore locations and boat ramps, such as the Department of Fisheries is testing in other locations, should be considered for use in monitoring recreational fishing effort in the Peel-Harvey Estuary in the intervening years.
viii. Development of multi-metric biotic indices (*e.g.* from fish or benthic invertebrate characteristics) for quantifying year-to-year changes in estuarine health condition;
ix. A pre-feasibility study involving an expert panel that identifies the contribution to estuarine nutrient loads by various land uses in the catchment, in order to ascertain the practicality of introducing a pricing or taxing arrangement that requires or enables funds to be applied to the future management of the estuary and its associated riverine and nearshore marine waterways.

***Comment***

*In developing this report, a number of identified gaps in science have emerged in writing Chapters 4 - 6 which need to be investigated. These are summarised in section 4.6. Undoubtedly as model development for the Peel-Harvey Estuary occurs, other gaps will emerge as information is found to be either not available or incomplete.*

*Those data requirements listed may have different time priorities around their development depending on the management issues requiring assessment and the overall state of model development. This is an issue that requires co-ordination and management by the PHCC in conjunction with the Senior Scientist appointment.*

*Judicious management of research proposals through PhD research scholarships and University sponsored research will assist through applications to existing granting bodies and co-investment to reduce costs.*

*One significant issue requiring priority consideration is that relating to (ix) above and section 5.9 covering new funding options. This has major relevance to broadening the case for new funding approaches for addressing management needs and supporting science for Western Australia's estuaries and its waterways, including adjacent nearshore marine areas.*

***Development of models and indices***

**Recommendation**

4. That the PHCC:
    i. Note that work is funded by the Western Australian Marine Science Institution (WAMSI) and currently progressing to develop a set of qualitative models for supporting the future development of quantitative ecosystem models that will provide decision support tools for the management of the ecosystem health of the Peel-Harvey Estuary;
    ii. Note that the funding of a modelling workshop to define the type of quantitative model required to meet future management needs of the Peel-Harvey Estuary has been approved by WAMSI. The work on both this and the above initiative is planned to be completed by early 2011 (refer to section 6.1).
    iii. Endorse the merits of the proposed strategy for development of the ecosystem health indices and predictive models as described in Chapter 6.
    iv. Subject to the outcomes of (ii) above, the priority is for the funding of the development of a coupled hydrodynamic, biogeochemical and ecological model, which can be used as a risk-based decision tool by providing predictions of estuarine physical and ecological status arising from current and future population and climate change scenarios. This model should also account for spatial and seasonal shifts in the physico-chemical characteristics of the Peel-Harvey Estuary, as required. The key to building this model is its construction in modular form that allows each component to be built independently and integrated as needed, or as resources allow. The construction of this model could be undertaken by a range of agencies, with the correct governance arrangements. The ownership, coordination and integration of such a tool by the PHCC will be a key driver for its successful completion and utilisation.

***Comment***

*The Western Australian Marine Science Institution, as part of its marine science program into sustainable marine ecosystems (node 4), is developing methods and generating information needed to assist with the management of fisheries and marine ecosystems of WA. This work is being co-ordinated by the Department of Fisheries Research Division at Hillarys.*

*As referred to in Chapter 6, this research, built around qualitative and quantitative modelling, will aim to define the key relationships for ecosystem assessment and model design and build requirements for the Peel-Harvey Estuary.*

*The PHCC has agreed to actively participate in the WAMSI modelling workshop and is encouraging all interested parties to support ongoing work in this area in the spirit of furthering development of partnership arrangements.*

*Reports resulting from these workshops will directly assist the PHCC in its future planning for development of diagnostic tools for predicting the future status of the Peel-Harvey Estuary and model design and build scoping requirements.*

*It is planned both reports will be available for the PHCC by early 2011.*

*Without appropriate quantitative model development, any scope for predicting future risks and impacts of catchment development, population growth and climate change scenarios on the status of the estuary will be* *extremely limited. Chapter 6 provides a pathway for progression of model development, which is dependent upon the successful appointment of a senior scientist to manage collaboration across a range of institutions. The outcomes of the WAMSI funded projects will continue to refine the work that is required.*

*Investment in the development of a completed hydrodynamic, biogeochemical and ecological model that can be used as a risk based decision tool for planning and assessment of different development and climate change scenarios, is considered an essential need. How it is developed and integrated as a co-ordinated, across government/university science evaluation tool, will be crucial to its ongoing utility and effectiveness.*

*The rate of the model's development and its modular construction, which will allow different agencies to independently build and use various components of the tool, will be a significant challenge and require effective co-ordination, integration and commitment across agencies. There is also the opportunity, as outlined in Chapter 6, to modify or directly use off-the-shelf models to facilitate early development and to build on modelling work already completed.*

*Such a model will require continual updating as the monitoring information and inputs alter over time (possibly decadal) and the types of management questions change both in terms of scale and complexity. The model would also need to be sufficiently flexible to eventually cope with changing assumptions around forecasts on the impacts of climate change, changes in freshwater flows and requirements for different engineering and/or restoration options.*

*Whilst a number of agencies could assume responsibility, it is proposed that the PHCC should be the lead organisation for facilitating the model's development, coordinating integration and ensuring its relevance and understanding as an evaluation tool that is linked to reporting and meeting community expectations for the ongoing management of the estuary. The Senior Scientist appointment as outlined in recommendation 2 could assume the integration and coordination role.*

**Recommendation**

5. Independent of the coupled model referred to above, it is plausible to fund, at lower cost, the development of estuarine health indices, including identification of their main environmental drivers, and provide the resultant information in forms that (i) are easily understood and accessed by the community and (ii) are appropriate for rigorous surveys of ecosystem status. Such an approach could be used to provide a comparative assessment of the ecosystem health of key south-western Australian estuaries over a time series. However, compared to the coupled model, its predictive capacity is limited.

***Comment***

*The case for effective reporting of estuarine health as a tool for improving community and government feedback on the status of the estuaries has been substantially raised throughout this report.*

*Section 5.1.1 and 6.3 specifically cover the opportunity to develop a statistically based estuarine health index. Murdoch University has the capacity to develop such an index relevant to measuring year-to-year variation in defined biotic assemblage metrics. Work on the development of such an index has progressed for the Swan-Canning Estuary within a current PhD research program. This work could be extended to other estuaries with sufficient funding.*

***Community, governance and science partnerships***

**Recommendation**

6. Management of estuaries needs to be adaptive and have an effective governance and accountability framework that engages a partnership between the community and governments in understanding not only the future risks for estuaries, their catchments and adjacent riverine and nearshore marine waters, but also in the mitigation strategies to effectively manage complex natural resource issues. The community must be empowered through effective reporting and engagement to bring overall management performance to account, politically and through legislation.

***Comment***

*The management of estuaries and their catchments fall within the context of 'wicked' problems, that is they are difficult to define, have many interdependences, often no clear solutions, involve changing behaviours and are characterised by chronic policy failure (refer 5.8). By their nature they are not easily resolved and require effective engagement of the community through multiple agencies with different roles and responsibilities. Solutions have to be adaptive assisted through effective reporting with clear accountabilities.*

*A successful policy mix must include measurement of performance and reporting to be understood by the community and, as necessary, application of mitigation strategies supported by science within an adaptive management cycle (refer 7.2). The empowerment of the community comes from knowledge, the recognition of arising problems and their willingness to engage with decision makers including political action.*

**Recommendation**

7. To facilitate an understanding of the effectiveness of existing management programs for reducing nutrient loadings into the Peel-Harvey Estuary, the Auditor General should be requested, via the Environmental Protection Authority (EPA), to undertake a performance audit of the progress of actions proposed by that agency under its Water Quality Improvement Plan (November 2008). This review would effectively establish a benchmark for future audits and reporting. One of the audit outcomes needs to determine a cost effective means of agency performance reporting on a regular basis, including the prospect of ongoing audits every five years.

***Comment***

*Much of the success of mitigation strategies aimed at reducing nutrient impacts on the estuary depend on the success of the EPA actions of best management practice and recommended actions for implementation of the Water Quality Improvement Plan.*

*Without an audit of funding/performance of current programs under these actions, it is not possible to assess levels of compliance or improvements in delivery of actions into the future. Without some measure of performance audit noting multiple agencies are involved, there is a real risk priorities could shift with no apparent accountabilities in performance reporting.*

*One approach could be to encourage the Office of the Auditor General to provide an initial impetus for ongoing regular performance measurement and reporting which falls within their audit scope across government. Guidance on future audit approaches would also assist in clarifying how best to undertake future assessments.*

**Recommendation**

8. That the PHCC work with the Minister for Water and the Minister for Environment to seek:
    i. the establishment of a new reporting framework to require Natural Resource Management (NRM) agencies, Local Government and relevant authorities to report to a single agency charged with providing annually a report on the ecosystem health status of the Peel-Harvey Estuary. This agency would also be responsible for describing the current and predicted impacts on the estuary and its catchment from climate change and anthropogenic activities, and separately on the progress and success of mitigation strategies to reduce risks to the health of this ecosystem.
    ii. the immediate development of an interim reporting format for assessing the ecosystem health status of the Peel-Harvey Estuary within the context of south-western Australia, covering at least the Swan-Canning Estuary, the Leschenault Estuary, the Vasse region, Hardy Inlet, Wilson Inlet and Oyster Harbour.
    iii. the requirement, by legislation, of relevant Government agencies to report to a single agency on the performance of their functions and programs relevant to the ongoing management of the Peel-Harvey Estuary, its catchment and its adjacent riverine and nearshore marine waterways. Importantly, this should include as relevant, programs such as the Water Quality Improvement Plan (EPA, 2008) and the Monitoring Requirements for the Peel-Yalgorup Ramsar Site (Hale, 2008).

***Comment***

*The lack of transparency and understanding by the community on the status of the Peel-Harvey Estuary and other important estuaries in Western Australia continues to be problematic. Without regular science based assessment and reporting within an agreed format on the current and future predicted health status of Western Australia's estuaries, it is difficult for government, politicians and the community to understand current and future risks to the health of the Peel-Harvey system from impacts of population growth, increasing freshwater extraction, climate change and regional development, as well as changing estuary usage and modification.*

*Some of the necessary information appears to be already collected, but in multiple agencies. There needs to be a clear focus on reporting that is easily understood by the community and government, with underlying detail for managers and scientists.*

*The process for development of an agreed reporting format will, by necessity, need to be iterative, based firstly on an interim format that is progressed through a cycle linking science and monitoring with reporting, performance measurement and adaptive management changes. Together, these should facilitate an ongoing review and improvement process with community engagement and empowerment in decision making. The adaptive decision making pathway outlined in Figure 4, Chapter 7, provides a suitable schematic for such a process.*

*Legislative obligation for reporting to a single community/government body would improve accountability and transparency and provide the opportunity for community empowerment.*

*In the absence of such a body/partnership, the PHCC could provide such a function.*

*There is a case, noting the emerging risks for the Peel-Harvey Estuary, its catchment and rivers, for early progression of this pathway as a pilot for, eventually, a state-wide program for the management of estuarine health in the face of ongoing population growth, development and climate change. That is, the learnings from the pilot study in the Peel-Harvey system could be easily modified and extended to other south-western Australian estuaries. Whilst this has relevance for those estuaries, those in the north-west of W.A. have a different set of dynamics, drivers and threats.*

**Recommendation**

9. The objectives of the PHCC should change to reflect stewardship responsibilities not only for the catchment, but also for the ongoing ecosystem health of the Peel-Harvey Estuary and its waterways, including its adjacent riverine and nearshore marine areas.

***Comment***

*The objectives of the PHCC, as the name suggests, focus on the catchment. The trend from other jurisdictions is for integration of management responsibilities to extend from the catchment and rivers to the estuary and adjoining marine waters. This needs to be considered by the PHCC explicitly in its charter and organisational structure.*

**Recommendation**

10. That the PHCC is sufficiently funded so that its core responsibilities can be undertaken without continually detracting from its role caused by the requirement to seek funds from various sources to ensure its ongoing operations.

***Comment***

*A significant degree of effort is exerted annually by the PHCC staff and Board members in raising sufficient funding through granting bodies and government sources to maintain operational currency.*

*This activity detracts from the core functions and effectiveness of the Council.*

*Security in funding would make the Council and its staff more effective in its role and enable better delivery of programs under its purview.*

*For this to occur requires a wider examination of governance arrangements (refer recommendations 2, 8, 11 and 12).*

**Recommendation**

11. That the Departments of Water and Environment and Conservation, in consultation with the State's NRM regions, catchment councils and EPA, explore the principles outlined in the Swan and Canning Rivers Management Act 2006 to determine how a similar but more general Act (or modification of the Waterways Conservation Act 1976) could be modelled to provide legislation relevant to the management of the State's other key estuaries and their catchments.

***Comment***

*The Swan and Canning Rivers Management Act 2006 passed by government in September of that year provides arguably the most coherent legislation for the protection of a Western Australian estuarine system.*

*The new legislation supports the "Healthy Rivers Action Plan" for the Swan-Canning Estuary (Swan River Trust, 2008) by:*

- *"Providing a statutory basis for water quality targets;*
- *Establishes a whole–of–government approach for river management including Ministerial approval of management programs;*
- *Establishes the Swan Canning River park;*
- *Providing a statutory basis for partnerships agreements and;*
- *Enabling the use of River Protection Notices as a mechanism to address activities affecting water quality".*

*The provisions of Part 4 Division 2-4 of that Act provides for strengthened governance around the "River Protection Strategy", defining accountabilities for performance and those responsible for management arrangements, and may inclusively specify reporting and compliance requirements. The Act also binds Chief Executive officers and their respective Ministers under 33 separate Western Australian Acts (refer schedule 5), subject to defined consultative and agreement procedures in the delivery of the River Protection Strategy or management program.*

*Differences arising from disputes in content of the strategy or management program between Ministers are to be resolved by the Governor; that is, in effect, Cabinet.*

*Another important component of the legislation is for the Trust to monitor and report on compliance to the Minister on the extent to which targets are met and on the ongoing operation and effectiveness of the strategic documents.*

*It is not clear from the legislation whether non-performances in reporting or delivery of programs by the accountable agencies, in accordance with the "approved" strategic documents, are made "public" beyond presumably their reporting under Section 66. Arguably non-performance in delivery and reporting should occur (refer Section 66(4)) and be transparent to the community.*

*The power to issue a River Protection Notice was also seen as an essential element in the legislation.*

*Whilst performance under the Swan and Canning Rivers Management Act 2006 is yet to be fully assessed, the principles adopted appear sensible and ought to be incorporated in the Waterways Conservation Act of 1976.*

*Whether a similar 'Trust' body needs to be created for other estuaries in order to provide clearer lines of accountability, improved governance and financial responsibility is not considered, but is an issue requiring exploration.*

*The Waterways Conservation Act 1976 (as amended) provides many of the powers reflected in the Swan and Canning Rivers Management Act 2006, but does not have the same level of accountabilities.*

*A case could be made for the PHCC to write to relevant Ministers seeking a review of existing legislation controlling management of the State's other estuaries and waterways towards having similar compliance requirements as that in place for the Swan and Canning Rivers.*

*Any findings from the announced appointment of a working group to examine "estuarine ecosystem health" and new requirements for legislative change should also form part of any legislative review (refer to recommendations 8 and 14).*

**Recommendation**

12. It is necessary to secure long-term funding to underpin a monitoring program that measures and reports on the current and predicted ecosystem health of the Peel-Harvey Estuary. The PHCC should consider the science strategy and develop the business case for the adoption and funding (where necessary) of the ongoing and proposed new monitoring and research, as summarised in Appendix 1 in this report. This science strategy will require a long-term funding commitment of about $14 million, in today's dollars, over a 10 year period.

***Comment***

*This issue of long-term funding has arisen due to uncertainty and lack of long-term commitment by Government for the management of estuarine health. Without an effective monitoring program and performance reporting on the current and predicted status of the estuary, support for action programs to mitigate or reduce nutrient impacts as a consequence of population growth, associated development etc. remains problematic.*

*Tables 1-3 presented in Appendix 1 specify, in tabular form, a science strategy and estimated costs for the Peel-Harvey Estuary.*

*Indicative cost estimates have been provided based on, where practical, known comparative costs from other like projects and programs, drawing from a number of sources. These need to be refined and updated as new information becomes available and used as an ongoing 'tool' for progressing the Science Strategy for the Peel-Harvey Estuary, in order to retain currency over time.*

*The next steps for the PHCC are to progress a business case built around the Science Strategy and develop priorities for funding and timelines for delivery of its key components. One of the key issues will be strengthening the partnerships and accountabilities for performance with Government, science providers and the community. These are addressed throughout this report.*

**Recommendation**

13. The pathway to gaining security around future funding for monitoring, evaluation and reporting on the current and future predicted ecosystem health of the Peel-Harvey Estuary requires appropriate problem recognition, community support and political action.

***Comment***

*Much of the success of the South-East Queensland Healthy Waterways Partnership and the European Union Water Framework Directive (refer Chapter 7) comes from community empowerment and a willingness to look beyond the catchment to the health of the estuary and adjacent riverine and marine waters. Adequacy for funding monitoring,* *evaluation and reporting on estuarine health by Governments will only occur through problem recognition and political lobbying. Unfortunately for the Peel-Harvey Estuary, political interest in its ecosystem health waned following the construction of the Dawesville Channel.*

*Ongoing population growth, intensification of development and freshwater extraction within the catchment and increasing use of the waterways will again threaten the ecosystem health of the estuary. There is evidence to suggest this is already the case (refer Chapter 3).*

*It is paradoxical that the loss of dolphins in the Swan-Canning Estuary has caused the Chief Scientist for Western Australia to report that these deaths are symptomatic of a larger problem,* i.e. *the ecosystem health of the estuary itself.*

*It is becoming more evident that there are growing risks for the ecosystem health of other estuaries in south-western Australia.*

**Recommendation**

14. One possible pathway is for the community to seek a formal, independent, Government-lead inquiry, with appropriate terms of reference, that examines the current status of the State's significant estuaries with respect to their funding, legislative and governance arrangements and their programs for monitoring, evaluating and reporting ecosystem health status. The inquiry needs to take into account the current and future risks for these estuaries from the impacts of climate change, population growth, freshwater extraction and catchment development. The inquiry, as a minimum, ought to focus on the Swan-Canning Estuary, the Peel-Harvey Estuary, the Leschenault Estuary, the Vasse region, Hardy Inlet, Wilson Inlet and Oyster Harbour, and their relevant catchments.

***Comment***

*The recently released report by the Chief Scientist Lyn Beazley on "Dolphin deaths in the Swan-Canning River Park and comments on the Bunbury inner waters, South West of Western Australia" has proposed a similar review to examine estuarine health (see recommendation 8 of that report). The above recommendation adds support and provides the basis for determining the "terms of reference" for a working group to be commissioned by the Minister for Environment, quoted below.*

*"The Minister to establish a working group with extensive experience of science and government policy. The group should report within six months and recommend initiatives that build on existing local expertise and science infrastructure in the field of marine mammal health and estuarine health. The working group should consider ways to achieve greater integration between government agencies, science institutions, industry and the community. Arrangements should ensure that the scientific activities are conducted to an international standard and that there are clear reporting mechanisms of achieved outcomes."*

*The authors strongly endorse this recommendation and welcome Minister Faragher's action to proceed with this recommendation.*

*The PHCC should consider the merits of a broader enquiry and, in the context of Lyn Beazley's report, seek support for the working group to consider the need for the community to have a greater understanding of ecosystem health* *in all estuaries in south-western Australia, and to determine action required for improving management of those systems. Should this not proceed, the option of a committee enquiry is recommended.*

## Chapter 3 Description of Status of Estuary and Rivers

### 3.1 Physical and Geographical Description

The estuary is located 75 km south of Perth, with Mandurah, a significant regional centre located at the 'natural' entrance of the estuary. This entrance channel, which is approximately 5 km long, connects the ocean at Halls Head to the northern end of Peel Inlet. The system consists of two shallow interconnected lagoons, the Peel Inlet and the Harvey Estuary. The two basins are broadly similar in area (Peel Inlet 75 $km^2$ and Harvey Estuary, 56 $km^2$) and mean and maximum water depth (mean of 0.8 m in Peel Inlet and 1.0 m in Harvey Estuary and a maximum of about 2.5 m in each basin). Three significant rivers, the Murray, Serpentine and Harvey, discharge into the estuary.

In 1994, the Dawesville Channel was constructed, connecting the southern end of Peel Inlet and the northern end of Harvey Estuary to the ocean.

The catchment of 11,930 $km^2$ is divided into 3 major sub-catchments comprising those for the Serpentine, Murray and Harvey (refer Fig. 1).

Since settlement, the rivers and floodplain catchments have been significantly modified through land clearing, agriculture, water supply reservation, drainage and urbanisation.

Approximately 75% of the coastal plain has been cleared of native vegetation with reportedly over 1,330 kilometres of waterways, both natural and artificial, in the catchment. When taking into account the extent of gazetted and unofficial drains in the catchment, the net result is that the coastal plain is extensively drained. Significantly, over 60% of the catchment has coarse sandy soils which, by their nature, have a low phosphorus retention index. Such soils readily leach phosphorous by movement of water through and across the soil.

This loss of phosphorus and other nutrients (principally nitrogen and organic carbon) has been and continues to be a significant factor in the high egress of nutrients into the drains, streams, rivers and underground aquifers, which eventually find their way into the Peel-Harvey Estuary, sometimes with considerable time lags of up to 50 years.

### 3.2 Water Quality and Hydrology

Following decades of declining water quality and major community concerns about severe micro- and macroalgal blooms within the estuary, Government acceded to the construction of the Dawesville Channel. This reportedly improved the quality of the water in the main body of the Peel Inlet and Harvey Estuary and slowly reduced the incidence of *Nodularia spumigena* (blue-green algae) blooms and extent of macroalgae production. Increasing salinity was an important factor in reducing the incidence of nuisance algae, and the flushing effect of both nutrients and water by the construction of the Dawesville Channel also provided some benefit towards improving longer term water quality. Exchange between the ocean and estuary was expected to increase three fold, having a significant annual flushing effect on both phosphorus (approx. 100 tonnes) and nitrogen (900 tonnes) through largely tidal action.

After the channel was opened, the amount of macro algae continued to decrease across the entire Peel-Harvey basin at least until 2000/01, when comprehensive surveys ceased. However, anecdotal reports suggest that macroalgal production is again starting to increase. A recently completed assessment of seagrass and macroalgal composition and biomass throughout the Peel-Harvey will provide confirmation of whether such reports are true.

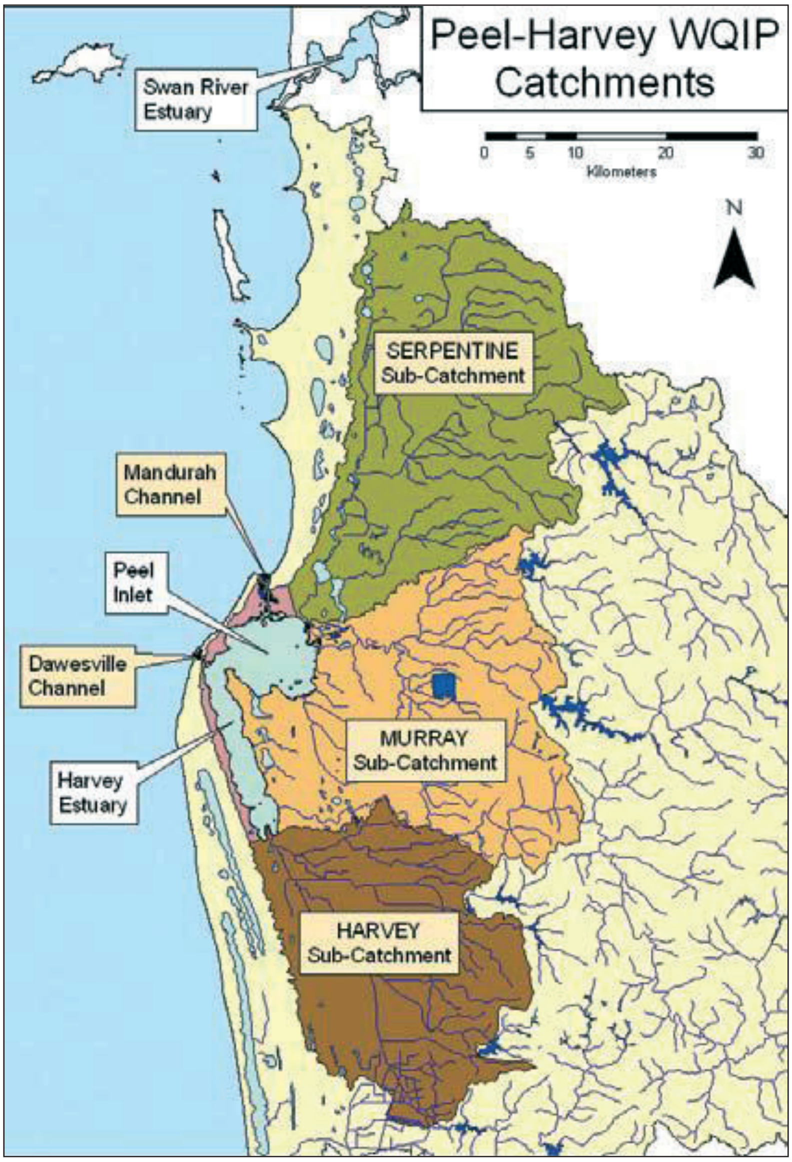


**Figure 1:** Main sub-catchments of the Peel-Harvey Estuary (EPA, 2008).

However, water quality and environmental problems remain in the rivers and over time have continued to get worse. The lower reaches of the Serpentine River, as an effective ecosystem, could now be described as biologically dead and perhaps not possible to save, and there are indications that the health of the lower reaches of both the Murray and Harvey rivers are in a parlous biological state.

The EPA report of November 2008 (*Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System – Phosphorus Management*) provides a good snapshot of current policy objectives, management and actions to reduce phosphorus discharge into the system. The observation that phosphorus targets of median loadings of 75 tonnes per year (for an average year) have not been met since 2003, but are largely occurring at twice that level, continues to be concerning. Whilst the monitoring and decision support systems for water quality protection and phosphate reduction systems appear to be meeting the task assigned for measurement of catchment nutrient inflows, these results are not integrated with the nutrient dynamics of the estuary or the estuarine ecosystem *per se*.

The water quality monitoring program is comprised of a fortnightly to monthly sampling regime at eight to 11 sites throughout the estuary (Fig. 2).

Whether such a regime is adequate depends very much on the intent of the monitoring program. The data collected provide scarce information on the levels of organic carbon and there is potentially insufficient spatial coverage of monitoring sites to provide an adequate understanding of how nutrient flows in the estuary relate to ecosystem function. A review of other accessible and relevant data sets known to Murdoch University points to insufficient current monitoring data being available for effective modelling of estuarine hydrology, biogeochemistry (including nutrient flows) and ecology without augmentation by a complementary field program. This aspect is further explored in Chapter 5 and summarised in Appendix 1, which supports an increased level of sampling of 19 sites from the current 8-11 sites.

The tidal range of the estuary above the datum for the Peel Inlet is about 0.62 metres with a higher range of 0.91 metres and 1.07 metres at the Mandurah ocean entrance and Dawesville Channel entrance, respectively. Whilst water inflows from the major rivers into the estuary are reasonably understood, the rate of flow and quality of water from underground sources are not adequately described. Since the Dawesville Channel has been constructed, the system overall has become more saline. Particularly high salinities have been recorded in the southern Harvey Estuary over the summer months, and the higher salinities in the upper reaches of the estuary are understood to be impacting on adjoining riparian vegetation.

Current and detailed bathymetry of the Peel-Harvey Estuary is not known. Existing bathymetrical data for the system was collected in 1971 using single beam sonar, with more recent data collected only for small areas of interest, such as those associated with new constructions (*e.g.* the Mandurah Ocean Marina). Although a LIDAR survey was recently commissioned by the Department of Water for the Swan Coastal Plain, the particular methodology employed is only useful for detecting contour elevation in terrestrial areas. While this information is useful for accurately reflecting the topography of the catchment (vertical accuracy of 0.15 m), it is of no use for the estuary itself. This is because the particular LIDAR used is not appropriate for water. The bathymetry of the system thus needs to be remeasured to provide sufficiently accurate data to construct a reliable hydrodynamic physical model for the estuary, which can then connect to one constructed for the adjoining land. The importance of this level of resolution applies when taking into account detailed hydrodynamic modelling connected to changes in sea levels associated with climate change. This not only has relevance for better understanding nutrient flows and fluxes and water movement in the estuary, but provides the basis for improved modelling of likely climate change impacts on the estuary and land forms, including modifications to the estuary entrances.

The model, in turn, will enable more accurate calculation of associated risk for buildings, structures, land inundation and salinisation of aquifers, and will facilitate the development of better models as predictors of ecosystem health of the estuary in the future.

### 3.3 Fish and Macro-Invertebrates

About sixty species of fish and larger crustaceans have been recorded for the Peel-Harvey Estuary (Brearley, 2005). Most are marine species, such as the popular Blue Swimmer Crab, King Prawn, Yellow-eye Mullet, Sea Mullet, Yellow-finned, School, Trumpeter and King George Whiting, Tailor and Mulloway, which spend most of their juvenile stages in the estuary. Others such as Estuarine Cobbler, Yellowtail Grunter and School Prawn, are true estuarine species, spending their entire life cycle in the estuary.

Both River Prawn and Cobbler populations have practically disappeared, probably due to a general decline in estuarine and river health and, perhaps for the latter species, also excessive fishing pressure.

Commercial fishing in the estuary has continued to decline both in tonnage of fish caught and numbers of active fishermen due, in part, to an active government program to reduce the number of commercial fishers in the estuary. Today, there are less than a dozen or so licensed commercial fishermen actively earning a living from the estuary, taking approximately 94 tonnes of fish and 85 tonnes of crabs in 2008. In contrast, recreational fishing has grown enormously over the decades, and is an important tourist activity and focal point in attracting new residents to Mandurah and adjoining areas.

Blue Swimmer crabs have become “iconic” to Mandurah as a festival tourist attraction. The fishing pressure in the Peel-Harvey Estuary is now so great that much needed seasonal fishing controls and tighter limits on catches by commercial and recreational fishers have become essential elements of fisheries management and research by the Western Australian Department of Fisheries. Without adequate management, the crab stocks and some fish species in the estuary will become, and, in some instances, have already become, overfished. Tighter controls will be critical for sustainability into the future.

With more people living in the area and forecast growth in residential developments, the numbers of recreational fishers in the estuary will continue to increase, exerting additional fishing pressure on fish stocks. At some point in time, it seems likely that the number of fishers will substantially impact on, and possibly already has impacted on, the quality of recreational fishing, thereby invoking a real need to limit total catches of key species to ensure sustainability.

The fish faunal composition of the Peel-Harvey Estuary underwent substantial changes between 1980/81 and 1996/97, *i.e.* prior to and just after the Dawesville Channel was built, reflecting significant changes away from weed-associated species to those characterizing a more marine environment (Young and Potter, 2003). The number of species also declined, probably reflecting the reduced habitat heterogeneity caused by the significant reductions in macro-algal production for the greater part of the estuary. The changed water flows in the estuary resulted in crab and prawn movements being substantially altered, and led to reduced catchability of these species.

It is generally claimed that some of the best indicators of ecosystem health for an estuary are the quality and biodiversity of the fish and invertebrates in the system, and the levels and nature of algal manifestations that occur. Any monitoring program thus ought to take into account such changes in biotic diversity and quality.

Since the Dawesville Channel has been constructed, the productivity of the estuary has sharply declined in accordance with expectation, and the densities of those fish species typically associated with weed has also declined. With the subsequent increased influence of marine waters in the estuary, the prevalence of the blue green algae *Nodularia* sp. in the Harvey Estuary has declined markedly as expected. Consequently, species diversity could be expected to increase for both fin fish species and invertebrates.

Whilst the level of biological research and monitoring into the estuary was sharply reduced following construction of the Dawesville Channel, early indications of the marked declines in micro- and macroalgal production, improved water quality and anecdotal evidence point to this construction being acclaimed as a success. Since the mid to late 1990s, however, a number of ecological changes have occurred.

- Contrary to management expectations, the benthic environment has deteriorated. This has been reflected by several changes in the benthic macroinvertebrate assemblage between the mid-late 1980s and early to mid 2000s. Thus, taxonomic distinctness (a measure of species diversity) has declined and species composition has become more variable. The Crustacea, the most sensitive of the major macrobenthic invertebrate taxa to environmental stress, has become proportionally less abundant and speciose whereas the Polychaeta (worms), the least sensitive, exhibit the opposite trend (Wildsmith *et al.*, 2009). While the characteristics of these faunal assemblages in the nearby Swan-Canning Estuary have also exhibited unfavourable changes over the same time period (*e.g.* declining abundances of crustaceans and increased abundances of polychaetes), they have not been as extreme as in the Peel-Harvey Estuary (Wildsmith *et al.*, submitted).

- The levels of macroalgae in the Peel-Harvey Estuary have been reported anecdotally by fishermen and others to again be increasing in volume, especially over the last several years. So much so, the Department of Water has re-initiated macroalgal surveys for the estuary.

- Preliminary comparative data of fish species composition in the early 1980s, mid 1990s (immediately after channel construction) and the late 2000s, indicates that while there were pronounced differences in the fish fauna between the first two periods, that in the latter period is becoming more similar to that recorded prior to construction of the Dawesville Cut. These findings are driven by an increasing prevalence in the late 2000s of weed-associated fish (*e.g.* Western Gobbleguts), particularly in the Harvey Estuary, as existed in the 1980s (S. Hoeksema and P. Coulson, pers. comm.).

These trends taken together point to an ongoing degradation of the Harvey Estuary in particular and, to a lesser extent, of the Peel Inlet. How significant these trends are, and their causative factors, is not known with certainty, but they are most likely linked to ongoing nutrient loading of the estuary from urbanisation and rural activity.

### 3.4 Waterbird Population

The waterbird populations of the Peel-Yalgorup Ramsar site comprise the Peel-Harvey Estuary, and the surrounding Yalgorup Lakes and Lakes McLarty and Mealup. The site was first designated as a wetland of international importance in 1990 and currently meets six of the criteria for listing under the Ramsar Convention (Hale and Butcher, 2007).

"The site comprises the most important area for waterbirds in south-western Australia, supporting in excess of 20,000 waterbirds annually, with greater than 150,000 individuals recorded at one time (February 1977). Numbers exceeding 20,000 birds have been recorded in all comprehensive surveys conducted in the 1990's in the Peel-Harvey Estuary" (Hale and Butcher, 2007, p12). Bird surveys in the Peel-Harvey Estuary during the last three years have shown considerable variability in bird numbers (see below).

The main types of waterbirds using the Peel-Harvey are:

| | | |
|---|---|---|
| i. | Migratory waders | (*e.g.* Red-necked Stint, Sharp-tailed Sandpiper and Red-capped plovers) |
| ii. | Resident waders | (*e.g.* Black-winged Stilts, Red-necked Avocets and Banded Stilts) |
| iii. | Long legged waders | (*e.g.* White-faced Heron, Little Egret, Australian White Ibis) |
| iv. | Fish eating birds | (*e.g.* Little Pied Cormorant, Little Black Cormorant, Pied Cormorant, Australian Pelican, Darter and Crested Tern) |
| v. | Water fowl | (*e.g.* Pacific Black Duck, Grey Teal, Black Swan, Australian Shelduck) |
| vi. | Gulls | (*e.g.* Silver Gull) |

A total of 77 bird species have been recorded in the Peel-Harvey Estuary, more than 30 of which are listed under bilateral arrangements for protecting habitats of migratory birds under Australian Government signatory.

The Peel-Harvey Estuary comprises a significant part of the internationally-supported Peel-Yalgorup wetland system (Hale and Butcher, 2007).

The numbers of birds sighted at the estuary fluctuate markedly from year to year, depending on conditions in adjacent wetlands, conditions within the estuary itself, wintering or seasonal conditions overseas for the migratory birds and ongoing anthropogenic impacts on the habitats and ecosystems supporting individual species. Moreover, the consistency of the bird counting program has varied among years. Noting the data below, there could be a case to review methodology.

The relationships between quality and available habitat, including the level of protection from threats, are critical to the distribution and abundance of the bird populations.

Results from the monitoring of waterbird populations within Austin Bay in the Peel-Harvey Estuary, a major bird aggregation site, show a significant decline in numbers from 1982, (41,161) to 1993 (20,636) then 2007 (13,585) (B. Rutherford, pers. comm.). Data collected in 2010 indicate much greater numbers (42,254), which is a surprising result, noting that 19,204 and 4,818 birds were reported in this area in 2008 and 2009, respectively. While the data set for the last three years is more comprehensive than in previous years, and data gathering is now supported by a centralised local framework managed by the PHCC, data collection is still heavily volunteer-dependent. Moreover, future monitoring is not resourced or funded to adequately understand bird population trends. This restricts the potential to develop indices of estuarine health from these data and gauge the success or otherwise of current management practices in managing the Peel-Yalgorup Ramsar complex. Without adequate long term data sets on bird populations, including an understanding of ecological energetics (including food chains), modellers and managers can only guess at the future.

In order to meet the obligations of the Ramsar-classified Peel-Yalgorup site, the linkages between threatening activities and their impacts on the natural assets of this system, including the waterbird populations, need to be understood. This is explored further in Chapter 4.

### 3.5 Acid sulfates and Sedimentology

Acid sulfate soil is a common name given to soils containing iron sulfides (pyrite). In an undisturbed state, such soils do not cause environmental harm, but if disturbed through dredging, excavation, digging, ground water extraction, dewatering or lowering of the water table, the sulfides oxidize and produce sulfuric acid. The acid mobilises metals bound to the soil, which can be flushed following rainfall and transported to rivers, streams, wetlands, estuaries and infiltrate into ground water. Concentrations of aluminium and iron are found to be higher in estuarine waters which are influenced by acid drainage.

A technique has been recently developed using a sulphur isotope indicator for identifying water resources affected by acidic drainage from disturbed acid sulphate soil. This potentially provides a new tool to better understand and monitor environmental harm arising from works associated with dredging and canal and foreshore development within or adjacent to estuaries.

Work undertaken in the Peel-Harvey Estuary has shown that wild-caught fish and shrimp at sites receiving acid drainage (*e.g.* near Yunderup Canal) were higher in aluminium and iron concentrations than those at sites where no acidic drainage was found (Department of Water, 2009). Dredging of unstable acid sulphate soils in the Peel-Harvey Estuary is also likely to have a negative environmental effect and has been shown to lead to a higher uptake of metals by mussels. Whilst metal accumulation in their tissues were principally iron and aluminium, depending on soil type, other metals such as arsenic (peat containing soils), cadmium, copper and zinc could be mobilised and absorbed by these biota.

While the toxicology of such accumulations has not been assessed, there is a need to better understand the potential for ecological harm, as well as possible impacts on human health.

Wetland acidification has been found to affect benthic macroinvertebrate and fish communities by reducing species richness and diversity and the complexity of trophic levels (Sommer and Horwitz, 2000). However, in the case of the Peel-Harvey Estuary itself, the buffering impact of both sea water on pH and lack of exposure of sediments to air due to permanent covering of much of the estuarine basin by water, probably means that acid sulfate risks for benthic macroinvertebrate and fish communities are generally relatively low. Exceptions are, as discussed, where soil disturbance by dredging, canal development and similar activities occurs.

The wetting and drying of the greater area of banks now exposed to greater tidal activity as a result of the Dawesville Channel construction may result in localised impacts of acidification, affecting the formation of monosulfidic black ooze (MBO).

Not enough is known on the distribution of MBOs within the Peel-Harvey Estuary or, specifically, within the intertidal area post 1994, to form a view as to whether this change in hydrodynamics has significantly impacted the distribution of this sediment type. Further work on MBO formative processes and its influence on water quality following sediment re-suspension or regular air exposure is warranted to better understand these processes within eutrophic estuaries and ultimately their impacts. Such knowledge is necessary to develop predictive capacity of the influence of MBOs on estuarine ecology.

However, increases in boat usage, fishing activity and various estuarine based activities continue to disturb sediments and may be an important feature and driver of sediment and nutrient transport and recycling.

On a more positive note, despite the presence of acid sulfate soils in Western Australia, the impact is significantly less than in the eastern states of Australia. No significant fish kills have been reported due to acid sulphate drainage. The impacts of acid sulfate in the Peel-Harvey Estuary overall could be expected to be relatively small, largely as a result of the buffering impacts of even greater salinity and water exchange as a result of the Dawesville Channel. With likely drying of the catchment from lower future rainfall and projected deepening of the estuary from sea level rises (both predicted climate change events), other environmental drivers, especially nutrient flows, may well continue to have a more significant influence on the ecology of Peel-Harvey Estuary.

The absence of any sediment balance modelling for the estuary, that takes into account the efflux and egress of major nutrient drivers, sediment movements and various water flows (rivers, groundwater and tidal flows), limits certainty of predicting the future ecological status of the estuary.

### 3.6 Current Trends in the Health of the Estuary

The lack of a comprehensive index or report card on the ecosystem health of the Peel-Harvey Estuary makes any conclusion as to direction of 'change', if any within the realms of natural variance, tentative.

What is known, is that since the Dawesville Channel has been constructed, many of the benefits of greater water exchange and increased salinisation, particularly of the Harvey Estuary, have been realized. Estuarine macroalgae production post 1994 was sharply reduced; *Nodularia spumigena* had virtually been eliminated from the estuary and water clarity, and therefore the 'aesthetic values' tied the estuary waters, vastly improved. As expected, the mean fish densities and number of species declined, tidal variation and flows became much stronger, King Prawn's more difficult to catch and the Blue Swimmer Crab fishery became the main stay of recreational and commercial fishing activity, both in terms of catch and value. In community terms, the construction of the channel was judged as being successful.

The Dawesville Channel construction, however, did not have a significant positive effect on either the Murray or Serpentine Rivers, with both continuing to exhibit regular fish kills associated with extremely poor water quality. Furthermore, increased salinisation of the Harvey Estuary is continuing to impact negatively on fringing vegetation, resulting in some loss of habitat.

In the last 15 or so years, Mandurah and its surrounding areas have experienced unprecedented population and urban growth, both as a residential area and tourist-holiday destination. Many of the 'drivers' of change within the estuary, such as ongoing residential canal developments, growths in recreational fishing, boat activity, water based and estuarine foreshore recreational activity, followed. Phosphorus and presumably other nutrients flowing into the estuary continue to remain high.

During the last five or so years, as described in subsection 3.3, some of the biological indicators of estuarine health point potentially to a gradual reversal of ecological conditions back towards the status of the estuary that existed immediately prior to the construction of the channel.

All of the biotic observations described in subsection 3.3, taken together with known drivers of ecological change, are indicative of a trend of failing “health” in the Peel-Harvey Estuary. Whether this is part of a longer term trend depends on the type and extent of the causative factors or ‘drivers’ of the current ecological changes. This is further complicated by the effect of time lags before changes in use (*e.g.* long term fertiliser applications and consequential nutrient flows) reflect in shifts in estuarine ecology. With ongoing population and urban growth and development of the catchment, without appropriate mitigation, the risks for the estuary will continue to increase.

It was against this background of observed change within the Peel-Harvey Estuary that workshop participants outlined what they saw as the key issues for future research and management in this system, which are outlined and reported in Chapter 4.

## Chapter 4 Emerging Issues, Risks for the Estuary and Economic Impacts

### 4.1 Population and Usage Trends, Including Urbanisation

The Peel region covers an area of 5,648 $km^2$ including 137 $km^2$ of inland waterways. There are five local government areas, the City of Mandurah and the Shires of Boddington, Murray, Serpentine, Jarrahdale and Waroona. A total of 99,252 residents live in the region with about 65,000 living in the City of Mandurah, one of the larger urban centres outside of Perth.

Over the next 15 years, the population growth rate for the Peel region is expected to slow down in line with state wide trends. However, that of Mandurah, Serpentine, Jarrahdale and the Murray region is generally is expected to increase at more than double the state average. Mandurah's population is currently experiencing a growth rate of approximately 4% per annum, with 120,000 residents anticipated to be living there by 2021 in 53,000 dwellings. This represents an almost doubling of the population over this time period.

Much of Peel region future population growth will be driven by outer local governments, with the projected annual growth rate of Murray Shire anticipated to more than double that of Mandurah during the period 2018 and 2023 (Table 1).

**Table 1: Population Growth Forecasts for the Peel Region** (Peel-Development Commission, 2010).

| Average Annual Growth Rates | | | |
|---|---|---|---|
| **Local Government Area** | **2008-2013** | **2013-2018** | **2018-2023** |
| Peel | 4.4% | 3.8% | 3.2% |
| Boddington | 0.0% | 0.0% | 0.4% |
| Mandurah | 3.7% | 3.0% | 2.2% |
| Murray | 5.9% | 5.5% | 5.6% |
| Serpentine/Jarrahdale | 7.1% | 5.6% | 4.3% |
| Waroona | 0.6% | 0.6% | 0.3% |
| **WA** | 1.5% | 1.4% | 1.2% |

| Population forecasts for the Peel Region | | | |
|---|---|---|---|
| **Local Government Area** | **2009** | **2014** | **2019** |
| Boddington | 1,402 | 1,400 | 1,398 |
| Mandurah | 67,053 | 80,252 | 93,238 |
| Murray | 14,676 | 19,588 | 25,557 |
| SJ Shire | 16,545 | 23,272 | 30,502 |
| Waroona | 3,655 | 3,764 | 3,869 |
| **Peel** | **103,331** | **128,276** | **154,564** |

Mandurah, in particular, and Pinjarra are prime destinations for daily visitation, recreation and tourism. Tourism is an important contributor to the Peel region with overnight visitors exceeding 439,000 for the period 2006-2008, dominated by intra state visitors, predominantly from Perth.

The recent completion of the Perth-Mandurah rail line (December 2007) and the new Perth-Bunbury Highway extension are anticipated to be significant catalysts for growth and tourism. In line with anticipated population trends, tourism (including daily visitation) is expected to at least double in the next ten or so years.

These anticipated trends will undoubtedly be a major driving factor on development, recreation and usage of the region's catchment and associated waterways for an array of activities with consequential environmental impacts. Increased urbanisation is also believed to have significant potential to increase catchment nutrient flows relative to some existing agricultural practices.

Intensity in the use of the region's waterways by boating, fishing, swimming and other water sports, and use of foreshores for diverse recreational activities, are also expected to substantially increase, resulting in new challenges for managing and maintaining the waterways and its associated assets.

The key challenge in managing an increasingly complex environment is understanding the cumulative impacts of population pressures and their associated impacts on the estuary. An approach largely based on the 2003 Coastal Catchment Initiative program, which was aimed at reducing pollution in water quality hotspots such as the Peel-Harvey, consequentially resulted in the production of the Water Quality Improvement Plan (EPA, 2008). This plan largely focussed identifying actions for reducing the flow of phosphorous from the catchment. These actions may not be sufficient, given the size of the predicted population change and a range of other likely drivers impacting on estuarine ecology.

Population growth is also an important driver in the use of freshwater for both urban development and agriculture in particular. Taken together with the reducing rainfall, policies around water extraction both through damming and groundwater usage, as well as treatment of greywater, sewage and desalinisation, will continue to change the landscape for stream and river flow. These factors could well shape new requirements for management of these impacts on water quality for streams, rivers and the estuary.

Noting that a significant major evaluation of the status of estuarine health and its forcing factors has not occurred since the Dawesville Channel was constructed, there is a clear need for reassessment. In addition to the influences of a growing population in the region, this assessment needs to include other catchment, as well as non-catchment, drivers.

### 4.2 Eutrophication and Nutrient Impacts

The Department of Water undertakes both riverine (catchment) and estuarine surface water monitoring in the Peel-Harvey system. Full details of the monitoring programs are described as part of projects KP-C-LMUCCI (Department of Water, 2008) and KP-E PHESTREACH (Department of Water, 2007).

In effect, the PHESTREACH program provides monthly monitoring of estuarine surface waters for key nutrients (Total N, Total P, oxidized nitrogen, ammonia, kjeldahl nitrogen and soluble reactive phosphorus ) as well as two-weekly monitoring of physical variables (salinity, conductivity, temperature, dissolved oxygen, pH and turbidity), chlorophyll (chlorophyll *a, b, c* and pheophytin *a*) and phytoplankton composition. The number of sites monitored is limited to 12, 3 each for the Murray and Serpentine Rivers as well as 3 each within the Peel Inlet and Harvey Estuary. However, the uppermost site in the Murray was not monitored after April 2010. Note also that nutrients are only measured nine and eight sites prior to and after April 2010, respectively (Fig. 1).

There is little recent information on organic carbon levels within the estuary, except for the data collected as part of an acid sulphate survey in the catchment and estuary. This snapshot information on carbon loads is insufficient to even begin to understand the importance of carbon cycling in the estuary or its role and implications for estuarine health.

Recent comparative analyses of sediments undertaken in a number of estuaries in south-western Australia point to the Peel-Harvey Estuary being unique in having both significant soft sediments with relatively high carbon levels, and a capacity under anoxic conditions to produce methane. The sediments have generally been described as being of relatively poor quality compared with those of the Swan-Canning Estuary and other west coast estuaries, although they do not appear to be particularly degraded, with little direct evidence of impacts from acid sulfate soils (Miller *et al.,* 2010). However, not enough basic information on sediment characteristics and distribution, nutrient fluxes between the water and sediment or the role of monosulfidic black ooze (MBO) in estuarine processes is known to form an adequate view. The latter is a particularly significant gap in knowledge, and could have an important role in the ongoing ecological health of the estuary.

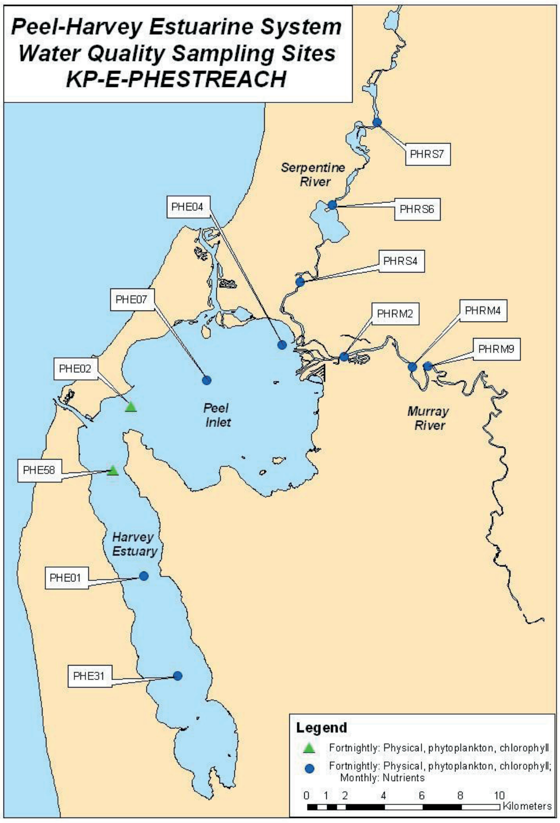


**Figure 2:** Map of the monitoring locations for water quality in the Peel-Harvey Estuary sampled by Department of Water under the PHESTREACH program (supplied by Department of Water).

Total phosphate and soluble reactive phosphorus levels in the estuary frequently exceed guideline values (P. Ridley, 2009, Department of Water, pers. comm.). This observation is consistent within the reported high levels of phosphorus entering the estuary from the catchment. The LMUCCI project measures water flow, nutrient levels and physical variables such as salinity across load measurement units located in key drains and rivers. These data will facilitate modelling of the nutrient loads flowing into the Peel-Harvey Estuary, and the production of a predictive tool for estimating future impacts on the system of changes in land use and management practices.

While the LMUCCI catchment monitoring program has a reasonable spatial and temporal resolution, and is probably sufficient for meeting data requirements to undertake future modelling of the nutrient loads entering the estuary, the within-estuary monitoring program lacks sufficient spatial resolution, and is thus proposed to be extended (see subsection 3.2 and Appendix 1). Furthermore, since the Dawesville Channel construction, there has been little integration or evaluation of that data in aggregate form, with most information maintained in raw unmodified form.

The Water Quality Improvement Program for the Peel-Harvey and its catchment (EPA, 2008) has identified 13 actions targeted at reducing phosphorous loads entering the estuary (refer Table 7 in EPA, 2008). Management of different parts of the catchment is aimed at mitigating phosphorous loads. The premise of this management being that, in the fresh to brackish parts of the river and estuary, phosphorus is the limiting nutrient generating excess algal growth.

However, in the more marine parts of the estuary, nitrogen may be the limiting factor and a strategy that reduces nutrient input from the total catchment drainage can be positive for both nutrients.

With increasing salinisation and human usage of the estuary and foreshores, nitrogen input from other sources may become of greater importance. In the absence of modelling approaches to estimate nutrient changes and fluxes in the estuary itself, the impact of environmental changes will become more uncertain and problematic, as will the prediction of future trends in ecosystem health.

It is only with the development of appropriate models and data that management can hope to assimilate all of the information required for understanding future health of the estuary.

### 4.3. Climate Change

The emerging issue of ongoing climate change poses the greatest environmental force likely to impact on the Peel-Harvey Estuary and its adjacent coastline this century. How Governments and communities cope and adjust, adapt and mitigate the effects of this change, will undoubtedly impact on the very form and nature of the estuary and its surrounding land into the future.

The three big impacts from climate change are likely to be increasing temperature, decreasing rainfall and therefore freshwater flows into the estuary, and greater inundation from a rise in overall sea levels. Inundation analysis undertaken as part of a nation-wide assessment projects that, based on an average rise in sea level of 1.1 metres, will result in approximately 2,000-3,600 residential buildings in Mandurah being at risk. This includes buildings adjacent to the estuary as well as near the coast that are vulnerable to inundation and shoreline erosion (Department of Climate Change, 2009).

How such changes affect the ecological function of the estuary requires more detailed analyses that take into account allowances for modelled high water level, vulnerability of sediment to coastal erosion, existing coastal protection (such as sea walls) and frequency of riverine flooding from intense rainfall events. These changes also need to be placed in context with changes in tidal cycles, broader oceanic events such as cyclic inter-annual variation in sea levels and the impact of storm surge events and wind forcing on water levels.

While detailed bathymetry of the estuary is not known, the recent LIDAR data collected by the Department of Water will, at least for the land adjoining the estuary, provide the basis for more precise estimates of the effects of anticipated inundation, and therefore of required building set-backs used by planners in today's building permit approval processes.

What can be expected, should climate change events continue as predicted, will be a significant deepening of the estuary, possible deepening and widening of the entrance channels (especially in the case of the Mandurah channel), and the estuary itself becoming even more marine in character. Hypersalinity could become a more prevalent feature of the upper reaches of the estuary, especially during the summer months, and may extend further into other seasons with the potential to generate changes in habitats and a wide range of biotic communities. For example, there may be further losses of adjoining riparian vegetation due to salinisation, as well as the loss of intertidal feeding grounds for wading birds, fish and crabs. This will depend on the rate of ecological adjustment.

Nutrient flows from freshwater sources and lower rainfall in the catchment could be expected to reduce nutrient inflows into the estuary itself. However, without comprehensive modelling of the hydrological, biogeochemical and ecological processes, no certainty can be provided as to the predictions of the future health status of the estuary, other than that change is inevitable.

By far the greatest impact of climate change is the punitive risk for existing building and structures within and in the zone of inundation of the estuary, the channel entrance and near entrance foreshore coastal areas. The mitigation costs for buildings, protective structures and replacement of facilities are likely to drive engineering-based solutions aimed at protecting facilities. This will depend on government acceptance of level of mitigation.

More detailed modelling of the estuary and possible changes to the channel entrances and adjoining foreshores is required to identify local risks and impacts for the Peel-Harvey Estuary. Any model developed would need to be sufficiently flexible as a decision tool to accommodate changes in climate scenario predications, both in timing and extent of likely change events.

This will enable local understanding of impacts and development of local adaptive strategies. It will also assist in prioritising risks specific to the region, noting adaption and mitigation consequences extend not only to the facilities and buildings within the catchment, but also to estuarine ecosystem health and human health.

### 4.4 Development, Continuous Change and Governance

Development brings with it a range of changing attributes to land and water resources, such as alterations in vegetation, drainage and nutrient and non-nutrient contaminant flows. Each development often exhibits different environmental impacts, depending on its location, proximity to waterways, underlying soils, function and engineering. The list is endless, multifaceted and variant. Single and cumulative impacts continue to change in time and space and their relevance to local and regional scale impacts is often not in a steady state.

To assume that the state of estuaries and waterways can stay constant is a misconstrued concept. It is simply not possible to consider, measure or take account of all factors impinging on an estuary or waterway, especially at the rate of development and change in land use currently being observed in the Peel-Harvey catchment. In this respect, it should be noted that many ecological processes exhibit long time lags between the driving force and the ultimate effect, as the direct impact of the force is passed through numerous indirect pathways, such as via the habitat and foodweb.

It is therefore not surprising that resource managers, including the EPA, the Department of Water and other agencies, have taken an adaptive management approach to the Peel-Harvey catchment and its associated riverine and estuarine waters.

The strategies adopted appear abundantly sensible, are multifaceted and seem likely to reduce ongoing risks from nutrient loading on the health of the Peel-Harvey Estuary.

In implementing these strategies come a number of responsibilities.

i. There should be regular reporting on the rate of progress being made in the adoption of these strategies;
ii. Monitoring data collected should be analysed annually and reported to provide the community with knowledge of trends highlight new risks and/or identify under performance;
iii. Recognition that the benchmarks established will, in the face of likely ongoing change and emergence of new data or knowledge, be subject to continuous reassessment;
iv. There should be a system of audit and accountabilities that matches responsibilities with delivery and performance.

There does not exist an easy to read report on the overall “**health**” status of the estuary or on the success of combating future risks for this system arising from ongoing catchment development, population growth and long-term climate change. Neither is there any real integration of reporting on the success and progress of the EPA-lead strategies for sustaining water quality and other community values for the Peel-Harvey Estuary.

To be adequately responsive to the ongoing impacts of pressures on valued natural assets, the community must be informed. This requires not only the integration of reporting across a number of government agencies, but a better coordination of science delivery across those agencies and a focus on an agreed set of performance measurements that have meaning to the community at large and are relevant to sustaining ecosystem health. It is through reporting and direct involvement in decision-making and governance, the community is empowered to act to protect valued assets.

Such a report should include trends in ecosystem health indices for the estuary and the monitoring and reporting of known drivers impacting on the environmental status of the estuary. The reporting also needs to be appropriately resourced, science-led and evidence based.

Without appropriate accountabilities, performance aimed at providing environmental security for the Peel-Harvey estuarine system will surely fail. Much of this accountability rests with having the correct governance, a requirement for real ownership and action by the community, appropriate legislation and continuous improvement in estuarine management performance with political support and secure, adequate funding.

Whilst these matters fall outside the scope of the development needs of a science strategy for the Peel-Harvey Estuary, such as strategy is less likely to succeed without these matters being addressed. Science has its relevance only if management, once informed can respond.

Noting much of the work outlined in the Water Quality Improvement Plan falls outside the direct roles of the EPA, it is not easy to determine the overall performance of this strategy. A benchmark assessment needs to be undertaken to clearly distinguish those things that are working, as distinct from those which are not, and to establish clear baselines. Reasons behind any systemic failing could also be identified. Action on this matter by the Office of the State Auditor General or EPA to undertake an audit is within their scope.

If this assessment was to be undertaken, Government and the EPA, along with the PHCC and the community, would be provided with invaluable insights regarding the likely future performance of the strategy, well before any major issues arise.

From a view point of compliance, generally, should an audit review be undertaken, noting building risks extending from future climate changes on the Peel-Harvey Estuary, a focus on adequacy of existing planning decision practices may also be a worthwhile inclusion.

### 4.5 Loss of Ramsar Status and Obligations

The Peel-Yalgorup Ramsar site comprises the Peel-Harvey Estuary, the Yalgorup Lakes and the Lakes McLarty and Mealup in the south-west of Western Australia. The monitoring guide also includes Lakes Goegrup and Black which are proposed as extensions to the Ramsar site.

The site was designated as a wetland of international importance in 1990 and reported to meet the criteria for listing under the Ramsar convention (Hale, 2008).

Of these six criteria, four in particular are relevant to the Peel-Harvey Estuary, and are represented in Table 2 below.

**Table 2: Criteria for identifying wetlands of international importance that are met by the Peel-Yalgorup Ramsar site** (Adapted from Hale and Butcher, 2007).

| Ramsar Criteria | Peel-Yalgorup Justification |
|---|---|
| Criterion 1: A wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region. | The site includes the largest and most diverse estuarine complex in south-western Australia and also particularly good examples of coastal saline lakes and freshwater marshes. |
| Criterion 4: A wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions. | The site supports an array of species and communities during critical life stages including: large numbers of migratory birds; breeding of waterbirds, fish, crabs and prawns; drought refuge for waterbirds, fish and invertebrates; and waterfowl such and Shelducks and Musk Ducks during moulting. |

| | |
|---|---|
| Criterion 5: A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds. | The site comprises the most important area for waterbirds in south-western Australia, supporting in excess of 20,000 waterbirds annually, with greater than 150,000 individuals recorded at one time (February 1977). Numbers exceeding 20,000 birds have been recorded in all comprehensive surveys conducted in the 1990s in the Peel-Harvey Estuary. |
| Criterion 8: A wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend. | The Peel-Yalgorup Ramsar Site is important as a nursery and/or breeding and /or feeding grounds for at least 50 species of fish as well as the commercially significant Blue Swimmer Crab and Wester King Prawn. In addition, the Peel-Harvey Estuary is a migratory route for the Pouched Lamprey (*Geotria australis*). |

As part of the obligations for retaining Ramsar status, the PHCC have developed a draft monitoring and evaluation guide in order to manage the site by detecting threatening processes that may alter or change the ecological character of the site (Hale, 2008). These are set as limits of acceptable change and incorporate abiotic components (mainly water quality), primary responses to the abiotic components (habitat and supporting biological components) and key faunal components (key species and communities).

The status of this proposed program is not clear, noting there is no secure long-term monitoring program effectively in place, and funding for the monitoring that has been proposed is often not based on core agency funds (refer Appendix 1). Inadequate consistent data collection and analysis has thus occurred, providing little real discrimination of trends, noting the numerous levels and sources of variation. Much of what is being sought in the proposed program in terms of monitoring water quality, fish communities, phytoplankton levels, macroalgae and seagrass distribution, littoral and fringing vegetation and water bird populations appears appropriate, but under-resourced.

The authors fully support the concurrent measurement of abiotic and biotic attributes of the system in order to better understand the ecological responses to changes in environmental conditions and changing stressors acting upon the physical environment.

Without effective design and regular monitoring and reporting of the above components and, in particular, the bird population, it could become difficult to sustain the argument for maintaining Ramsar site status, particularly if those populations severely decline in numbers. More recent information points to bird numbers during 2007 in Austin Bay (Peel Inlet) falling well below the levels existing in the 1990s and the 1980s. Bird numbers have fallen to about one third compared with those recorded in the 1980s (B. Rutherford, 2009 pers. comm.).

The reason for the shifts in bird populations is not known, but could be linked with international trends of falling migratory bird numbers due to environmental changes somewhere along their migratory route, changing local environmental issues in the Peel-Harvey Estuary and its associated Ramsar wetlands, or attributable to sampling issues (refer to section 3.4).

There is a clear need to meet Ramsar obligations for more regular direct reporting, analysis and assessment of those factors impinging on bird numbers within these wetlands. This monitoring and evaluation work needs to be adequately resourced, noting particularly that much of the data gathering is presently sourced from volunteers, with limited future funding commitment.

For the estuary itself, there is a broader requirement for a regular program reporting on longer term changes in other fauna including fish communities, and supporting habitats such as seagrass and littoral and fringing vegetation. Each of these components will provide useful indicators of longer term changes in the health of the estuary, spatially and temporally.

Without adequate funding, reliance on non-aligned research and community-sourced programs, which are typically short term, will almost certainly prove to be insufficient to meet Ramsar obligations.

### 4.6 Requirement for Monitoring Programs and Research

The Department of Water is the lead agency for the management of the Peel-Harvey Estuary and its catchment. It has in place the Water Quality Improvement Program (WQIP) and, since the release of that publication, has redone the catchment modelling and land use delineations and included nitrogen in its monitoring program. Much of this work is focussed on nutrient (in particular, phosphorous) concentration measurements and on calculating load reduction targets per subcatchment.

Whilst this program has strategic value for management strategies focussed on the catchment, it is the specific total nutrient loadings flowing into the estuary, that have a direct bearing on the health of that ecosystem.

At this stage, it is not possible to assess whether the strategies outlined in the WQIP are working, as it has only recently started and received funding for only one year. Without **ongoing funding**, the effectiveness of this core element for monitoring of the performance of catchment management strategies and the impacts on the environmental status of the Peel-Harvey Estuary cannot be assessed.

It is suggested that the key to the ongoing successful management of the Peel-Harvey Estuary, including Ramsar obligations, needs to be built around the following abiotic and biotic monitoring elements:

i. The Water Quality Improvement Plan (EPA, 2008).
ii. Total nutrient loads flowing into the estuary, ideally for phosphorous, nitrogen and organic carbon.
iii. Analysis, performance measurement, reporting and adaption of the strategies employed to reduce nutrient flows into the estuary.
iv. Key biotic components, including:
    a. Submerged macrophyte (macroalgae and seagrass) and littoral and fringing vegetation cover, composition and biomass throughout the estuary (3 yearly intervals);
    b. Macrophyte wrack cover, composition and biomass throughout the estuary as a proxy for year-to-year variation in macroalgae and seagrass production;
    c. The species composition and proxies for biomass of fish and benthic invertebrate communities (including crabs and prawns) throughout the estuary and its adjacent nearshore marine waters (3 yearly intervals);
    d. Water bird species counts throughout the estuary (3 yearly intervals).
    e. Spatial coverage of other habitat types, such as shallow mudflats, throughout the estuary (every 3 years);
    f. The composition of the phytoplankton communities at nominated sites throughout the estuary (2 weekly);
    g. The growth and reproductive biology of key fish and crustacean species (10 yearly intervals);

   h. Collection of data relevant to human health issues (annually as available).

v. Nutrient and non-nutrient contaminant loads in estuarine sediments.

New investment in science is required to integrate the monitoring data with predictive models for the estuary, and thus produce tools to better inform management and future research needs. This focus should lead to better estimates on the future health status of the estuary and development of appropriate adaptive management strategies for the estuary and their review.

This science should build on existing knowledge and include the following.

i. Development of a quantitative food-web to enable an understanding of the trophic pathways for bird and fish populations in the estuary;
ii. The adoption of remote-sensing technologies to allow mapping of the spatial coverage of submerged macrophytes, accumulations of macrophyte wrack along the shores, littoral and fringing vegetation and shallow mudflats;
iii. Basic but accurate bathymetry that provides data to build a hydrodynamic and sediment transport model for the estuary, capable of defining future impacts of changing water fluxes from river flows, changes in sea level, storm surges and wind conditions;
iv. The role of sediments, particularly monosulphidic black oozes (MBOs), in the de-oxygenation of water and the entrapment and release of nutrients;
v. Estimation of nutrient and sediment fluxes within the estuary, through production of a biogeochemical model based on the hydrologic and sediment transport model that is linked to ocean interchanges and entrance channel modification;
vi. Detailed sedimentology throughout the estuary, including in coastal waters and land near the estuary entrance, to facilitate more accurate predictive models of longer term climatic change on the estuary and its foreshores. Its basic form should allow scenario testing for assessing various engineering solutions for adaptive management, and be able to cope with various and changing assumptions around climate change predictions;
vii. Research surveys of recreational fishing be undertaken at least at five-yearly intervals, and that the potential of using fixed video cameras at jetties, shore locations and boat ramps, such as the Department of Fisheries is testing in other locations, should be considered for use in monitoring recreational fishing effort in the Peel-Harvey Estuary in the intervening years.
viii. Development of multi-metric biotic indices (*e.g.* from fish or benthic invertebrate characteristics) for quantifying year-to-year changes in estuarine health condition;
ix. A pre-feasibility study involving an expert panel that identifies the contribution to estuarine nutrient loads by various land uses in the catchment, in order to ascertain the practicality of introducing a pricing or taxing arrangement that requires or enables funds to be applied to the future management of the estuary and its associated riverine and nearshore marine waterways.

Suggested monitoring programs for the majority of the above components are provided in Chapter 5 and Appendix 1.

Key to the success of such a program of monitoring, analysis, evaluation and reporting is the integration of the science with future management directions and outcomes. This will require the ongoing commitment of a ‘science leader’ prepared to bring all parties together at least annually to review, interpret and re-prioritise the work undertaken. This integration process is the key to developing an ongoing successful program, and must cross agency boundaries and incorporate government, university and private researchers. Without appropriate funding and governance, co-ordination and integration, including accountabilities, the outcome is likely to be far less successful. Community education, engagement and involvement in this process is also fundamental to the success of this program.

### 4.7 Human Health

One of the main factors affecting human health from estuarine environments relates to disease vectors carried by mosquitos, such as Ross River Virus and Burimulo Forest Viruses. Two mosquito species (*Ochlerotatus couptorhynchus* and *O. vigilax*) are known to inhabit the salt marshes that fringe the Peel-Harvey Estuary (McLeod, 2007).

It seems that natural predators for these mosquito species do not exist or have any significant effect on their larvae in the Peel-Harvey Estuary. The increasing abundance of mosquito larvae in the wetlands is also reported to be an indicator of declining health of water quality and the wetlands.

Mosquito larvae tolerate a wide range of conditions and adapt to conditions of low pH that may be generated by acidic soil conditions and increasing algae abundance. It is therefore not unreasonable that those factors which induce declines in estuarine health conditions (*e.g.* higher nutrient inputs or increases in the exposure of wetlands to tidal influence) may increase larvae and mosquito numbers.

With higher temperatures and potentially increased inundation of estuary salt marsh from long term climate change, risk to human health from mosquito-borne viruses could be expected to increase. Whilst current programs of mosquito control include application of pesticides specific to larvae and adults, there is little reported work on long term impacts of these agents on the community or the environment.

Increases in temperature as a result of long term climate change also have the potential to increase the uptake of pollutants by particular biota, such as pesticides in fish (Schiedek *et al.,* 2007). This could increase contaminant toxicities for some species and induce long term changes in their community composition. There may also be secondary risks for human health, through either food chain accumulations as well as aerosol ingestion of pesticides.

The effects of the mosquito control program itself, including developing resistance within the mosquito population and its relationships to known and ongoing estuarine health, warrants monitoring and evaluation. A parallel risk resulting from declining estuarine health relates to greater prevalence of toxic algae, and the resultant impacts on human health from direct contact and accidental ingestion by swimmers. A program for monitoring this risk has been implemented and is managed by the Department of Water. Reporting of fish kills and known impacts on human health is also currently in place. How this shifts over time could provide insights as to how the longer term health of the Peel-Harvey Estuary is changing.

There would be value in bringing together the data sets collected by various agencies on human health issues and incidence over time and other evidence of toxins and infection risks as an independent reflection of changing estuarine health over time. Much of this data is likely to be currently available from responsible agencies.

# Chapter 5 Priorities for Future Research, Monitoring and Policy Development

## 5.1 Development of a Report Card for Estuarine Health and Performance Reporting

The requirement for developing an effective reporting system reflecting the status of the estuary has been recognized previously by the Department of Water, the EPA in their Water Quality Improvement Plan (November 2008) and numerous stakeholders.

An effective report is likely to be multifaceted, needs to be easily found and read, summarised in one place, and provide a meaningful snapshot of current health status and the progress of the implementation and performance of any key mitigation strategies. The detail of information provided will depend on the purpose, the scope sought and nature of stakeholder interest.

The EPA in its 2008 WQIP presented the Cockburn Sound Report Card 2005, developed by the Cockburn Sound Management Council, as a prospective example. An appropriate report card is understood to be undergoing development.

It is proposed that a comprehensive reporting scheme for the Peel-Harvey Estuary should address the following three questions.

i. What is the current health status of the estuary and how does that relate to observed historical trends in estuarine health?
ii. What is the current progress and level of success of key mitigation strategies?
iii. What are the observed and anticipated trends in the more significant environmental drivers impacting on the health of the estuary?

As some change responses could be substantially time lagged in their influence, some concept of future projection of ecosystem health will better assist risk interpretation and earlier mitigation. Assessment approaches for each of these questions are discussed below.

### 5.1.1 Statistically-based Ecosystem Health Index

Biotic indices incorporating multiple measures (metrics) of assemblage composition (*e.g.* fish or benthic macroinvertebrates) can reveal the effects of integrated natural and anthropogenic stressors on community structure, biodiversity and trophic interactions, and have proven to be an effective and sensitive method for measuring the broader ecological health of estuaries in the USA, Europe and Africa (*e.g.* Hughes *et al.,* 2002; Harrison and Whitfield, 2004; Breine *et al.,* 2007). They also provide a simple yet robust way of summarising trends in estuarine condition over time (years).

A current Murdoch University project is developing such an index for the nearby Swan-Canning Estuary employing fish assemblages. The methodology arising from this project could be applied to develop the same type of ecosystem health index for the Peel-Harvey Estuary, via the following stages:

i. Selecting from a candidate list those metrics of a given biotic assemblage which most sensitively and consistently reflect temporal (interannual) changes in estuarine condition;
ii. Establishing appropriate reference conditions for each of the selected metrics using reliable historical data;
iii. Establishing scoring thresholds for each selected metric based on the deviation from its reference condition;
iv. Calculation of index values by summing metric scores for those periods in which reliable historical data exist;
v. Validation of index sensitivity and reliability.

This approach would enable (i) production of an index of ecosystem health for the Peel-Harvey Estuary based on various measurements of a given biotic assemblage, and calculation of that index for each historical year in which reliable data are available, (ii) translation of that index into a colour-coded "report card" which is easily interpreted by the wider community and (iii) establishment of a monitoring regime for that biotic assemblage, comprising a subset of the most informative sites and seasons, to enable the health of this estuary to be reliably tracked in the future and compared to statistically-determined thresholds.

To achieve these goals, such a project would need to include all existing historical data of a given biotic assemblage for the Peel-Harvey Estuary, and would also require further seasonal sampling of those biota at the same sites as those sampled during previous studies. This would enable the development and validation of an index capable of quantifying the health of the system and its four component regions (namely Eastern and Western Peel Inlet, Northern and Southern Harvey Estuary), and tracking changes in their condition over time. The most extensive historical biotic assemblage data in the Peel-Harvey Estuary is for the fish and submerged macrophytes, which date back to the late 1970s.

The same approach could also be extended to other key estuaries in the south-west to provide comparable indices of estuarine health for each of these systems, as has already been adopted in other regions of the world (*e.g.* Harrison and Whitfield, 2006).

### 5.1.2 Monitoring Performance of Mitigation Strategies

The EPA has identified in its 2008 WQIP for the Peel-Harvey system a multitude of best catchment management practices and recommended implementation activities to reduce nutrient loading in the streams, rivers and ultimately the estuary. Responsibility for delivery of these outcomes rests with a number of agencies, with any reporting likely to be diffuse or, due to different agency priorities, difficult to coordinate and present in a single report. Much also depends on the priority of funding within agencies.

Although a reporting framework is proposed, a KPI-based system, except for key deliverables of the plan, is likely to be complex and perhaps have little real meaning for the community. An alternative option, now that the WQIP has been announced, is to establish an independent performance audit program that assesses the effectiveness of the plan and the performance of agencies in the delivery of recommended outcomes.

A benchmark report now, again in five years, and towards the end of a 10 year plan, would provide a valuable insight on progress. It could also highlight significant areas of inaction, non-compliance and priorities for action and is likely to be more effective in assessing and reporting performance progress. However, at least for key outcomes, for example total nutrient loads (N & P) entering the estuary, aggregate loads and trend information would assist community interpretation of progress.

### 5.1.3 Drivers Effecting Estuarine Health

There is no easily identifiable information that provides the community with readily accessible trends on how drivers of ongoing environmental change are impacting on the ecological status of the estuary. Such data could include annual statistics which show trends of direct and indirect impacts on the estuary.

For example, regional population numbers, annual visitation to the region, total length of canals, area of littoral and fringing native vegetation adjacent to the estuary, total N & P loads entering the estuary, number and size of fish kills' annual level of public complaints concerning fish kills, closure to swimming and/or offensive odours, an index of estuarine-based recreation, the level of foreshore development, annual catchment rainfall and river flows and longer term predictors of these parameters , water temperature and sea level trends. These data need to be drawn together from a range of sources, bench-marked and measured and reported annually. Ideally, these data could eventually provide an accurate reflection of historical trends..

Ideally, the development of a suitable biogeochemical/hydrologic/ecological model, that has the capability to integrate biological, physical and functional aspects of the ecosystem, would provide a tool to give planners and other decision makers the ability to make reliable predictions about future estuarine health, catchment planning, fisheries and an array of other applications. Such a tool has the capability to identify impacts from anthropogenic activities and therefore to enable the prediction of the value of various mitigation and adaption strategies.

### 5.1.4 Reporting Summaries

A report on the status of the estuary for the State of the Environment, which is meant to inform parliament, is very different to that required for general consumption by the community. There is a case for a simple-to-read report that signals to decision makers the current and likely future status of all key estuaries in the south-west in particular, especially those that are heavily impacted by development and urbanisation. The priority estuarine areas for reporting, as a starting point, are the Swan-Canning, the Peel-Harvey, the Leschenault, the Vasse, Hardy Inlet, Wilson Inlet and the Albany harbours.

Starting the process is possibly more important at this stage of reporting development than the content itself. Refinement in reporting can only come with sophistication of analysis and understanding as well as through increased investment in data gathering and analysis, accountability and clarity of governance, along with integration of science and reporting. At the present time, it is very difficult indeed to gain a suitable snapshot on the status of Western Australian estuaries within any common framework. The last great treatise on the state's southern estuaries is Ernest Hodgkin's *Swanland* (Brearley, 2005). Subsequently, there is little evidence of real integration of knowledge, science and its reporting currently at hand. With increasing population, attributed activity and development around these estuaries, collective summary reporting of estuarine ecosystem health, and their predicted futures, is the key to marshalling community support. Governments and their agencies alone, without real and sustained community action, will continue to find it difficult to manage the quality of our catchments and estuaries. Integration of science delivery and reporting across agencies on the status of estuaries is paramount.

### 5.2 Habitat measurement

Remotely-sensed imagery obtained from satellites or air-borne sensors, in combination with Geographic Information System (GIS) techniques, can play a key role in the efficient and accurate measurement of multiple aspects of estuarine environments that are important either for building indices of ecosystem health, or in their role as environmental drivers. They facilitate the measurement of the spatial cover, distribution and/or composition of benthic habitats, such as submerged macrophytes (seagrass and macroalgae), macrophyte wrack that has accumulated along shorelines and shallow mudflats, and also those of emergent habitats such as littoral or fringing vegetation. Thus, spatially-explicit and continuous maps of the different habitat categories present throughout the estuary can be produced by, firstly, classifying differences in habitat "colours" or spectral signatures captured by the remotely-sensed imagery and, secondly, undertaking a rigorous ground-truthing regime to determine the accuracy of the classified map.

Given an acceptable level of accuracy, this classified and validated map then provides a sound benchmark against which any future changes in the spatial cover and distribution of the various habitat categories can be measured. It can also be used to overlay spatial data for other biotic groups (*e.g.* benthic invertebrates, fish and birds) to determine the extent of any relationships in their distributions.

The detail of the habitat categories that can be mapped with confidence in this way depends on several factors. The first of these is the type of sensor used to acquire the imagery. Some of the more recently developed satellites (*e.g.* Quickbird or IKONOS) can provide imagery with a high spatial resolution (1 pixel ~2 m on the ground) and reasonable spectral resolution (*i.e.* ability to discern different benthic habitats). They can also capture large areas in a single pass, the latter of which overcomes the spatial and misclassification errors associated with the need to "mosaic" together numerous small images which may vary markedly in their light and atmospheric conditions. The last two characteristics are considerable improvements over traditional aerial photography techniques. However, while the spectral resolution of the above satellite imagery is reasonable, it is ideally suited to distinguishing among broader categories of habitats that differ considerably in their light reflectance, *e.g.* sand *vs* macrophytes and potentially among seagrass *vs* macroalgae. In contrast, hyperspectral imagery, acquired from a specialised air-borne sensor, can detect many more spectra and thus is much more useful for distinguishing finer categories of habitats, *i.e.* potentially down to different macrophyte genera or species under ideal conditions.

While acquiring hyperspectral imagery is costly, it has the advantage of measuring a number of key indicators and, if done at scale across a range of estuaries, may well provide a very cost effective long-term tool. A short pilot study comparing the degree to which different submerged macrophyte/fringing vegetation groups can be distinguished reliably from satellite *vs* hyperspectral imagery in the Peel-Harvey Estuary is thus advised.

A second major factor, particularly for subtidal habitats, is the extent to which light is attenuated by water column conditions, *i.e.* by turbidity, depth or colour. The large areas of shallow, marine-influenced water in the Peel Inlet and Harvey Estuary will thus provide the most suitable conditions for classifying submerged habitats from remotely-sensed imagery, while the dark, tannin-stained waters of the rivers and deeper waters in the basins will provide very limited, if any, opportunity to employ this methodology.

Assessment of the accuracy of habitat maps produced from classifying remotely-sensed images requires a large number of spatially-referenced sites to be visited in the field to record the type and, ideally, the quantity of the various habitats they contain. This field data is then compared to that for the same locations on the classified map, and the number of correct "matches" is calculated. There are various ways of undertaking such ground-truthing exercises. However, for benthic habitats in particular, one of the more efficient and informative methods is to use a camera system, which not only provides a permanent record of each field site, but also allows for the camera images to be examined in detail to accurately quantify the various habitats present. A novel and particularly rigorous camera system was devised by Wildsmith *et al.* (2008) for ground-truthing benthic habitats in the shallow coastal waters along the Perth metropolitan coast, which calculated and labelled the field of view, geographic location, positional error and water depth for every photo taken. This system could be easily modified for use in the Peel-Harvey Estuary.

Further details of the monitoring regimes proposed for each of the main habitat types in the Peel-Harvey Estuary are given below. It is suggested that these data are collected during late spring/summer every three years (with the exception of macrophyte wrack, for which annual measurement during winter is proposed), which coincides with:

i. the period of greatest vegetation growth or biomass;
ii. favourable climatic conditions for acquiring remote-sensed imagery;
iii. the collection of data for the key faunal groups.

Moreover, in order to ensure the longer-term value of these data sets, consistent or readily-interchangeable remote-sensing and ground-truthing methodologies must be employed among sampling occasions.

### 5.2.1 Submerged macrophytes

Regular, quantitative monitoring of the cover, distribution, composition and biomass of submerged macrophytes (seagrass and macroalgae) in the Peel-Harvey Estuary is essential for:

i. determining the status of primary production, arguably the most critical ecosystem process;
ii. understanding the ecological consequences of changes in a large suite of water quality parameters, such as nutrient availability, turbidity and salinity;
iii. explaining trends in the distribution and abundance of every major faunal group in the estuary, including small benthic and planktonic invertebrates, larger invertebrates such as crabs and prawns, fish and birds;
iv. building a further index of ecosystem health that complements those developed from other biotic groups at higher trophic levels, such as fish and benthic invertebrates;
v. providing reliable information to the community on how this highly visual component of the environment, which, in large volumes, can markedly reduce the aesthetic and recreational quality of the system, is changing over time and/or in response to environmental improvement schemes.

An assessment of macrophyte characteristics in the Peel-Harvey Estuary has not been undertaken since 2001, and the importance of establishing such a monitoring regime is clearly reflected by its high priority status in the recent *Monitoring and Evaluation Guide for the Peel-Yalgorup Ramsar Site* (Hale, 2008). However, it should be noted that the Department of Water, in conjunction with the Marine and

Freshwater Research Laboratory at Murdoch University, have just recently completed a field survey of macrophyte biomass, composition and nutrient concentrations at selected sites in the system.

While macrophyte cover, distribution and composition can be measured from remotely-sensed imagery and ground-truthed as described above, measurements of macrophyte biomass are best undertaken in the field using transect or site-based surveys at nominated sites throughout the estuary. While some recent studies have focussed on calculating macrophyte biomass from remotely-sensed imagery, this type of work is still largely experimental. The former type of field survey has been undertaken in the Peel-Harvey Estuary at varying spatial and temporal scales between 1978 and 2001 (*e.g.* Wilson *et al.,* 1997, 1999) and more recently in early 2010.

The sites selected for a future monitoring regime should include those that provide sufficient spatial coverage to allow estimates of macrophyte biomass to be reliably extrapolated throughout the system, and that coincide with sites that have been surveyed in previous years to maximise the usefulness of that historical data set. Field survey of macrophyte biomass could be undertaken in conjunction with the ground-truthing regime described above for assessing the accuracy of the map of benthic habitat cover, distribution and composition produced from the remotely-sensed imagery.

In addition to the measurement of living submerged macrophytes every three years, it is also proposed that the biomass of detached macrophyte wrack accumulations along the shorelines of the estuary be monitored on an annual basis. It is envisaged that these measurements will provide a surrogate index of year-to–year variation in macrophyte production. Such biomass measurements should be undertaken in the field during winter (*i.e.* when many of the macrophyte species that occur in the Peel-Harvey Estuary undergo a net loss of biomass due to plant die-off/uprooting) at a representative number of replicate sites/transects in those areas of the estuary at which accumulations typically occur. It is imperative that such measurements are undertaken prior to any removal of nuisance wrack by local council.

### 5.2.2 Shallow mudflats

The cover and distribution of shallow mudflats throughout the Peel-Harvey Estuary, which provide important roosting and/or feeding habitats for a range of bird species, can easily be measured and ground-truthed using the above techniques and in conjunction with the measurements collected for submerged macrophytes. The only other information required to measure the spatial extent of this benthic habitat type is a digital elevation model of the estuary, which is produced from available bathymetric data and will be used to isolate those areas of the system that are shallower than a specified depth.

### 5.2.3 Littoral and fringing vegetation

The emergent littoral and fringing vegetation along the banks of the estuary, which includes reeds, saltmarshes and paperbark trees, provide critical nesting and roosting habitats for several bird species, stabilise the shorelines and provide a buffer zone for reducing the levels of sediments and nutrient and non-nutrient contaminants entering the estuary from diffuse catchment-wide sources. The cover, composition, biomass and/or condition of the littoral and fringing vegetation of the Peel-Harvey Estuary has been measured on several occasions between the late 1950s and mid 2000s from either aerial photography or field transects.

Like the submerged macrophytes, it is suggested that measurement of the cover, distribution and composition of the emergent vegetation are measured from the above remotely-sensed (*e.g.* hyperspectral) imagery, but that biomass measurements are acquired in the field from nominated sites or transects. Such sites/transects should include those that have been monitored historically, as well as any others required to provide sufficient spatial coverage throughout the system. The groundtruthing regime for assessing the accuracy of the classified remotely-sensed image can be conducted at the same time as these biomass measurements are undertaken. However, given the emergent growth form of this vegetation, groundtruthing measurements are more appropriately made using transects or quadrats, rather than the camera-based system suggested for benthic habitats.

### 5.2.4 Integrated habitats

Classification of the various habitats present in an ecosystem based on their collective environmental differences, rather than single obvious features (such as the presence of submerged macrophytes), provides a host of management and ecological applications. Firstly, a reliable habitat inventory of the whole system can be produced, enabling identification of those habitats that are relatively unique, the ability to determine which particular combination of environmental characteristics best distinguish habitats of interest, and the establishment of a benchmark against which future changes in habitat characteristics can be measured. Secondly, and perhaps more importantly, habitat classification schemes can provide the basis by which the faunal species likely to occur at any site of interest in the ecosystem can be reliably predicted, simply by classifying that site into its most appropriate habitat. This latter function, which has countless applications for estuarine management and ecology, can be achieved by establishing reliable correlations between spatial differences in habitat types and those in the composition of faunal assemblages.

Repeating this habitat classification in subsequent years provides the ability to identify spatial shifts in the various habitat types over time as a collective or integrated index of changing estuarine condition.

A classification of the nearshore habitats throughout the Peel-Harvey Estuary was produced in 2005-07 by Valesini *et al.* (2009, 2010). This scheme used a suite of “enduring” environmental characteristics (*i.e.* those not subject to frequent and pronounced temporal changes) that fell into three main categories, namely site location (representing its vicinity to marine and freshwater sources and thus providing a surrogate for a large number of water quality parameters such as salinity, turbidity etc.), exposure to wave activity and the contributions of different substrate/submerged vegetation types comprising the benthos. Each of the environmental variables employed in this scheme could be accurately and readily measured from high-resolution remotely-sensed imagery (with the exception of the ground-truthing regime to validate substrate/submerged types) and, as those variables were largely enduring, the resultant habitat types were applicable at any time of year. Furthermore, spatial differences in the compositions of the nearshore fish assemblages were shown to be significantly correlated with those in the habitats in each season, thus enabling fish species to be predicted at any site of interest and time of year.

All of the data required for the above habitat classification scheme can be measured from the previously described remotely-sensed imagery which has been classified and ground-validated according to benthic cover type.

Given the largely enduring nature of the habitats that can be derived from the Valesini *et al.* (2010) scheme, or another scheme based on these type of environmental criteria, it is suggested that this type of integrated habitat classification be repeated for the Peel-Harvey Estuary every 10 years, and can be carried out in conjunction with measurement of each of the other habitat attributes identified in subsections 5.2.1-5.2.3. It is also suggested that this type of scheme be applied to the offshore waters of the Peel-Harvey Estuary.

The nearshore and offshore habitat types produced from a habitat classification such as this also have further potential application in the extrapolation of faunal biomass estimates that are required to develop the ecological model (see subsection 5.7).

## 5.3 Sediment monitoring

The characteristics of the subtidal sediments throughout the Peel-Harvey Estuary, including their contaminant levels (nutrient and non-nutrient) and other physico-chemical characteristics such as their particle size, organic matter content and redox potential, have not been comprehensively and consistently assessed since the construction of the Dawesville Channel. Furthermore, this issue has been given little attention in the recent *Monitoring and Evaluation Guide for the Peel-Yalgorup Ramsar Site* (Hale, 2008), or by any State management department.

Regular, quantitative monitoring of the above-mentioned characteristics is essential to;

i. assess the spatial and temporal trends of key (bioavailable) nutrient and non-nutrient contaminant stores in the sediment and determine their relationships with concentrations in the water column;
ii. determine whether non-nutrient contaminants (*i.e.* metals and organic contaminants) exceed the Interim Sediment Quality Guideline Trigger Values established by the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ);
iii. enable reliable correlations to be drawn between sedimentary conditions and observed trends in biotic distributions;
iv. facilitate the development of predictive ecosystem models for the Peel-Harvey Estuary.

While there have been some studies addressing particular sediment attributes following channel construction (*e.g.* Hale and Paling, 1999, Wildsmith *et al.,* 2009), they have not provided information on the full range of characteristics outlined above over sufficient spatio-temporal scales. Prior to channel construction, several unpublished and published studies measured various sediment characteristics at a range of spatial and temporal scales, including those by Gabrielson (1981) and McComb *et al.* (1998), who investigated nutrient concentrations, moisture content and organic matter content on a monthly to biannual basis at numerous sites in the estuary basins during 1978-1980 and 1978-1989, respectively; Gerritse *et al.* (1998), who examined the accumulations of particular nutrients and heavy metals, particle size and organic matter content at single sites in each basin on one sampling occasion in 1991; and Hale and Paling (1999), who measured particular nutrient concentrations and organic matter content at highly variable spatio-temporal scales between 1982 and 1988 and, following channel construction, in 1998. Those latter authors also highlighted the need for a comprehensive and consistent sediment monitoring program in the Peel-Harvey Estuary.

The sampling design of the proposed monitoring regime needs to account for the spatial, temporal and inherent variability in sediment characteristics. Thus, spatially, a sufficient number and distribution of sites needs to be selected to (i) provide adequate general coverage of the basins and estuarine portions of the rivers and (ii) represent areas in the vicinity of major drain sites discharging into the estuary to locate potential high-priority "hotspots". Secondly, given the pronounced seasonality of rainfall in south-western Australia, sampling should, at a minimum, be carried out in summer and also in spring, following the high riverine and drain discharge in winter. Lastly, given the large inherent variability in sediment characteristics among replicate samples (*e.g.* Nice, 2009), at least five (and up to 10) replicates (*i.e.* cores) should be collected at each site on each sampling occasion. It is suggested that this sampling regime be repeated every three years. The only exception is the collection of cores to measure sediment grain size, which need only be measured every 10 years.

If necessary, the above sediment monitoring regime could also complement a range of other monitoring regimes for the Peel-Harvey Estuary, namely (i) contaminant levels (nutrient and non-nutrient) in the drainage systems and groundwater, (ii) bio-accumulation and toxicity studies and (iii) investigations of contaminant interchange between the sediments and overlying water. The scope and necessity for this work is likely to be further defined in the proposed quantitative modelling workshop scheduled for October 2010.

### 5.4 Fish and benthic invertebrate faunas

Regular quantitative sampling of the species abundance composition of estuarine faunal communities provides invaluable information for assessing, and ultimately predicting, the ecological consequences of environmental change in these systems. That is, fauna respond to or integrate many aspects of their environment, such as their surrounding water and sediment quality, features of their habitats and their interactions with other biota (*e.g.* through dietary interactions or competition). Changes in their assemblage composition, such as the loss of more sensitive species or increasing dominance of opportunistic species, thus provide an excellent "summary" of the status of the various ecosystem components and their complex interactions. This forms the premise of the multimetric biotic indices of ecosystem health outlined in subsection 5.1.1.

Likewise, regular monitoring of the biology of key faunal species (*i.e.* their growth, reproductive, age and/or dietary characteristics) provides significant insight into how the populations of these species are being impacted by their environment, interactions with other species (or individuals within their population) and, in the case of particular species, exploitation from recreational and commercial harvesters. An excellent example of this has been provided by recent Murdoch University research on Black Bream in the nearby Swan-Canning Estuary (Cottingham, 2008), in which their growth, body condition and length at maturity declined markedly, and age at maturity increased, between 1993-95 and 2007-08. Such changes possibly reflect higher abundances of individuals in the population, dietary shifts in response to a reduction in their preferred prey and declining water quality over that time period.

The fish fauna of the Peel-Harvey Estuary has been sampled as part of several research projects since the late 1970s. These have included Loneragan *et al.* (1986, 1987), who sampled the fish fauna throughout the shallow and deeper waters, respectively, of the basins, natural entrance channel and tidal reaches of the rivers in 1979-81, Young and Potter (2003), who replicated and extended the above nearshore fish sampling regime in the basins and channel in 1996-97, Valesini *et al.* (2009), who sampled numerous nearshore sites throughout the estuary in 2005-07 and a current Murdoch University and WAMSI project, which replicated and extended the nearshore sampling regime of Young and Potter (2003) in 2008-10. In contrast, there have been no studies of the biology (*i.e.* growth, reproductive, age or dietary characteristics) of any fish species in the Peel-Harvey Estuary with the exception of the Six-lined Trumpeter, whose biology has only recently been examined in the above 2008-10 study.

The biology of Blue Swimmer Crabs were examined throughout the estuary on a monthly basis between 1995 and 1998 (de Lestang *et al.* 2000, 2003), and various characteristics of the crab population (*i.e.* abundance, size structure, sex-ratios and numbers of berried females) have been recently assessed by the Department of Fisheries throughout the estuary on a monthly basis between 2007 and 2010 and, in the last two of those years, in the nearby coastal waters. The biology and/or movements of Western School and Western King prawns throughout the estuary and/or nearby coastal waters were last assessed in the late 1970s to late 1980s (Potter *et al.,* 1986, 1989, 1991).

The assemblage composition of small benthic macroinvertebrate communities has been measured seasonally at four sites in the estuary basins in both 1986-87 and 2003-04 (Wildsmith *et al.,* 2009).

While the above research projects provide useful historical information, their value in supporting the requirements for robust ecosystem evaluation tools, *i.e.* the multimetric biotic indices and the integrated ecosystem model, is limited. This is due either to inconsistencies in sampling methodology among studies or an insufficient time series of data.

It is thus proposed that the fish faunas, crabs, prawns and small benthic invertebrate faunas be monitored at a representative number of sites in the shallow and deeper waters of the estuary basins, natural entrance channel, lower reaches of the Murray and Serpentine rivers and in the nearby coastal waters every three years during spring/summer. For the first three of these faunal types, the species abundances, lengths (or carapace widths) and weights should be recorded in each replicate sample. Furthermore, for key species, the age, sex, gonad stage and gut composition should be recorded. Note that, while the latter biological information will be collected every three years, it will only be analysed every 10 years to test for differences in growth, age and reproductive characteristics. Samples will be collected by seine net in the shallows and gill nets and traps (for crabs) in the deeper waters. Although trawling has been used previously in the deeper waters of this system to sample these fauna, it has proved ineffective in more recent years due to macroalgal accumulations and/or very soft substrates. For the small benthic invertebrates, species abundances and weights of key species should be recorded in each replicate sample. These samples should be collected using sediment corers or grabs.

In addition, to support the requirements of effective annual health indices (and thus report cards) and the ecological module of the integrated model, it is also proposed that the above faunal sampling regime is carried out at a subset of the most informative sites throughout the estuary and nearshore marine waters on an annual basis (again during spring/summer). However, for these sampling events, measurement of biological information for the key species will be restricted to recording the ages, sex and gonad stage of a random subsample of individuals.

It is imperative that the sampling methodologies for the above fauna remain consistent over sampling occasions to ensure the long-term value of the data sets. Furthermore, wherever possible, sampling should be undertaken at sites that have been sampled in the above historical studies to maximise the usefulness of those data.

### 5.5 Movement of fish between estuary and nearby marine waters

Any attempt to understand fisheries and energetics of estuaries requires knowledge on the movement of marine species between the estuary and adjacent coastal waters. To date, however, no studies have been undertaken of the numbers or ages of individuals of such species moving between the Peel-Harvey Estuary and oceanic waters. There are two approaches to addressing this problem. First is a tagging regime for key species to be designed to provide an estimate of population and thus total biomass moving between these waters. The second is the potential to use passive acoustic techniques, *i.e.* an acoustic array of hydrophones in the entrance channels, to track schools of fish moving in and out of the estuary. The latter study would initially require tagging of individuals of key species using pinger tags to develop acoustic signatures for different species and to calibrate acoustic signals to numbers of fish. Any such study examining fish movements between the estuary and nearby ocean would benefit from being repeated every 10 years.

### 5.6 Food web

Food webs provide a method for determining the flow of energy through the ecosystem and establishing the primary energy source. Such knowledge enables prediction of the likely consequences for an ecosystem of changes in the prevalence of particular biotic groups, and is essential for constructing reliable models of estuarine function. The development of a food web requires quantitative data on the dietary compositions of species from each faunal group that span the major feeding guilds (see below), and which is spatially and temporally comprehensive. However, in the case of the Peel-Harvey Estuary, there is either very little or no dietary available for any faunal group. For example, in the case of fish and birds, the former of which is typically the best studied in terms of dietary composition, there is only a general knowledge of their diets based on studies carried out in other estuaries.

Construction of a reliable food-web requires (i) quantitative information on the volumetric proportions of the various food types most recently ingested by a faunal species and (ii) an understanding of those food sources that are assimilated into the tissues of an organism over their life-time. While the former can be achieved using traditional gut-content analyses, the latter requires analysis of the stable isotope ratios (often $\delta^{13}C$ and $\delta^{15}N$ ) in predator tissues and those of their prey.

It is thus proposed that both of the above methodologies are used to establish the trophic linkages among representative fish and bird species and their prey throughout the Peel-Harvey Estuary. Representatives of the main feeding guilds of fish (*i.e.* planktivores, opportunistic omnivores, detritivores, herbivores and benthophagous species) and birds (*i.e.* piscivores, herbivores and migratory and endemic waders) will thus be collected for gut-content examination (*i.e.* stomach contents and regurgitate for fish and birds, respectively) and stable isotope analyses (*i.e.* of muscle tissue and feathers for fish and birds, respectively). Samples of the main food sources for fish and birds, namely benthic invertebrates, plankton, macrophytes, benthic microalgae, detritus, fish and terrestrial insects, will also be collected and their tissue samples subjected to stable isotope analyses to ascertain the food or nutrient sources that they each consume, and the extent to which they contribute to fish and bird diets. It is suggested that these fish, bird and prey samples are collected and analysed seasonally for two consecutive years, with the study being repeated every 10 years to capture potential shifts in dietary linkages in response to any significant ecosystem changes.

### 5.7 Fisheries

One of the important values of the Peel-Harvey Estuary is the recreational and commercial fishing activities it supports, and its function as a significant fish, prawn and crab nursery area. The crab population also supports a major tourism attraction through the annual crab festival at Mandurah.

Future modelling of the estuarine ecosystem will require a detailed time series of the age compositions, abundances and biomasses of key species of both the exploited and unexploited fish and invertebrate fauna within the estuary, and also of those marine species that enter and leave the estuary. For each of the key exploited species, time series of the catches, estimates of fishing mortality and biological data, *i.e.* growth, reproductive data, diets, natural mortality, spatial distribution within the estuary and age and sex-specific movement between ocean and estuary (if any), will also be required.

The Department of Fisheries is charged with the responsibility of sustainable management of the commercial and recreational fisheries of the estuary. Regulations also effectively limit the number of commercial fishers, and there are size limits and gear, temporal and spatial controls operating within the estuary for both recreational and commercial fishers. Bag limits also apply for most exploited species targeted by recreational fishers.

The commercial estuarine fishery is a multi-species, multi-gear fishery, however, and fishers target the species that provide the greatest economic return. Catch and fishing effort data on exploited species are collected monthly from the commercial fishers, who are required to report details of their fishing activities and catches, by species, to the Department. With the exception of trap fishing for Blue Swimmer Crabs, estimates of fishing effort cannot be attributed reliably towards particular species. Estimates of catch per unit of effort, a metric that is typically used as a measure of the abundance of a species, thus exhibit considerable inter-annual variability and are imprecise measures of abundance. Data collection from the commercial fishery should be continued, with catches and fishing effort being recorded on a daily basis, and with both estimates of numbers and weights of each species caught being recorded. Details of numbers of fish or crabs released should also be collected from the commercial fishery, as such data could assist when assessing exploitation of the fishery. Similar data should be collected from adjacent marine waters.

Mandatory reporting of all fishing activity and catches by recreational fishers is impractical, and data for these fishers must be collected using research surveys. Only two surveys of recreational fishing in the Peel-Harvey Estuary have been undertaken, one in 1998/99 and the other in 2007/08, as the high cost of well-designed, statistically sound research surveys constrains their frequency. The collection of recreational fishing data on randomly-selected weekdays, weekend days and public holidays throughout the year, from which accurate estimates of annual recreational catches of different fish species may be calculated, is expensive. However, the newly-introduced boat licence provides a sampling frame that may assist in reducing survey costs for boat-based fishers.

The keenness of certain recreational fishers, *i.e.* frequency with which avid fishers fish, has the potential of biasing catch rate estimates derived from surveys of different forms. While voluntary recreational logbook and diary systems are often proposed as low cost alternatives to research surveys, the data collected by such systems are typically heavily biased towards the data provided by avid, more experienced fishers, and lack the statistical rigour and design necessary to allow calculation of reliable estimates of total annual catch. While such data are biased, they could be employed both in years in which research surveys were conducted and in intervening years. If the voluntary recreational logbook and diary systems were well-designed and well-managed, based on a statistical sampling frame, and subjected to appropriate statistical analysis, there is potential to use the data from years in which both the research and voluntary systems operated to assess the magnitude of the bias associated with the latter system. These estimates of bias could then be used to adjust the results of the voluntary system to provide estimates of recreational catch in intervening years between research surveys.

It is proposed that research surveys of recreational fishing be undertaken at least at five-yearly intervals, and that the potential of using fixed video cameras at jetties, shore locations and boat ramps, such as the Department of Fisheries is testing in other locations, should be considered for use in monitoring recreational fishing effort in the Peel-Harvey Estuary in the intervening years. This work needs to be undertaken by the Department of Fisheries as part of their core responsibilities, or contracted out as appropriate. This information will supplement that collected as part of the fish community monitoring program proposed in this study (see subsection 5.4). As described above, a statistically-sound voluntary logbook or diary survey of the recreational fishery should be designed to complement the research surveys and provide data in intervening years between such surveys. If, after reviewing the design of this voluntary survey, it appears possible to overcome the issues associated with bias, then such a survey should be implemented.

Species such as Blowfish, and many of the smaller fish species such as gobies and hardyheads, are not targeted by recreational or commercial fishers. For these species, estimates of abundance can only be obtained using research sampling, as identified in subsection 5.4. This research sampling will also collect species that are targeted by fishers, and will provide statistically sound and consistent measures of abundance and age composition to supplement estimates of abundance indices derived from fishery-dependent data, and which can be used to determine spatial and temporal trends in fish distribution. Such research sampling, including the dietary analyses outlined in subsection 5.6, will also provide the data for population biology studies of growth, age and reproduction of key species.

The Department of Fisheries has identified Estuarine Cobbler, Black Bream and Perth Herring as key indicators of the health of the Peel-Harvey and other estuaries in the south-west. In assessing the status of the Peel-Harvey Estuary, the Department has also used data on trends in abundance of Yellow-eye Mullet, Blowfish, Bar-tailed Flathead, Blue Swimmer Crabs, School Prawns, and Western King Prawns. However, with the exception of the School Prawns, these latter species all spend at least part of their life cycle in marine waters, and their abundances are thus influenced by those environments.

The extent to which marine fish of different ages and species move between the estuary and the adjacent marine environment is as yet unquantified, but is likely to be significant for some species. Such movement will need to be considered when developing an ecosystem model, and thus studies such as those suggested in subsection 5.5 should be initiated to investigate this.

As ecosystem modelling requires an estimate of the absolute biomass of each of the functional groups of fish, rather than an index of relative abundance, consideration should be given to undertaking a study to determine the relationship between the abundance indices reported by fishers for the key fish species and the absolute biomass of the exploited individuals of those targeted species in the estuary. Such a study might involve a tagging or depletion study, the former possibly providing valuable information on the movement of marine fish between the estuary and the ocean. Determination of the age composition of targeted fish species within and outside the estuary would also provide information on fishing mortality, from which estimates of biomass might be derived.

Alternatively, estimates of total biomass for the species caught during the research sampling program outlined in subsection 5.4 could be estimated by using the fish densities recorded at the various sites and extrapolating them throughout the whole estuary on the basis of the habitat classification scheme described in subsection 5.2.4. Thus, each sampling site would be assigned to its most appropriate habitat, and the average of the fish densities recorded at sites belonging to the same habitat would be extrapolated over that area of the estuary occupied by that habitat type.

A biological sampling program to obtain annual age composition data separately for the commercial catches within the estuary and in the adjoining marine waters should also be initiated, recognising that the selectivity of fishing gear used by commercial fishers produces an age composition of the catch that differs markedly from that of age compositions of the population in the estuary (where the latter age compositions are derived from the research samples). Such age composition data from both the research samples and the commercial catches will be essential to assess the fishing mortality on the different targeted species and will be invaluable for the estimation of biomasses. Length composition data collected during research sampling under subsection 5.4 can be analysed to estimate total mortality for the species in the various samples.

Lastly, a simpler multispecies model of the species for which data provided by the commercial fishing sector exist should be developed to complement the full ecosystem model. Such a model is less demanding of data and its development could proceed in parallel with the development of the ecosystem model, calculating the estimates of the biomasses of some of the species targeted by commercial fishers that are required for input to the ecosystem model. In addition, a multispecies fishery model with a two component spatial structure representing the estuarine and adjacent marine waters could also be used to explore the extent to which catches per unit of effort within the estuary are correlated with those indices of abundance in the adjacent marine waters and possibly provide information on the extent of interchange between the water bodies.

## 5.8 Governance Arrangements

"To provide authority without funding or power through accountability results in no authority at all"

The PHCC is a not-for-profit, incorporated body established by the then Department of Agriculture. It has no specific legislative powers or ability to coerce or demand performance of any agency in the delivery of its responsibilities or functions. Its role as a community-based organization is set down by the objectives found within the council's constitution.

The key objectives focus on informing, inquiring and involving the community in an agenda of facilitation, promotion, leadership, coordination and integration of planning and delivery of outcomes for NRM across the Peel-Harvey catchment, including the estuary (although the latter is not specifically mentioned). The Council has no legislative powers and is totally beholding to third parties for both funding and the delivery of services to provide effect to its charter.

The key tools open to the Council are those of persuasion, communication, education and community pressure to encourage a range of Commonwealth, State and local authorities to work collaboratively on arguably an agreed set of planning horizons and action strategies.

Unlike the Swan River Trust, which is unique for W.A.'s estuaries, there exists no legislative power to act or ability to enforce performance or even to require agencies to report. The Council's existence depends very much on the priorities of bodies such as the South-West Catchment Council, and funding through the Caring for our Country funds and other non-core grant application funding streams. There is thus no long term funding security that underpins the operations of the Council.

The day to day responsibilities for water quality and nutrient loadings in the waterways, recording of fish kills, levels of algae and the like fall directly in the scope of the Department of Water. Similarly, matters pertaining to fisheries management and fall within that of the Department of Fisheries, boating, navigation and moorings controls fall in that of the Department of Transport, building approvals in the Local Government and Department of Planning, etc. In other words, the delivery of services and policy framework fall properly within the scope of the accountable State and local government authorities, with priorities for limited funds determined within the scope of each department and Ministerial portfolio, rather than in the overall context of priorities for the Peel-Harvey Estuary.

No Minister is uniquely responsible for the on-going health of the Peel-Harvey Estuary and its catchment, and yet almost all, through their operational departments, have some degrees of responsibility.

Unlike the Swan River Trust legislation for the Swan-Canning Estuary, there is currently no obvious mechanism for collective accountability for performance reporting or assessment of risks for the ongoing health of the Peel-Harvey Estuary.

The management requirements of the Peel-Harvey Estuary and the respective catchments fall within the public policy scope of what is defined as a "wicked problem" (Briggs, 2007). Successfully tackling such problems requires broad recognition and understanding, including that of governments and Ministers. There are no quick fixes and simple solutions. The approach to solving these problems has to be adaptive, often innovative and requires effective collaboration.

The term "wicked" in this context refers to an issue highly resistant to resolution. The characteristics of wicked problems" are described adequately by Briggs (2007) and summarised as follows.

i. Problems are difficult to define;
ii. Problems have many inter-dependencies and are often multi-caused;
iii. Attempts to address wicked problems often lead to unforseen circumstances;
iv. Often the problems are not stable;
v. Usually they have no clear solutions and require ongoing management;
vi. Wicked problems are socially complex;
vii. Wicked problems mostly are not within the responsibility of any one organisation;
viii. Wicked problems involve changing behaviours;
ix. Some wicked problems are characterised by chronic policy failure.

It is self evident that managing the catchment and ecosystem health of the Peel-Harvey Estuary has all the characteristics of a "wicked problem". Collaborative strategies are particularly important where sustained behavioural change by many stakeholders is a necessary part of the solution. The range of active strategies for implementation of the WQIP for the Peel-Harvey Estuary catchment, let alone the future ecosystem health of the estuary, identifies clearly the need to engage large sections of the community as well as the importance of working across organisational boundaries. Without the support of the community and active engagement of stakeholders, chronic policy failure is likely to occur.

It is worthwhile briefly reiterating key messages for policy solving across agency boundaries for the resolution of wicked problems. These fall into four areas.

i. Supportive structures and processes;
ii. A supportive criteria and skills base;
iii. Facilitative information management and infrastructure;
iv. Appropriate budget and accountability frameworks.

When assessing the current governance arrangement for the Peel-Harvey Estuary and its catchment, feedback from the workshop indicated an existing failure in governance. This has been recognized previously by the EPA and the Department of Water (EPA, 2008). It appears to stem from a failure in funding certainty, lack of accountability and an absence of shared understanding of science advice and strategy. These issues extend beyond catchment goals to the maintenance of ecosystem health for the estuary, which are overall aspirant community objectives.

The challenge becomes how to modify "existing processes and practices that might promote better communications and remove obstacles to collaboration that devolution of responsibility for governance may raise. These include having the right skills and culture, an adequate information-sharing infrastructure and governance arrangements that focus accountability on the collective outcomes the government is seeking" (Shergold, 2004).

From our perspective, much of what is being undertaken is largely fixable without warranting major change. The value of collaboration and having a science leader with power and influence to bring together decision makers, scientists and the community, and to integrate science knowledge with a range of solutions, is a significant factor.

Professor Ernest Hodgkin in the 1980s and early 1990s was the driving force in such a role that led ultimately to the decision to construct the Dawesville Channel. The crisis depicted by the poor state of the Peel-Harvey Estuary at the time engendered a sense of urgency, funding and a need for resolution of a clearly identified problem that was apparent to all. Decisions were made.

Fifteen years on, the urgency has disappeared but, as outlined earlier, there is growing evidence that all is not well in the estuary, with more significant risks potentially facing those responsible for its health and well being (refer section 3.6).

In examining the elements around solving wicked problems, a number of possible solutions are discussed under each of the four areas identified earlier.

***(i) Supportive structures and processes***

As mentioned earlier in this report, a great deal of research and action has occurred. While a wealth of information exists on the Peel-Harvey Estuary, much of that which is available is either old information and predates the 1994 opening of the Dawesville Channel, found in organisations with traditional bureaucracy and a silo approach to information, and/or not sufficiently analysed or integrated to provide a clear view to the community on the ongoing status of the estuary and its likely future. Also, much of the post-1994 science, particularly that produced by the University sector, primarily fell into areas of science interest rather than forming part of an overall pre-planned science approach facilitating strategic integration.

As described above, the PHCC is without power to enforce agencies to report or act. The focus of traditional bureaucracies, and rightfully so, is on their core business, with little real impetus to integrate and report on their findings relevant to the PHCC and its operation. The role of the PHCC in empowering the community, independently of government, to act and participate in programs to improve catchment management and subsequent waterway and estuarine health, is pivotal to overall success in effective governance.

Community ownership and action independent of government is crucial for ongoing adaptive management of what is largely a community derived 'wicked' problem, and thus has to be part of the solution. Governments and Ministers need to recognize this requirement. Governments cannot do it alone. Similar to the provisions of the Swan and Canning Rivers Act 2006, there is a requirement to change governance and process arrangements for future management of the Peel-Harvey Estuary and its catchment. These changes are not revolutionary but incremental, building on those successes and directions already achieved, and are enunciated as follows:

1. The objectives of the PHCC need to change to reflect stewardship responsibilities not only for the catchment, but for the ongoing ecosystem health of the Peel-Harvey Estuary and its adjacent waterways, now and in the future;
2. That Government agencies be required by legislation to report to the PHCC on matters of performance of their functions and programs relevant to the ongoing management of the Peel-Harvey Estuary, its waterways and catchment. Importantly, this should include programs such as the Water Quality Improvement Plan (EPA, 2008) and monitoring requirements for the Peel-Yalgorup Ramsar Site;
3. That Government institute, through the EPA, a regular performance audit of agencies having responsibility for action programs relevant to water quality improvement in the catchment, maintaining and improving ecosystem health of the Peel-Harvey Estuary and its waterways. Desirably, this audit needs

to be undertaken at least every five years and take into account risk arising from climate change (refer section 4.3);

4. That PHCC is sufficiently funded so that its core responsibilities can be undertaken without continually detracting from its role by seeking funds from various sources to ensure its operations;
5. That PHCC is sufficiently funded to enable the ongoing appointment of a Senior Scientist to deliver the following outcomes:

    i. The integration of science across the University, Government and broader community sectors and facilitation and co-ordination of a science strategy that addresses current and future risks for the Peel-Harvey Estuary, its catchment and its adjacent riverine and marine waters.
    ii. Provides, with the co-operation of the Western Australian science community and advice from government agencies, reporting on the current and projected status of the ecosystem health of the Peel-Harvey Estuary and its adjacent riverine and nearshore marine waters, and on the performance of catchment management strategies.
    iii. Helps establish priorities for research in the Peel-Harvey Estuary, its adjacent riverine and marine waters and its catchment.
    iv. Facilitates community liaison and communication on the outcomes of research relevant to the objectives of the PHCC.
    v. Facilitates co-investment and funding for monitoring, research and model development and evaluation.
    vi. Maximises the opportunity to build science capacity in the region using PhD programs, relationships with the university sector relevant to estuarine, catchment, riverine and nearshore marine adaptive research (including restoration) and Commonwealth and State funding programs.

6. That the Department of Water, in consultation with the State's catchment councils and EPA, explore the principles outlined in the Swan and Canning Rivers Management Act 2006 to determine how a more general Act could be modelled to provide a set of legislation relevant to the management of the State's other key catchments and estuaries.

Whilst other changes in governance are possible, including substantially improving the powers of the Department of Water and funding coupled with a stronger regulatory approach to achieving both catchment and estuarine management solutions, the preferred direction has to be one that maintains community support, active involvement and empowerment.

***(ii) Supportive Culture and Skills Base***

The skills base necessary to meet future management needs already exists within the Western Australian science community. The primary challenge is that of problem recognition of the overall future risks facing the community and the ecological status of the Peel-Harvey catchment and its waterways, and a willingness of Governments and Ministers, supported by the community, to engage. Better integration of available science, telling the story and projecting futures for the estuary based on the available knowledge, is an essential part of the process for effective community engagement and ongoing and sufficient action.

Community action for that support may be, by necessity, the only pathway forward.

### *(iii) Facilitative Information Management and Infrastructure*

Public access to data and information has never been greater. The requirement to establish a single focus for reporting does not mean information has to be centralised or necessarily managed by a single agency.

Projects already underway, including that aimed at establishing a database of metadata for all past research in the Peel-Harvey Estuary which was recently commissioned by the PHCC, will go a considerable way to addressing this need. The passage of data and information between government agencies and community-based organisations such as the PHCC is not seen as limiting. Web-based products and access to internet facilities, including the Western Australian Government's investment in iVEC super computing facilities, makes data sharing, analysis and communication much more achievable.

### *(iv) Appropriate budgets and accountabilities*

Without adequate funding certainty and appropriate accountabilities, performance in dealing with the enormity and complexity of the Peel-Harvey and its associated issues, will, at best, be difficult. This has certainly been the experience for funding the monitoring, science and management needs arising from proposed deliverables around the WQIP, and the Ramsar monitoring requirements for the Peel-Harvey system.

Improvements in reporting and audit previously outlined are expected to assist accountabilities and performance for what is seen as a region-based government-community issue. Current directions in research, focused on integrating the outcomes of science and monitoring towards developing integrated qualitative and quantitative models as decision support tools for future management of estuarine health, are timely.

Without a full audit of performance, the extent of funding shortfall in dealing with the future risks for the system cannot be understood, particularly in the scope of population growth, development and evolving climate change risks.

It is also not necessarily a cost that ought to be sheeted home to government alone. There exists a shared responsibility for the community, which benefits from living near the Peel-Harvey Estuary and associated waterways, to share those costs in maintaining its health. Arguably, the benefits are already reflected in the values which attract an increasing number of residents and tourists and, more directly, in considerable housing and property values. Investment by these owners towards maintaining these values into the future is a reasonable expectation. There is also a valid case for those generating high levels of catchment effluent and therefore nutrient loads that ultimately impacts on the estuary to be taxed to fund mitigation, and encouraged to reduce their environmental footprint.

Whilst funding and taxation policy is as much an issue for government as the risk of funding inadequacy, there is a case to look at evolving new policy and associated financial instruments that could assist in developing funding solutions to solve what is clearly a wicked problem. Further details are provided in the next section.

## 5.9 New Funding Approaches

There is no magic procedure for determining who should pay for maintaining the ongoing health status of the Peel-Harvey Estuary. In many jurisdictions, this cost of managing the estuarine environment has generally been borne by Government with other sectors contributing where the case is made. The two main alternatives are (a) that payment continues to come from the environmental services budget of State and/or local government agencies, or (b) that it is effectively privatized and thus managed by a specific authority that has the ability to raise revenue from the beneficiaries, be they industry, property owners, or users of the many services the waterway provides.

The polluters (including nutrients and non-nutrient) to the estuary fall within three major groups: agriculture, urban development and significant specific point "industry" sources. All three can be regulated and charged for the pollution they are causing, which has the effect of reducing pollution and also raising revenue to help manage the water resource.

Those that own valuable real estate within canal estates or from foreshore developments currently benefit as "free riders" from collective action taken within the catchment to manage the environment or that taken to improve the state of the waterways. In a similar vein, real estate developers who do not adequately contribute to urban environmental abatement programs, may extract considerable profits from current values to living in the region but, at the same time, potentially extend longer term costs to those that live adjacent to or use the waterways as a result of cumulative impacts of future environmental degradation. How such events are manifest depends on the overall accumulative capacity of the waterways to successfully assimilate pollutants. Other free riders include visitors and residents of the area who have free access to recreation on the waterways. Those that use the region for recreation and contribute nothing directly to managing the environment are "free riders" in every sense of its meaning. Taxing of recreation is an optional funding strategy which is likely to be less politically acceptable and not further considered.

Whilst it may be easier to assume managing the waterways environment for the common good of all falls within the scope of a "public good", particularly if everyone has equal and ready access and the exclusion of people from the estuary is impossible, that need not be the case. This issue is primarily an issue of exclusion, however, in the case of the Peel-Harvey Estuary, there is unlikely to be the political will to exclude those who do not pay or to charge a fee for access.

Privatisation of the waterways may open other policy alternatives for funding the management of ecosystem health and, although not necessarily advocated, it is worthy of examination.

Should the community and government reject such a notion, then Government(s), as part of its collective action and perhaps responsibility, needs to provide the necessary funds from general revenue. The observation that insufficient funds are provided simply increases the long-term ecosystem health risks for the Peel-Harvey system and will cause obvious decline in the value of its environmental services as population growth and climate change impacts continue. It may also increase Government's longer term costs, especially if intervention becomes crucial. Collective support for action, whereby the community incites politicians to adopt policies for dealing with funding requirements, can block 'free riding' and require polluters, and those that benefit from improved ecosystem health, to each contribute to the cost of providing it.

Such an approach requires the community to be actively involved in the debate. In other words, the community itself reaches a point of agreement on both a willingness to pay and acceptance for the case to contribute directly to funding. This may require a shift in community attitudes to have currency.

Another pathway for consideration is to focus on those who are the major contributors to pollution and appropriately define their contribution to meeting the cumulative cost of managing the ecosystem health of the waterways.

In order to proceed, such a proposal requires a quantification of the extent polluters (or classes of polluters) contribute to the problems of declining ecosystem health, and identification of the best pollution abatement and pricing instruments that will limit ongoing polluting behaviours and facilitate user adjustment. To be successful, this approach requires a quantitative understanding of cause and effect pathways, not only within the catchment, but on the ecosystem health of the estuary itself. Thus far, there is no effective numerical ecosystem model on how the Peel-Harvey Estuary behaves to long-term shifts in nutrient loads, and that allows damage of pollutants to be estimated. However, work done by the Department of Water and the Department of Agriculture and Food on sources of nutrient loading should provide insights as to the contribution by various classes of polluters in the catchment, at least for phosphorus and nitrogen.

Ecosystem evaluation using Cost-Benefit approaches is very much in its development phase, and much of the work is characterized by extensive uncertainty, irreversibility and nonlinear, lagged relationships. These factors alone could limit the practical value of the approach, although it is worthy of consideration. Expert panels are often used to give first order approximation of damage estimates, which allow the scale of any loss and the cost of remedial action to be gauged.

If a better estimate of the share that various classes of polluters should contribute could be established as a proxy to future sharing of the cost of estuarine health management, appropriate taxing or pricing instruments could at least be examined, discussed and considered by the broader community.

As most classes of polluters fall within the different areas of the catchment and are linked to different types of land use, local government, through rating systems (should a tax system be applied) or licensing arrangement, have the necessary mechanisms for cost recovery, and therefore have a key role to play.

It is argued that any ecosystem evaluation approach using Cost-Benefit techniques is likely to be fraught with difficulties and ought not proceed without a pilot pre-feasibility study using available evidence and expert panel approaches. This approach will also highlight the important knowledge gaps that need to be filled to enable a more comprehensive analysis. The cost of such a pre-feasibility study is likely to be in the order of $150,000, whereas a comprehensive cost-benefit analysis could cost $0.5 million.

Any findings from such examinations could be extended to other estuaries and catchments and has strategic value for Western Australia.

This argument does not extend to the broader issue of climate change, where the drivers and governance issues can be sheeted home to the collective impacts of human endeavour on the environment. Governments, both State and Commonwealth, have a primary role in funding strategic issues, along with the insurance industry, into research and risk evaluation of impacts.

## Chapter 6 Estuarine health evaluation and predictive tools

### 6.1 Background

There are broadly two approaches for evaluation tools to assist in managing estuarine ecosystem health, namely multimetric indices and predictive models.

The first of these are covered in subsection 5.1.1, with data requirements addressed later in this chapter.

Among the modeling studies sponsored by the W.A. Marine Science Institution since its establishment in 2006, were two that investigated the role that ecosystem models could play in an ecosystem-based approach to fisheries management. These studies fall within the broader project of WAMSI project 4.3 *Trophic interactions an ecosystem modeling for ecosystem based fisheries management*, and more specifically within WAMSI subproject 4.3.2 *Ecosystem Modeling*. The studies used models of two very different forms. The first of these used qualitative modeling (currently being undertaken by Jeffrey Dambacher and Sarah Metcalf, and which is described below in subsection 6.1.1), while the second (currently being undertaken by Hector Lozano-Montes and Ben Chuwen, and which is described in subsection 6.1.2) involves quantitative modeling . A workshop will be held later in the year to define the best way of moving forward for the latter type of modeling of ecosystem function for the Peel-Harvey Estuary, having scientific community agreement on the way forward. There is also a funded PhD program to assess the value of Ecopath/Ecosim in the development of an ecosystem model for the estuary.

#### 6.1.1 Qualitative modeling

Qualitative modeling explores the structure of the processes that link the different variables within a system, *e.g.* fishers catch crabs (a positive link from crabs to fishers), which reduces the number of crabs (a negative link from fishers to crabs). The resulting network of such processes, which relate each of the variables in the system to each of the other variables, may be analysed using a technique known as "loop analysis". This determines the number and type of feedback cycles and thus system stability, and allows exploration of the likely effect on other variables of an increase or decrease in a given variable, either through a pulse or a sustained pressure.

Loop analysis theory has a very sound mathematical basis and is used frequently in the engineering field. The qualitative modeling approach offers a number of benefits, not least the fact that it is a very rapid way of exploring alternative model structures and of identifying those that are consistent with observations of system behavior. It allows inclusion not only of ecological processes, but also of socio-economic processes and behavior. The current qualitative modeling study of the Peel-Harvey Estuary, which will be completed by early 2011, is examining the factors and processes that threaten estuarine assets, and is identifying ways in which these processes might be modified to improve estuary management. In particular, the study is exploring deficiencies in current communication and governance structures, and considering ways in which these might be modified to produce a more effective system capable of maintaining the values of estuarine assets.

Preliminary qualitative modeling work has indicated that there are broadly four spatial regions within the basins of the Peel-Harvey Estuary, with different hydrological conditions and resultant biochemical and ecological characteristics influencing ecosystem function. These regions change seasonally, primarily due to changes in freshwater flow and need to be accommodated in any future model development. The increased sampling proposed will help clarify spatial and temporal resolution.

#### 6.1.2 Quantitative modeling

Quantitative ecosystem modeling considers the animals and plants in the ecosystem as a number of functional groups, each of which contains species with similar diets and predators, and has individuals of similar size. The functional groups are linked by the dietary composition of the individuals in the functional group. Thus, a functional group such as “carnivorous marine fish” might act as a predator of the functional group, “Blue Swimmer Crabs”. Using estimates of the biomass of each of the functional groups in the estuary, their rates of consumption and production (*i.e.* growth in biomass), and their dietary compositions, the model can calculate how those biomasses might change when, for example, subjected to an increase in the catches of a species, *e.g.* Blue Swimmer Crabs.

In contrast to a qualitative model, which can only predict the direction of response to change, a quantitative ecosystem model predicts the absolute values of the biomasses within each of the functional groups that might be expected, due either to direct or indirect effects, when the system is perturbed. The modeling tool that was employed in the PhD project to represent the Peel-Harvey estuarine ecosystem was Ecopath/Ecosim, a model that is widely used to describe aquatic ecosystems. Quantitative models are far more complex and demanding of data than qualitative models, and require a very large number of parameters to be estimated when fitting the model to the available data.

Although a number of data gaps were identified, the study demonstrated that there were sufficient data for an Ecopath/Ecosim model to be developed for the system. It became apparent during the modeling exercise, however, that a model with greater functionality than Ecopath/Ecosim was required to provide the predictions required by estuary managers. When taking into account the broader trends of population growth, ongoing catchment development and climate change, a different and more substantial modeling approach is required to meet management challenges for the Peel-Harvey Estuary, its catchment and adjacent riverine and nearshore marine waters.

Thus, not only is the model required to represent the ecosystem, but it needs to allow exploration of the flow of nutrients through the catchment and the estuary and the implications of the impacts of sea level/climate change on the system. As mentioned earlier, a scientific workshop to consider the type of quantitative model that needs to be developed for the Peel-Harvey Estuary to assess the impacts on the ecosystem of the continued high level of nutrients entering the estuary and the implications of climate change, has been approved by WAMSI and will be held later in 2010. Without preempting the findings of this workshop, it appears highly likely that a model of the type required for the management of the Peel-Harvey Estuary and its catchment will need to contain modules that integrate predictions resulting from a number of interrelated processes. Such a model is likely to be developed incrementally, in a number of phases and by a number of agencies over time. The sub-model components are “catchment”, “hydrological”,” biogeochemical” and “ecological”, and are each discussed below in subsection 6.2.

### 6.2 Data requirements for Modelling

Without preempting the findings of the quantitative modeling workshop, it appears highly likely that a model of the Peel-Harvey Estuary of the type required to support the management of the estuary and its catchment will need to contain modules that integrate predictions resulting from a number of interrelated processes (for example, the CSIRO SHOC model). Such a model could also be usefully used across a range of estuaries in south-western Australia, making investment more cost-effective. Although such a model is likely to be developed incrementally, in a number of phases and collaboratively by a number of agencies over a period of approximately ten years (refer recommendation 4), we outline below the sub-models that are likely to be included as modules of the final completed model.

(1) A model of the catchment that relates land use, fertilizer application and rainfall to the water flow and nutrient load entering the rivers and the estuary.

(2) A hydrologic and sediment transport model that describes the flow of water through the lower reaches of the rivers and the estuary and water exchange between the estuary and the ocean, and is able to assess the implications of the impacts of climate change, *e.g.* through rising sea level.

(3) A biogeochemical model that is built on the hydrodynamic model, which models the flow of nutrients through the estuary and, via primary production, into the food web.

(4) An ecosystem model that describes the flow of biomass from the primary producers to the secondary consumers through the estuarine food web, and that takes into account the effects of fishing, environmental factors and movement of marine species between the estuary and adjoining marine waters.

#### 6.2.1 Catchment model

A suite of models of the Peel-Harvey Estuary catchment, *i.e.* hydrologic models of the flow of water and nutrients from the catchment to the rivers and estuary, have already been developed by the Department of Water. The first of these models, which is based on the Large Scale Catchment Model (LASCAM), and which is described in the WQIP (EPA, 2008, and as amended), provides the ability to predict how land use management decisions are likely to affect the load of nutrients delivered from the catchment to the estuary. This catchment model, coupled with the Support System for Phosphorus Reduction Decisions (SSPRED), which is also described in the WQIP, provides a valuable tool that allows managers to explore the cost-benefit of alternative options for phosphorus reduction. A further model, PHRAMS, was developed to predict the flow of groundwater, and the Department of Water has proposed the development of a new groundwater flow model for the Murray catchment, based on the Mike SHE tool (Hall *et al.*, 2010).

The data requirements and monitoring program for the LASCAM and SSPRED models are well described in the WQIP, and that for the Mike SHE model in the above conceptual model report. In broad terms, catchment models require data on precipitation, evapotranspiration, topography, land use, runoff, groundwater levels, geology, composition and loads of pollutants (nutrients, etc.) entering drains and rivers, bore, stream and river water levels and seasonal flows (baseflow and surface runoff) of water entering the estuary. Details of the Peel-Harvey water quality monitoring program of the Department of Water, as at April 2009, are given in http://www.water.wa.gov.au/PublicationStore/first/85163.pdf and described for the estuary in subsection 4.2.

Modeling requires that the data have a broad spatial (watershed wide) and temporal (a long time series of years) coverage, and be measured at an appropriate spatial and temporal resolution (sub-daily is preferred for data relating to precipitation, water levels, flows, etc.). The quality of the predictions is thus determined by the quality of the data used to estimate model parameters and validate model predictions. While the resolution of the model predictions required for management is likely to be at the monthly level, storm events and precipitation are likely to be episodic and thus predictions relating to such events will be required at a higher resolution, *e.g.* daily. The temporal resolution of the data that are required to be produced by the catchment model for input to a hydrologic model, is likely to be similar to that required for the input data for the catchment model. Fortunately, advances in instrumentation will allow automation of much of the data collection required for the various catchment models. The potential to monitor changes in land use and vegetation cover through remote sensing also exists and has recently been undertaken by the Department of Water. This has required ground validation of land use and nutrient loads.

Outputs produced by the catchment model and assessments of nutrient loads entering the estuary are likely to require updating at time scales reflecting reporting requirements (*i.e.* annually).

### 6.2.2 Hydrologic model of the rivers and estuary

Development of a detailed hydrologic and sediment transport model to describe the flow of water in the rivers and estuary, and the exchange of water between the estuary and the ocean, is considered of high priority for the Peel-Harvey Estuary. Such a model would provide valuable predictions of the effects of sea level change on the estuary and its shoreline and, with an appropriate model structure, could be used to explore the effectiveness of alternative strategies to mitigate the effects of sea level rise, the expected increase in tidal range, and the potential impact of storm surge. While the effects of sea level change will only become evident over a decadal time scale, planning decisions that are made today must consider the risks that are likely to arise as a result of climate change impacts on the hydrology of the estuary. Thus, the hydrologic model could be used to explore the implications of alternative plans for urban/canal development. Furthermore, urban development of the catchment and population growth is likely to lead to increased sediment runoff and thus dredging activity in the estuary. The ability of the hydrologic model to predict the transportation of sediment is likely to be of value in determining appropriate times of the year when dredging should be scheduled to minimize plume impacts.

Numerous hydrologic models have been developed and could be applied to model the Peel-Harvey Estuary. Among these alternative models, two that have been, and are being, employed in other Australian locations are the Computational Aquatic Ecosystem Dynamics Model (CAEDYM) and Sparse Hydrodynamic Ocean Code (SHOC). In broad terms, the data required by these catchment models are the physical constraints on the system (land boundaries, bathymetry, measurements of bed friction), data on the conditions at the seaward boundaries of the modeled area (*e.g.* salinity), data on the drivers (tides, wind, atmospheric pressure, temperature, flows from rivers, temperature) and data used when calibrating the model (sea and estuary water levels, flow velocity and direction, salinity and temperature, wave measurements). For the hydrologic model to provide predictions of sediment transport, data on sediments (*e.g.* sediment load of rivers, concentration and distribution of total suspended solids in the rivers and estuary, rates of sedimentation and re-suspension, turbidity, grain size of bottom sediments) will be required. Note that, as with the catchment model, the spatial and temporal coverage and resolution of data will determine the quality of the predictions that the calibrated model will be able to produce.

Hydrologic models, which have already been developed for the ocean off south-western Australia, could provide data on the conditions at the boundaries of a hydrologic model developed for the Peel-Harvey

Estuary, while the catchment models developed by the Department of Water could provide predictions of flow. It would be necessary to ensure consistency of the driving variables used in the two hydrologic models however, and thus issues of compatibility of model inputs, outputs and assumptions need to be considered. Good tidal data exist for the estuary, and data from the water quality samples collected in the estuary by the Department of Water could assist. However, these latter data may need to be supplemented by further sampling to provide the coverage and detail required for model calibration.

Although the hydrologic model would undertake its internal calculations at a high level of spatial and temporal resolution, predictions required for management would represent summaries of data over broader spatial and temporal sales, *e.g.* monthly or seasonally. The model would need to be updated at regular intervals, as more reliable predictions of the effects of climate change become available.

The development of hydrologic models is likely to be incremental, based on available knowledge of storm surge propagation and coastal flooding linked with predicted changes in sea levels with longer term climate change, and will build on the work undertaken in Node 6 of the WAMSI science program. This will take into account changes in coastal stability and vulnerability across the W.A. coastline, estimated for the Mandurah region. This could provide valuable insights into longer term development (C. Pattiaratchi, pers. comm.). How this would progress with changes in coastal erosion and consequential changes to the structure of the estuary entrance channel and basins, will need further development.

### 6.2.3 Biogeochemical model

Biogeochemical models describe the flow of nutrients (nitrogen, phosphorus, carbon, etc.) as they are cycled through the various physical and biological components of a system, or are exported from the system. Probably the most well-known example of such a model is that which was produced for the Port Phillip Bay Study, and which was subsequently adapted for the Fitzroy Estuary in Queensland (http://www.ozcoasts.org.au/pdf/CRC/8-fitzroy_conceptual_models.pdf). A biogeochemical model for the Peel-Harvey Estuary would build on the catchment model and the hydrological and sediment transport model for the estuary and, in addition to providing estimates of the export of nutrients to the ocean, would provide predictions of phytoplankton and macroalgal production in different regions of the estuary, and zooplankton biomass (which grazes on phytoplankton). There would thus be a need, when developing the hydrologic and sediment transport model for the estuary, to consider the data input requirements for the biogeochemical model. Consequently, there would be value in having the same organization develop both the hydrologic and biogeochemical models, to ensure consistency and compatibility between data inputs and outputs and model assumptions. Note that development of the biogeochemical model could occur in parallel with development of the hydrologic model but, of necessity, its completion would follow the completion of the hydrologic model. In the interim, while these two models are being developed, empirical (statistical) relationships between nutrient concentrations and chlorophyll *a*, phytoplankton concentration and macrophyte density could be explored.

Biogeochemical models are typically calibrated using observations of nutrient and chlorophyll *a* concentrations and macrophyte densities. Other data used by the biogeochemical model would include observations on turbidity, total suspended solids, sediment nutrient loads, salinity, temperature, depth, dissolved oxygen, oxygen saturation, etc. The location and time of collection of water quality samples should be recorded at a precision commensurate with the resolution of the hydrologic model, such that the biogeochemical model can be calibrated.

Again, as in the case of the catchment and hydrologic models, the predictions produced by the biogeochemical model for use by managers and, in this case, for use as input to an ecosystem model, would be aggregated over space and time, for example to monthly, seasonal and annual values.

#### 6.2.4 Ecosystem model

The final component of the integrated model is a model of the estuarine fauna, which reflects the foodweb and thus trophic structure within the estuary. This foodweb links to the biogeochemical model through primary production and, ultimately, in the integrated model, will feed nutrients back to the biogeochemical model through the processes of excretion and detrital decay. To reduce model complexity, species will be classified into functional groups that reflect similarities in their lifecycles and diets. The processes that are represented in the ecosystem model are those of production, consumption, natural mortality and, in the case of marine species, exchange of individuals between the estuary and ocean. In the case of exploited fish and crustacean species, populations within the estuary are also reduced through capture by fishers and other predators.

Development of the ecosystem model will require data on the biomasses of the various functional groups, on their production and consumption per unit of biomass, and on the composition of their diets. Details of detrital biomass are also required. For species that migrate into and out of the estuary, estimates are required of the proportion of time they spend outside the estuary (*i.e.* of the energy imported to and exported from the estuary).

Time steps used in the model will be need to be monthly, *e.g.* to allow an appropriate representation of the life-cycle of the Blue Swimmer Crabs or seasonal changes in bird numbers. In the initial stage of model development, to simplify the model, the estuary will be considered a single compartment, *e.g.* the distribution of fish within the different regions of the estuary will not be considered.

Clearly, to develop a comprehensive predictive model of the Peel-Harvey Estuary to address emerging management issues for the system associated with population growth and longer term climate change, will take considerable time and resources. There are an array of existing model choices and approaches. Finding the correct pathway, which has the support of the W.A. science community, is a crucial first step. The qualitative and quantitative modeling approaches identified by WAMSI, and the planned workshop for the latter type of model, will be integral to gaining acceptance for a collaborative pathway for building or acquiring the most appropriate solution for the Peel-Harvey Estuary.

### 6.3 Data Requirements for Monitoring Estuarine Health

The health status of estuaries and, in particular, how integrated anthropogenic and natural stressors impact on the structure and function of these ecosystems, can be comprehensively monitored using quantitative indices that incorporate a range of measures (or metrics) of biotic assemblages occupying the estuarine environment. These multimetric biotic indices are described using fish assemblages as an example in section 5.1.1, but can be developed for any other biotic assemblage (*e.g.* benthic macroinvertebrates or birds). They essentially distil the complex workings of an ecosystem into a single index value ("signal") which can be used to track changes in estuarine health over time, and can be used to ascertain how the health status of the system compares to established ecological condition "thresholds". Such a monitoring tool thus provides a way of gauging the type of management responses that are required to address the state of estuarine health, and for readily communicating the condition of the estuary to the wider community.

The essential data requirements for (i) developing and sustaining effective multimetric biotic indices of estuarine health and (ii) interpreting the most likely environmental driver(s) of changes in index values to assist in directing management responses, are as follows.

i. Biotic data (*i.e.* species abundance and/or size and/or biomass) needs to be quantitatively recorded in each main region of the estuary at representative monitoring sites on an annual basis. Biotic samples should be collected either seasonally, or during that season in which the assemblage of interest exhibits minimal natural variability in terms of biodiversity. It is important to ensure that sampling of the biotic assemblages is replicated sufficiently within each region and season to overcome any misleading changes in index values that are attributable more to variability among replicates ("noise") rather than to real changes in ecosystem health ("signal").
ii. At least five years of historical biotic data needs to be collected prior to index development in order to (a) establish reliable reference conditions for each metric comprising the overall index and (b) understand the extent of replicate to replicate variability in the biotic data and the effects of this spatio-temporal variability on index values.
iii. The method of collection of biotic samples needs to remain consistent among years to avoid any bias in index values that may be attributable to gear type.
iv. Data for potential environmental drivers of ecosystem decline (*i.e.* pressures and stressors), such as water and/or sediment quality or measures of anthropogenic activities such as the extent of foreshore development, must be recorded at comparable spatio-temporal scales to those of the biotic data in order to establish reliable relationships between those data sets.
v. An independent measure of ecosystem condition, such as that constructed from attributes of habitat quality, is useful for validating observed trends in the biotic index.

### 6.4 Current Data availability

The Water Quality Improvement Plan published by the EPA in 2008 provides a good starting point for progressing model development, as proposed above for nutrient receival into the estuary. There has also been considerable effort in linking land use to phosphorous loads within the various sub-catchments. Whilst there exists variances in the quality and consistency of data, with proposed revitalisation of monitoring for abiotic and biotic parameters outlined in this report, the existing monitoring and research data will provide a basis for ongoing development of a comprehensive modeling strategy. Appendix 1 summarises a range of proposed studies for building on the existing data sets to progress the development of evaluation tools to cope with different aspects of ecosystem change within the Peel-Harvey Estuary, inclusive of its physical, hydrological, biogeochemical and ecological attributes.

Research studies of the species composition and densities of the individual species comprising the fish fauna have been undertaken on a number of occasions since the late 1970s, at approximately 12-yearly intervals. Estimates of total absolute biomasses of the populations of these species, using data held by researchers, could be derived for use in ecosystem models. It should be noted, however, that the research samples were taken at selected sites using standard sampling protocols, which were intended to provide data that could be compared between time periods and sites, not to estimate total biomass. Estimates of the total biomass of fish and crustacean species targeted by fishers therefore will need to be determined using available fisheries data, or new research data collected with the objective of sampling these species to determine abundance and age composition. Studies of the production, consumption and diets of most of these fish species have not been undertaken (refer subsection 5.4 and 5.6).

The densities of Western King Prawns and Blue Swimmer Crabs have been reported and a study of the diets of the latter species has been undertaken, but no details of the production or diet of the Western King Prawns, or the consumption per unit of biomass for either species, has been reported. Studies of the species densities of small benthic macroinvertebrates have been undertaken in 1986-87 and in 2003-04 at a small number of sites mainly in Peel Inlet, but no details of production, consumption or diets are available. Comprehensive data on detritus in the Peel-Harvey Estuary were collected in the 1980s, and occasional samples were collected subsequent to the opening of the Dawesville Channel, *e.g.* by the Marine and Freshwater Research Labs (MAFRL) at Murdoch University. Data on concentrations of phytoplankton are available from the fortnightly sampling undertaken by the Department of Water (see subsection 4.2), from which rough estimates of biomass can be derived.

Data on the distribution, composition and biomass of macroalgae and seagrass are available from MAFRL, Murdoch University. The most recently reported study was undertaken in 2000-01 but, at the request of the Department of Water, MAFRL undertook a new study in 2010.

It should be noted that research sampling of most biotic components of the ecosystem occurs at intervals determined by the availability of funds or academic interest. Past sampling has not been designed to provide data at regular intervals for the purpose of providing input to an ecosystem model. Adoption of recommendations 1 and 3 (also see subsections 5.2 - 5.6) should resolve these data requirements.

Data on catches and fishing effort by the commercial fishing sector are reported to the Department of Fisheries on a monthly basis, as a requirement of the fishing licence. Shore-based fishers for fish and crabs do not require a fishing licence. Such a licence would allow cost-effective phone-diary surveys of recreational fishing to be undertaken. However, in the absence of the statistical data frame provided by such licences, the Department is obliged to collect recreational fishing data using more costly on-site surveys. While the cost of these constrains the frequency of data collection from the recreational fishing sector, they need to be measured at least five-yearly to provide suitable data for developing the predictive model for the estuary. A critical issue for the future is the potential loss of the commercial fishery sector, and therefore source of catch information, in the event of resource reallocation. This will require revisting of catch monitoring at this time.

With introduction of boat-licensing, a combined survey based on phone diary surveys for people fishing in the estuary with a limited creel survey approach to cover shore fishing ought to be sufficient, with consequential lower monitoring costs compared with a full creel census approach.

### 6.5 Data warehousing, management and access

Studies of the Peel-Harvey Estuary are hampered by the silo-nature of the data storage that is employed currently by the different custodians. Thus, it is not possible to be fully aware of the extent and nature of the data that are available within the different organizations. The databases established by the custodians of the data were designed to maintain the integrity of those data and to provide access by individuals within the agency/organization, but consideration was not always given to facilitating access by those in other organizations or institutions.

The full value of the collective datasets is likely to be realized only through the establishment of a data warehouse. While the individual databases would continue to remain in the custody of those responsible for the collection and maintenance of the data, a data warehouse would provide protocols and procedures to share and access those data using an internet-based frontend. Interfaces would be required to be developed within each agency/organization to serve requested data to the user, using an agreed format. Access would still be restricted to those registered users authorized to use the system, and confidential data would not be available for access. Summarized, non-confidential data presented in an appropriate format would need to be readily accessible by the public and external scientists for independent research, preferably through web-based products.

Once agreement is reached on a strategic approach to modeling for the Peel-Harvey Estuary, work should commence on the integration of modules. This will require the establishment of standard formats for data exchange, and agreement on the units of measurement and the spatio-temporal resolution of the data that are output and required for input. Approaches to sharing data should be considered through consultation with existing data warehouse facilities such as iVEC, BlueNet, WASTAC and the Australian Oceans Data Network, and the feasibility (and cost) of establishing a data and model warehouse should be explored.

This is not to be confused with an appropriate website available to the public that provides an effective evaluation and reporting system to communicate trends in indices of estuarine health, and model predictions, and assessments of risks to managers, property investors and the wider community. For example, an investor/owner may wish to be informed of the potential risk to his investment from the impacts of climate change.

It is envisaged that software to provide the frontend of the interface to the users of the data warehouse might be developed and maintained within a centralized facility (*e.g.* iVEC), while the databases and the software to serve data on request from the warehouse would be maintained and developed within the different agencies. The warehouse would also serve as the interface for data requests for model and sub-model development and other specific research needs. The interface should also provide the mechanism by which different agency sub-models can communicate and integrate, thus progressing predictive capability. The development of such a data warehouse will require sophisticated information technology support, much of which already exists in the State's funded WASTAC and iVEC programs at Curtin University.

Whether these options can be used depends on their acceptance and level of funding support.

It is recognized, however, that development of a data warehouse and distributed model needs to go hand in hand with the development of the predictive submodels that form the modules of a full integrated model of the Peel-Harvey Estuary and its catchment. In the initial stages of model development, strategies to access model predictions and data will require interchange of data or access to shared files, and summarized data will be made available over the internet in predetermined forms. As the model development progresses, consideration will need to be given to how existing data warehouse facilities might best be used to develop an interface between Government departments, CSIRO, universities, the PHCC and the community. This coordination role could be undertaken on behalf of the community by the Senior Scientist appointment.

### 6.6 Strategy for modular development of an effective ecosystem-based Decision Support System

There is currently no governance arrangement that ensures a strategic approach to research, data collection, assessment, development of research tools and reporting for the Peel-Harvey Estuary. In particular, there is a lack of designated leadership and accountabilities that ensures the level of integration of research efforts by different agencies and academic institutions that is required for the modular development of an ecosystem model of the Peel-Harvey Estuary and its catchment. For a strategic and integrated research approach to be adopted, there would need to be approval by the various agencies and authorities on the process, and an agreement to work constructively towards its implementation. Alternatively, empowerment through changes in governance and legislative fiat could provide the necessary impetus for such a process to be adopted.

It is the authors' hope that this report, by identifying the problems faced by managers and the community and the need for a strategic approach to providing scientific advice on the estuary, will provide the catalyst for this.

Following agreement on the approach, one of the first tasks in initiating this process would be to appoint a Senior Scientist charged with the responsibility of developing and coordinating a collaborative research strategy, such as that described in this report, and to create (a) a group (*e.g.* a virtual or real research institute) entrusted with the responsibility of delivering such an approach and (b) establish a Steering Committee to oversee that coordinating group.

The approach proposed in this document would need to be assessed critically and, if approved, endorsed by the above Steering Committee. In brief, the development of the research and data collection programs, research tools, reporting mechanisms and, in particular, the fully-integrated model of the Peel-Harvey Estuary and its catchment, will be complex, and it thus appropriate that a phased development approach be adopted. In this context, it should be noted that the development of both the multimetric indices of ecosystem health (including the associated report cards) and a fully-integrated model of the estuary and its catchment may be regarded as vehicles through which research activities may be strategically directed towards the common goal of achieving a holistic approach to better management of the Peel-Harvey Estuary.

It should be recognised at the outset that the proposed strategy is not intended to replace existing data collection and research programs. These should continue, but be overlaid and extended with a more strategic and holistic focus. It would be highly inappropriate to modify existing data collection programs if such modifications had the potential to introduce inconsistency or disrupt a time series of data. Strategies to improve data collection and research that are already in place, or in the planning stages, should be continued. It would be inappropriate for these developments to be delayed or abandoned, as they have almost certainly been considered thoroughly and assessed as being of value.

The research activities outlined in Appendix 1 of this report are required to be undertaken in parallel, although many of these activities will be undertaken in phases at intermittent times.

All organisations would be assisted having greater and shared access to modelling expertise. Funds provided for model development ideally should be open to tender by competent researchers to maximise the benefits through collaborative programs.

It should be noted, however, that other responsibilities of the various agencies may require that the models be developed to also meet broader objectives than those that we have proposed. Thus, it is appropriate that responsibility for model development be continued with lead agencies, recognising that those agencies need to ensure ongoing maintenance of the modules. Collaborative arrangements through external research providers could substantially improve cost-effectiveness though parallel developments and applications, *e.g.* shared work in south-east QLD.

It should also be noted that we envisage progressive development of models, and essential that models have ongoing support and commitment to continued refinement and development. The models must, however, be developed of a standard and structure that allow them to be interfaced readily with other modules of a fully-integrated model. Thus, in developing a hydrologic model for example, consideration should be given to the data inputs required by a future biogeochemical model, and to the management objectives and data requirements of the various agencies and the broader community. For this, oversight and coordination by the Senior Scientist, and the development of a collaborative network of scientists engaged in modelling of the Peel-Harvey Estuary, will be essential, as already indicated.

It will be necessary for the Senior Scientist to develop the processes of communication between scientists, managers and agencies that ensure that collaboration occurs, and to achieve maximum synergy between the efforts of the different groups in a strategic partnership. Specification of model inputs and outputs, and documentation of model structures, spatial and temporal scales of data and model currencies (units of measurement), will be essential to the successful integration of the different modules. The specifications should provide for a staged approach of modular development, with clear specifications of the output at each stage. Once these have been brought together and the broader model defined, a more detailed specification of both data collection and modular development could be produced.

All code developed, all input data and predictions, and full documentation of the models, the underlying maths, and descriptions of the use of the models will need to be shared to allow other researchers to use the outputs of one model as the inputs to the next. Publication of the models should also be encouraged.

It is important to recognise that, although the focus of the research strategy is directed towards the Peel-Harvey Estuary, the tools that are developed for this estuary are likely to be able to be modified for application to other estuaries in the state. Thus, where possible, to achieve maximum return on investment in research funding, tools with general applicability to other estuaries should be developed.

## 6.7 Testing of indices of ecosystem health and sub-models

### 6.7.1 Indices of ecosystem health

To assess the validity of biotic indices of ecosystem health, it is necessary to determine whether trends in the index are:

(i) sensitive to changes in environmental quality and
(ii) reliable, *i.e.* are not unduly affected by natural spatio-temporal variability or sampling variability.

Validation of biotic index sensitivity may be achieved by testing the extent to which index values are correlated with an independent measure of environmental condition, such as physicochemical indicators of water quality or measures of habitat loss or human impact (*e.g.* Harrison and Whitfield, 2006). However, the most powerful validation of the efficacy of an index is a demonstration of its ability to track changes in ecosystem health in response to documented anthropogenic degradation or ecological recovery following rehabilitation measures, such as construction of the Dawesville Channel.

Assessing the reliability or repeatability of index trends requires a comparison of index “signal” relative to index “noise”. This may be achieved by examining the extent to which index values vary, for example, among replicate samples collected within each region of the estuary and season, or by simulating the expected differences in index values that may be caused by random sampling variability using resampling techniques.

### 6.7.2 Predictive models

Testing of the accuracy and precision of estimates derived from the hydrological, sediment transport, biogeochemical and ecosystem models can be undertaken in several ways. One such method, when sufficient data are available (as is often the case for hydrologic models), is to divide the data into two sets, one of which is used for model calibration, while the second is reserved for validation. Such validation compares predicted with observed values to determine the extent of their correlation.

When there are fewer data, and it is impractical to preserve data for validation, it may be necessary to use all available data for model calibration, and then to predict future values and subsequently, when observations become available, to compare these with the model predictions.

In fisheries modeling, it is becoming relatively common to develop a management strategy evaluation (MSE) framework, which generates synthetic data to which a fishery model is fitted. Its results are passed through a decision rule to determine the management response, which in turn then influences the synthetic observation data generated for the next time step. Such MSEs may be used to assess the accuracy and precision of model output, and have also been employed within the ecosystem modeling context. An advantage of the MSE approach is that the effectiveness of alternative reference points (*e.g.* critical levels of nutrient load) in achieving management objectives can be assessed. This is of considerable value when nutrients exhibit lags in response to management actions.

## 6.8 Linkage of monitoring to management evaluation/response feedback loop

Qualitative modelling and loop analysis demonstrate that a feedback loop is essential for system stability. Thus, it is important that outputs of monitoring and model predictions provide a clear indication to managers when ecosystem health is deteriorating to the extent that management action is required.

The indicators of ecosystem health, represented either by the multimetric indices of health derived from monitoring or from model predictions, should be accompanied by reference points or thresholds. Decision rules that compare the value of the indicator to the reference points are then used to advise managers if intervention is required and, if so, the magnitude of an appropriate response given the value of the indicator. Rephrasing this, it is of little practical use if a value of an indicator is presented without also providing a context, such that the implications for management can be assessed.

When developing indices of ecosystem health or producing model predictions, it is important that these indicators are related to target values that represent acceptable system states and management goals. Such reference points thus need to be determined by the objectives of management, noting that those objectives may sometimes be inconsistent. Similarly, managers will need to be consulted to determine the appropriate management response, should the indicator fall beyond the limit reference points.

As many of the reference points are arbitrary in nature and based on experience, there is also a responsibility to continue to assess the validity of reference points and their underlying assumptions as new information becomes available. Clearly, iterative learning through the adaptive management cycle and modelling route provides the basis of a powerful tool for coping with a changing environment and continuous change.

## Chapter 7 Learning from other Jurisdictions

### 7.1 Introduction

Recognition by governments, especially over the last 30 or so years, of their responsibilities for protection of environmental values whilst permitting development, continues to be a major policy dilemma. A mixture of policies and principles around ecological sustainable development, natural coastal policy development, elements of the Coast and Clear Seas program under NHT, the regional delivery model for NRM based on catchments under NHT2 and the Caring for our Country initiative, have all aimed to address these conflicts by attempting to manage the tensions between different interests in land and water resource use and their impacts.

In the case of the estuaries and nearshore marine areas, the consequences of such tensions and the final development outcomes of accommodating ongoing population growth and changes in the use of land and water resources, ultimately reflect in the environmental quality of these systems.

Solutions aimed at addressing this major policy dilemma extend across virtually all world jurisdictions. Increased involvement of communities, greater collaboration of local, state and national management agencies and increased understanding of approaches to gaining solutions to so-called wicked problems, has facilitated progress in resolution, with ultimately many varied adaptive solutions and pathways, including a significant body of science focussed on habitat and ecosystem restoration and enhancement.

However, a scrutiny of the current status of Western Australia's estuaries, let alone those in other regions of Australia and the world, suggest many problems still remain. These include adequacy of problem recognition, a lack of focus on effective governance, inappropriate administrative structures, etc. Two case studies are briefly examined below to ascertain whether there are any lessons relevant to the management of the Peel-Harvey Estuary, and perhaps to the broader management of Western Australia's waterways.

Both examples, the south-east Queensland and the European Union 2000 Water Framework Directive/Marine Strategy Framework Directive (2008/56/EC), are considered to be successful programs in their own right. They both balance the impacts of population growth and development with the maintenance and or improvement in catchment and waterway health. Undoubtedly, there are many other such examples.

### 7.2 South East Queensland Healthy Waterways Partnership

(Source: http://www.healthywaterways.org/home.aspx)

The South East Queensland (SEQ) Healthy Waterways Partnership is a government-industry-community-research collaboration committed to improving the health of catchments and waterways (including estuaries and near-shore marine areas) of south-east Queensland.

The Partnership facilitates the efforts of over 70 groups across local government, industry and the community in delivering more than 500 management actions identified under the SEQ Healthy Waterways Strategy 207-2012.

Some 100 of these actions are regionally focussed and are delivered by the Partnership's regional officer. Presently the Queensland Government (through the Department of Environment and Natural Resource Management) funds 70% of the regional program activities, with SEQ local governments and industry partners funding the other 30% of its activities. Specific project funding also significantly extends the capacity of partners to deliver a range of management activities (*e.g.* development of catchment plans, sewage treatment plant upgrades, restoration programs etc). Further information on the regional program including its links to other regional initiatives and policies is available at http://www.healthywaterways.org/.

Figure 3 below highlights the policy and program context of the Healthy Waterways Partnership's work.

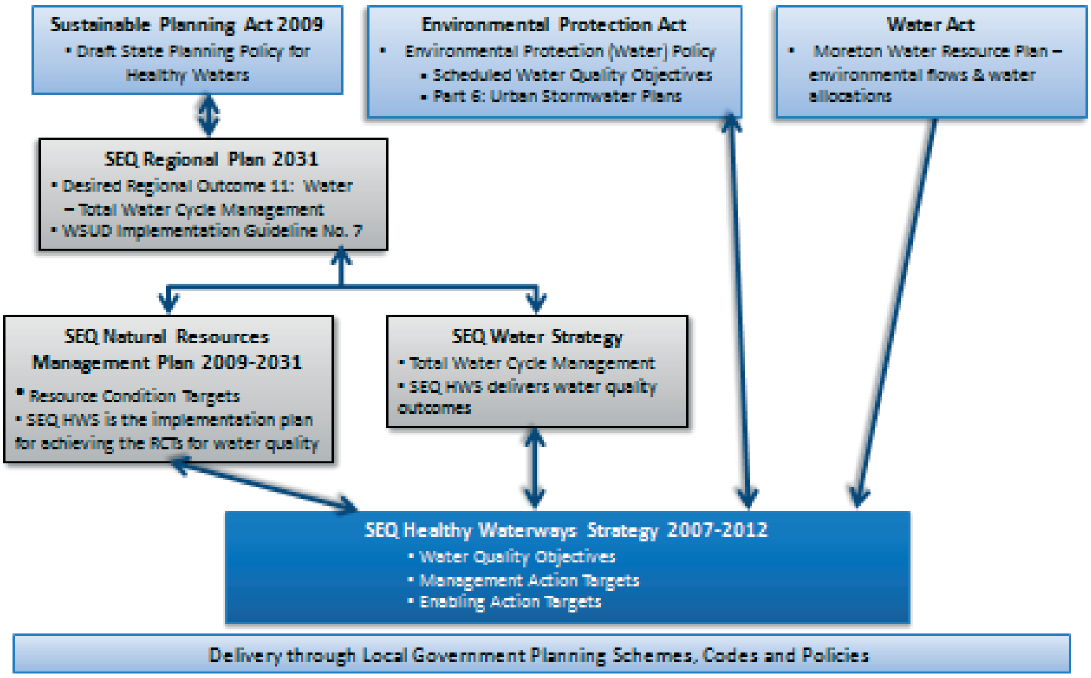


**Figure 3**: The SEQ Healthy Waterways Partnership and SEQ Healthy Waterways Strategy 2007-2012 contribute to the following policy and planning framework. (Source: http://www.healthywaterways.org/).

In summary, the Healthy Waterways Partnership delivers five regional programs. These include:

- **Science and Innovation –** providing research-based and independent scientific advice to Partners and developing tools to help management decisions.
- **Ecosystem Health Monitoring Program** – monitoring the health of 19 catchments, 18 estuaries and Moreton Bay, and produces the annual Ecosystem Health Report Card.
- **Water by Design** –building capacity in urban areas to use water-sensitive urban design.
- **Communication, Education and Motivation Program** – promoting the adaptive achievement of the SEQ Healthy Waterways Partnership vision.

- **Strategy and Performance Reporting** – coordinating and tracking the 500 actions that Partners have committed under the SEQ Healthy Waterways Strategy 2007-2012.

The partnership was formed in 2001 following the advocacy taken in the mid 1990s by a range of community groups and researchers. This led, ultimately, to the development and adoption of the South East Queensland Regional Water Quality Management Strategy (Bunn and Smith, 2001).

The achievements of the program are substantial (refer to above web site), with major successes in the upgrade of sewage treatment plants and consequential reductions in nitrogen loads to the waterways by approximately 40%, with a further 20-30% reduction expected once the upgrades are complete. Phosphate load reductions were also achieved.

Significant progress and performance were also realized in monitoring aquatic ecosystem health, the delivery of annual report cards for freshwater, estuarine and marine waters, protection and restoration of riparian vegetation and development of decision support tools including water quality models for most estuaries and Moreton Bay.

Extensive education and awareness programs, including the annual issue of the Ecosystem Health Report Cards and Healthy Waterways Awards, facilitated branding and support for the program.

More recently however, despite considerable progress, overall water quality in Moreton Bay declined in 2009, with significant increases in sediment and nutrient loads throughout the Bay. This was linked to high rainfall events during the summer and autumn of 2009 which resulted in above average loads of nutrients and sediments from catchment run-off entering Moreton Bay and coastal estuaries.

In assessing the overall performance of the Partnership, however, the view was presented by the Project Director that whilst water quality in Moreton Bay had not significantly improved over the last decade, it had maintained a generally good rating despite the region experiencing one of the highest population growth rates in Australia accompanied by ongoing urbanization in the south-east Queensland region (Diane Tarte, pers. comm. 2010).

Whilst there are significant and substantial institutional differences between south-east Queensland and the south-west of Western Australia, the success of the Queensland program is reported to be hinged on the following key elements (Diane Tarte, pers. comm. 2010).

i. The Partnership has access to an independent group of research institutions and key scientists for advice, defining the priorities and program for research and establishing quality assurance of major programs;
ii. An effective robust monitoring program which the Partnership manages
iii. The creation of an effective annual report card system on ecosystem health, covering the catchment, rivers, estuaries and nearshore marine waters, that is transparent to all;
iv. The development of modelling-based decision support tools that are calibrated and validated by the monitoring data and are used to evaluate options for management interventions to optimise achievement of water quality objectives;
v. The adoption of water quality objectives and environmental values for SEQ freshwater, estuarine and coastal waters as legislative standards included in Schedule 1 of the Environmental Protection (Water) Policy 1977 (EPP Water), effective 1 May 2006. These standards facilitate the adoption of benchmarks and assist with building compliance for water quality standards;

vi. Has in place governance arrangements that facilitate an effective adaptive management pathway, which enables self-evaluation based on the robust science-based evidence (refer Fig. 4). This facilitates ownership and accountability for performance by those involved and responsible.

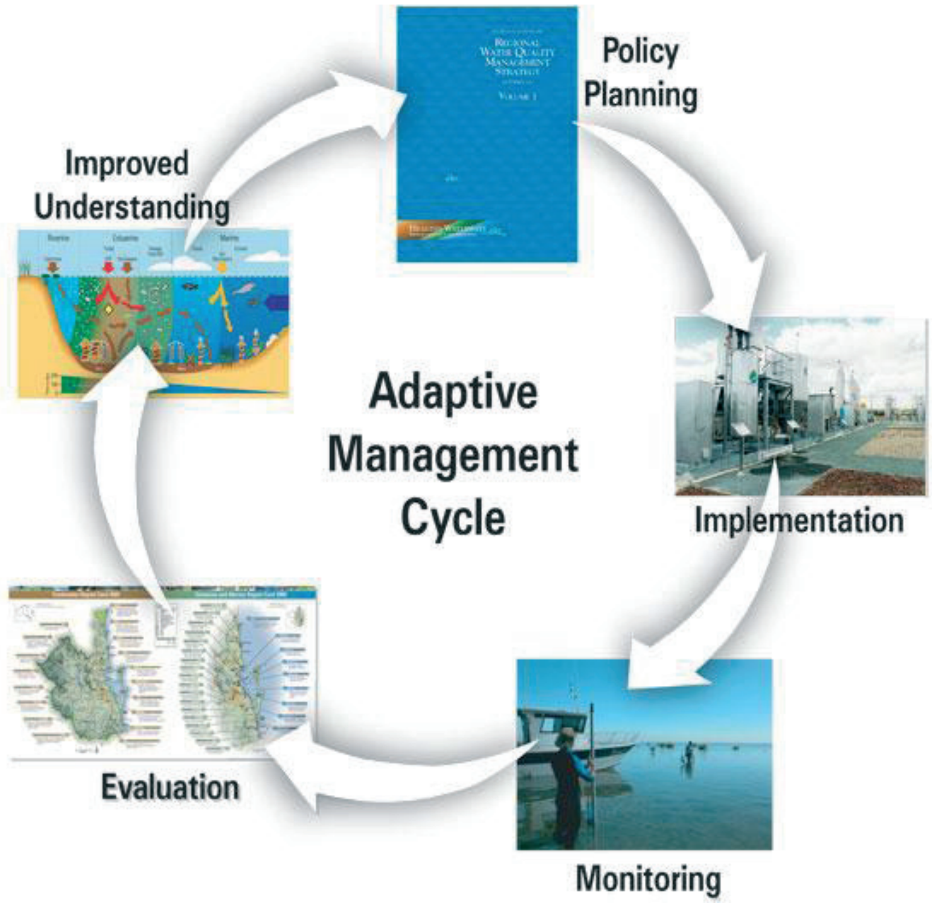


**Figure 4:** Adaptive Management Pathway Schematic (Source: http://www.healthywaterways.org/).

"Whilst commitment and support from the State and local governments and continuity of funding for the Partnership was crucial, the science driven outcomes and therefore program creditability in the eyes of stakeholders was also significant in achieving voluntary buy-in to the Partnership, as well as long-term funding commitments and engagement by partners. Communication, transparency and branding of the program to the community was also seen as key" (Diane Tarte, pers. comm. 2010).

The Partnership is now undertaking further development of estuarine and nearshore marine embayment models to facilitate understanding and predictive reporting of the effects of future population growth and associated development on the ecosystem health of these systems and, longer term, modelling to interpret impacts of climate change.

### 7.3 European Union Water Framework Directive 2000

The Water Framework Directive 2000 requires surface and ground water bodies, such as lakes, streams, rivers, estuaries and coastal waters, to be ecologically sound by 2015. The major components of the directive are reflected by the following key aims.

- Expanding the scope of water protection to all surface waters (rivers, lakes, transitional and coastal areas) and ground waters;
- Achieving “good status” for all waters by a set deadline;
- Water management based on river basins (catchments);
- “Combined” approach of emission limit values and quality standards;
- Getting the prices right;
- Getting the citizens involved more closely;
- Streamlining legislation.

The Directives from the European Union set down the legislative principles and guidelines through the EU Parliament, which become legal performance requirements of its member states. In effect, each state develops its own legislative and funding arrangements to give effect to the delivery of these performance requirements, often with supporting processes and reporting requirements, including technical definitions, measurement and performance timelines.

The directive requires a river basin plan (*e.g.* the Rhine) with co-operative and joint objective setting across Member State borders, which needed to be updated every six years. There are a number of objectives with respect to water quality protection. These include general protection of aquatic ecology in all surface waters, specific protection of unique habitats, and protection of drinking and bathing water in specific waters whereas ecological protection applies to all waters. The central requirement of the Treaty is that the environment is protected in its entirety. Surface water standards were established for ecological and physico-chemical status, defining a set of procedures and guidelines to ensure consistency and comparability.

In contrast, the approach to groundwater was different. Whilst standards for elements such as nitrates, pesticides and biocides were set in some instances, the approach focussed on a prohibition of direct discharge into groundwater and, to cover indirect discharges, a requirement to monitor groundwater so as to detect changes in composition and reverse any anthropogenically-induced pollution trends.

Limits on extraction of groundwater were also a central plank in facilitating a framework for integrated management of both groundwater and surface water for the first time at European level. This new approach was supported by other Directives covering waste water treatment, nitrates and chemical pollution.

The framework importantly allowed basic measures to be undertaken in the catchment; source based controls to be implemented, but allowed the development of other priority list of substances to be actioned at the EU level and adoption of most cost effective measures to reduce load reduction of those substances.

The river basin plan effectively described how the deliveries of water quality objectives are to be reached within a specified timeframe. Through analysis describing the “gap” to achieve water quality objectives and effectively involving the community in both plan preparation and solutions towards closing the gaps in the context of economic analyses of water use and finding the most acceptable cost effective solution.

Like the SEQ, public participation was deemed an essential component of engagement. Public engagement firstly required setting of appropriate measures to achieve a transparent set of objectives. It secondly required enforceability through the imposition of measures and the reporting of standards. This influenced the State to act with appropriate legislation and, thorough empowerment of its citizens, if dissatisfied, they had the option to raise complaints or take court action. A further important part of the strategy was a requirement for bi-annual reporting through a conference, to facilitate member state communication and allow early identification of implementation issues and encourage compliance.

Gaining improvement in water quality of the rivers has been an important step towards improving ecosystem health in the estuaries.

The EU Water Framework Directive facilitated, with a range of other instruments, international co-operation on integrated management of estuaries in the North Sea region, ultimately leading to ecosystem restoration which ensured sound environmental management of interconnected coastal zones (de Graff *et al.,* 2007).

In reality, whilst the Water Framework Directive was central to improving water quality of European rivers and estuaries, the considerable complexity in the various State EU Directives frequently caused problems in harmonisation of legislation. The application of the Water Framework Directive also created significant challenges, with missing elements for monitoring, the need to develop new tools and evidence of important knowledge gaps (de Jong *et al.,* 2006). A fuller review could provide new insights.

More recently, the European Union has issued Directive 2008/56, establishing a framework for community action in the field of marine environmental policy (Marine Strategy framework Directive). This Directive has many principles that could equally apply to estuarine and nearshore marine waters. Although the application is limited to marine waters, beyond the base line from which the extent of the Territorial sea is measured to the outer edge of their marine jurisdiction, the qualitative descriptions for determining good environmental status for marine waters have appropriate relevance to the management of estuaries.

These are summarised below (ref. Directive 2008/56E of the European Parliament and of the Council, 2008).

In essence, the Directive establishes a framework for community action in the field of environmental policy to:

(a) Protect and preserve the marine environment, prevent its deterioration or, where practicable, restore marine ecosystems in areas where they have been adversely affected;
(b) Prevent and reduce inputs in the marine environment with a view to phasing out pollution as defined in Article 3(8), so as to ensure that there are no significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the seas.

It also sets out qualitative descriptors for determining good environmental status, referred to in Articles 3(5), 9(1), 9(3) and specified in detail in Annex I.

(1) "Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions;

(2) Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems;
(3) Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock;
(4) All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity;
(5) Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters;
(6) Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected;
(7) Permanent alteration of hydrographical condition does not adversely affect marine ecosystems;
(8) Concentrations of contaminants are at levels not giving rise to pollution effects;
(9) Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards;
(10) Properties and quantities of marine litter do not cause harm to the coastal and marine environments;
(11) Introduction of energy, including underwater noise, is at levels that do not adversely effect the marine environment.

To determine the characteristics of good environmental status in a marine region or subregion as provided for in Article 9 (1), Member States shall consider each of the qualitative descriptors listed in this Annex in order to identify those descriptors which are to be used to determine good environmental status for that marine region or subregion. When a Member State considers that it is not appropriate to use one or more of those descriptors, it shall provide the Commission with a justification in the framework of the notification made pursuant to Article 9(2).”

Similar to the Water Framework Directive 2000, the Marine Strategy Framework Directive prescribes, under separate articles, a range of requirements. These include, within an overall governance framework, subject matter and aims, scope, definitions, strategies, regional co-operation, marine regions, assessment, competent authorities, determination of good environmental status, monitoring programmes, establishing environmental targets, processes for notification, programme of measures, exemptions, recommendations for community actions, Commissions assessment, updating reports and public information, public consultation and information, interim reports, Commission evaluation reports, review, technical adaption, etc. (refer Official Journal of European Union 25.6.2008).

The strength of both Directives lies in prescribed governance, accountability, reporting, clear strategy definition and performance in specified timelines, extending State responsibilities through transparency of process and reporting to its own community constituents and the Commission itself.

### 7.4 Conclusion from the Case Studies

The idea of transposing institutional frameworks for managing waterways from other jurisdictions to Western Australia and, in this case, to the Peel-Harvey Estuary, requires substantially more analysis than provided here. There are many more case examples that require exploring, including a detailed analysis of governance arrangements within Western Australia.

However, like other complex problems of the dimension being discussed in this report, the key processes as seen from the case examples are as follows:

- Community support for overall strategy and objectives;
- Commitment by Government(s);
- Clear accountabilities for performance, including monitoring, evaluation, reporting and transparency to the community;
- Effective collaboration facilitated by legislative obligations;
- Involvement and empowerment of the community;
- Linking objectives and performance outcomes to adaptive management action;
- Adequate funding commitment;
- Appropriate independent science support that extends evaluation beyond the catchment, into the estuary and including the nearshore coastal zone;
- Ecosystem evaluation decision support tools that assist management strategy evaluation and adaption.

## Chapter 8 Funding the Science Strategy

Tables 1-3 presented in Appendix 1, specify in tabular form, a proposed science strategy for the Peel-Harvey Estuary.

Indicative cost estimates have been provided, based, where practical, on known costs from other comparable projects and programs drawn from a number of sources. These need to be refined and updated as new information becomes available, and used as an ongoing 'tool' for progressing the science strategy for the Peel-Harvey Estuary and retaining currency over time.

The costs provided are direct project costs and do not take into account overheads or organisational structures. Also note that all costs over the projected 10 year period are based on today's direct costs. The final costs will depend on the various organisational responsibilities for delivery of the required research and monitoring and, ultimately, development of the evaluation tools. In developing the strategy, the authors have not attempted to manage the variation in year-to-year costs linked to intermittent monitoring/research requirements.

How this is managed remains a challenge. However, should a similar program be extended across a number of estuaries in south-western Australia, management of the larger program could be achieved to offset year-to-year cost variation to provide a more evenly funded estuarine health program. Furthermore, with scale, significant efficiencies and cost-sharing across estuaries will be achieved, with broader benefits for the State.

The direct costs projected for the science and monitoring required for the Peel-Harvey Estuary over 10 years is about $14 million in today's dollars, supported by a Senior Scientist. This total cost, relative to the issues and risks facing the Peel-Harvey Estuary and its community, is relatively small, noting the likely consequences of environmental change if corrective and adaptive strategies are either unsuccessful or not adopted.

These costs do not take into account the substantial programs already underway by different agencies, land developers and the community towards ongoing mitigation and restoration of the estuary, catchment and adjoining waterways. These fall outside the scope of this strategy and will become more substantial in the future.

Without adequate guiding information, as proposed by this strategy, the risks and therefore costs of getting it wrong, will be substantial. Decisions today, particularly in relation to buildings, infrastructure, planning etc, are likely to endure well beyond 30 years and extend into the end of this century.

In other jurisdictions, for the reasons outlined in section 5.8, most of the costs are normally met by the State with contributions being made directly by local governments, industries and the community. There is a case for sectors of the community to contribute directly to the funding of estuarine management, including monitoring, without all of the burden falling on the State.

In developing the science strategy, it is self-evident that organisational structure, and governance in particular, impacts directly on the business model, its performance and ultimately costs. Appropriate governance is critical for successful implementation of the strategy and remains a crucial element to be resolved. Without adequate funding and governance, this strategy will languish. The costs associated with acquiring such governance fall outside the scope of this study and thus have not been considered.

Collaborative arrangements between management departments and research organisations, including universities, and empowerment of the community, can substantially reduce and share costs through a range of funding programs. Improving integration and coordination can only improve efficiency and cost-effectiveness in the delivery of science required for the future management of the estuary.

Based on the south-east QLD experience, 70% of total costs for governance of partnership arrangements and relevant research, monitoring, evaluation and reporting for waterways health came from the State, with multiple sources from the community providing the remainder. In the final analysis, who pays and how much is often a bargain agreed between the community and the State having overall recognition of the problem and acceptance of the solutions.

## Appendix 1

**Table 1a:** Summary of the environmental and biotic sampling regimes currently &/or most recently undertaken in the Peel-Harvey Estuary by State and local management agencies, university researchers or consultant groups.

**Table 1b:** Summary of the environmental and biotic sampling regimes proposed by the PHCC (PHCC) for the Peel-Harvey Estuary in the *Monitoring and Evaluation Guide for the Peel-Yalgorup Ramsar Site* (Hale, 2008).

**Table 1c:** Summary of the environmental and biotic sampling regimes proposed for the Peel-Harvey Estuary under this proposed science strategy.

**Table 2:** Frequency of data collection for each of the ecosystem components of the Peel-Harvey Estuary under this proposed science strategy.

**Table 3:** Annual cost, over a 10 year period, of this proposed science strategy for the Peel-Harvey Estuary.

Note in reading these tables:-

"X" = measurement recorded

"na" = not applicable

"?" = A target or limit of acceptable change has not been set.

**Table 1a:** Summary of the environmental and biotic sampling regimes currently &/or most recently undertaken in the Peel-Harvey Estuary by State and local management agencies, university researchers or consultant groups.

| | | | | Current Monitoring | |
|---|---|---|---|---|---|
| **Key Ecosystem Components** | **Monitoring program** | **Monitoring agency** | **Funding status** | **Performance & Evaluation** | |
| | | | | **Targets** | **Action** |
| **Abiotic components** | | | | | |
| **Estuarine surface water quality/hydrology** | | | | | |
| Physical water quality | 11 sites (3 each in Peel Inlet, Harvey Est. & Serpentine R. & 2 in Murray R.) sampled 2-weekly (surface & bottom waters). | DoW | ongoing but uncertain | | Regular (?) review of targets & management response for life of WQIP. Suggested development of estuarine model that couples existing catchment model & an estuarine report card. |
| *Dissolved oxygen* | X | " | " | 70-80% saturation in basins & 5 mg/L in rivers. | " |
| *pH* | X | " | " | ? | ? |
| *Salinity* | X | " | " | ? | ? |
| *Conductivity* | X | | | ? | ? |
| *Temperature* | X | " | " | ? | ? |
| *Turbidity &/or Secchi depth* | X | " | " | ? | ? |
| *Total suspended solids* | na | na | na | na | na |
| *Light penetration* | na | na | na | na | na |
| *Biological oxygen demand* | na | na | na | na | na |
| Hydrology | | | | | |
| *Tidal state* | Tidal gauges at each entrance channel & in middle of Peel Inlet & Harvey Est. Record water levels every 5 min. | DoT | ongoing but uncertain | na | na |
| Nutrients | 8 sites (2 each in Peel Inlet & Harvey Est., 3 in Serpentine R. & 1 in Murray R.) sampled monthly (surface & bottom waters). | DoW | ongoing but uncertain | | Regular (?) review of targets & management response for life of WQIP. Suggested development of "estuarine model" that couples existing catchment model & an estuarine "report card". |
| *Total P* | X | " | " | 30 µg/L in basins & 100 µg/L (W median) in est. reaches of rivers. | " |
| *Filtered reactive phosphorous* | X | " | " | ? | ? |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Funding status | Performance & Evaluation | |
|---|---|---|---|---|---|
| | | | | Targets | Action |
| *Total N* | X | " | " | ? | ? |
| *Total oxidised N* | X | " | " | ? | ? |
| *Total kjeldahl N* | X | " | " | ? | ? |
| *NH3* | X | " | " | ? | ? |
| *Bioavailable inorganic nutrients (PO4, NH4, NO3, NO2)* | na | na | na | na | na |
| *Total C* | na | na | na | na | na |
| **Ground water quality/hydrology** | 108 bores monitored across Murray groundwater area six times per year since 2007. Under review as part of 2010 Murray GW Allocation Plan (MGWAP) | DoW | ongoing but uncertain | | Review current monitoring, licensing & allocation arrangements (as per 2010 MGWAP). Annually assess GW resources against targets & status of actions. |
| Water levels | X | " | " | Min. levels in summer do not decline by >0.1m/yr over 3 yrs | " |
| Salinity | X | " | " | ? | " |
| pH | X | " | " | > 4 | " |
| **Subtidal sediment** | | | | | |
| Sedimentology | | | | | |
| *Grain size* | na | na | na | na | na |
| *Organic matter content & biomass* | na | na | na | na | na |
| *Moisture content* | na | na | na | na | na |
| *Redox potential* | na | na | na | na | na |
| Nutrients | | | | | |
| *Total P* | na | na | na | na | na |
| *Total N* | na | na | na | na | na |
| *Total organic carbon* | na | na | na | na | na |
| *Bioavailable inorganic nutrients (PO4, NH4, NO3, NO2)* | na | na | na | na | na |
| Non-nutrients | | | | | |
| *Polyaromatic hydrocarbons* | na | na | na | na | na |
| *Organochlorine pesticides* | na | na | na | na | na |
| *Bioavailable metals* | na | na | na | na | na |
| Sediment/water interchange of contaminants | Longmore & Nicholson (2007) | na | na | na | na |
| **Bathymetry** | Existing survey carried out in 1971 (single beam sonar). | DoT | opportunistic | na | na |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Funding status | Performance & Evaluation | |
|---|---|---|---|---|---|
| | | | | Targets | Action |
| **Catchment (river) monitoring** | 3 primary LMUs @ Murray, Serp. & Harvey & 8-11 secondary LMUs sample at fixed intervals (1-2 weekly data downloads); 8-13 grab sampling sites monitored 2 weekly in winter & monthly in summer | DoW | ongoing but uncertain | | Regular (?) review of targets & management response for life of WQIP. |
| Physical water quality | | | | | |
| *Dissolved oxygen* | measured in grab samples (see above) | " | " | ? | " |
| *pH* | X | " | " | ? | " |
| *Salinity/conductivity* | X | " | " | ? | " |
| *Temperature* | X | " | " | ? | " |
| *Turbidity &/or Secchi depth* | X | " | " | ? | " |
| *Total suspended solids* | grab samples/LMUs every 1-2 weeks | " | " | ? | |
| Hydrology | | | | | |
| *River flow* | Measured consistently at LMUs | " | " | maintain current flows in all rivers | " |
| Nutrients | | | | | |
| *Total P* | grab samples/LMUs every 1-2 weeks | " | " | 25T reduction of Total P at primary LMUs | " |
| *Filtered reactive phosphorous* | grab samples | | | ? | " |
| *Total N* | grab samples/LMUs every 1-2 weeks | " | " | ? | " |
| *NH3* | grab samples | | | ? | " |
| *Nitrates/nitrites* | grab samples | " | " | ? | " |
| *Total & dissolved organic carbon* | grab samples | " | " | ? | " |
| **Social & environmental drivers** | | | | | |
| Regional population level | Measured every 5 yrs | ABS | ongoing | na | na |
| Landuse in catchment | Recently updated (classified on remotely-sensed imagery of catchment) | DoW | opportunistic | ? | ? |
| Total foreshore developed | **to be developed* | ? | ? | ? | ? |
| Loss of adjacent wetlands (claimed for land development) | **to be developed* | ? | ? | ? | ? |
| Loss of riparian vegetation | **to be developed* | ? | ? | ? | ? |
| Canal development & extent/location of dredging | **to be developed* | ? | ? | ? | ? |
| Index of recreational use of estuary & catchment | **to be developed* | ? | ? | na | na |
| Median value of urban property | **to be developed* | ? | ? | na | na |
| Number & size of confirmed fish kills | Fish Kill Response Unit | DoW/DoF | ongoing but uncertain | Zero | Regular (?) review of targets & management response for life of WQIP. |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Funding status | Performance & Evaluation | |
|---|---|---|---|---|---|
| | | | | Targets | Action |
| Level of public complaint about health of estuary | Incident control system | DoW | ongoing but uncertain | Zero | ? |
| **Key habitats** | | | | | |
| **Benthic plants (seagrass & macroalgae)** | Biomass & comp[n] monitored at 43 sites in PHE in summer 2010. Same sites monitored annually (1-4 times/yr) from 1977-2001. | DoW | opportunistic | ? | ? |
| **Littoral & fringing vegetation** | 8 transects sampled throughout PHE in 2008-9. Cover, comp[n], biomass &/or cond[n] assessed sporadically from 1957-98. | MU/ Peel Pres. Group/ DEC | opportunistic | ? | ? |
| **Shallow flats** | na | na | na | na | na |
| **Integrated habitats** | Assessed in nearshore waters of PHE in 2005-07 | MU | opportunistic | na | na |
| **Supporting biological components** | | | | | |
| **Phytoplankton** | 11 sites (3 each the Peel Inlet, Harvey Est & Serpentine R. & 2 in Murray R.) sampled 2-weekly (surface & bottom waters). | DoW | ongoing but uncertain | | Regular (?) review of targets & management response. |
| Chlorophyll *a, b, c* & pheophytin | X | " | " | 3 µg/L in basins & 10 µg/L in est. reaches of rivers | " |
| Species abundance | X | " | " | ? | " |
| Biomass | na | na | na | na | na |
| **Macrophyte wrack** | na | na | na | na | na |
| **Key faunal components** | | | | | |
| **Fish, crabs & prawns** | | | | | |
| Abundance, lengths & weights of all species | Fish sampled seasonally from 2008-10 at 20 shallow sites in basins/channel, & seasonally-biannually at varying no's of shallow&/or deeper sites in 2005-07, 1996-7 & 1979-81. Crabs sampled monthly from 2007-10 at 19 shallow & 4 deep sites in basins/ channel/river & from 2008-10 at 9 sites in nearby coastal waters. | MU (funded by WAMSI, FRDC, DEC or DoF) or DoF | opportunistic | ? | ? |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Funding status | Performance & Evaluation | |
|---|---|---|---|---|---|
| | | | | Targets | Action |
| Biology of key species (growth, age, reprod[n] &/or diet) | Six-lined trumpeter monitored from 2008-10. Blue-swimmer crabs examined in 1995-98. Western School & King prawns examined in late 1970s-late 1980s. | MU (funded by WAMSI, FRDC, DEC or DoF) | opportunistic | ? | ? |
| Interchange of key species between estuary & ocean | na | na | na | na | na |
| Commercial fishers | CPUE data reported annually | DoF | ongoing | ? | ? |
| Recreational fishers | Creel census undertaken in 1998/9 & 2007/8. | DoF | opportunistic | ? | ? |
| **Small benthic macroinvertebrates** | | | | | |
| Species abundance & biomass | Species composition measured seasonally at 4 sites in Peel Inlet in 1986/7 & 2003/4 | MU (funded by FRDC or MU) | opportunistic | ? | ? |
| **Waterbirds** | | | | | |
| Total counts of each species (inc. life cycles stages where possible) | Counts done annually at sites throughout the PHE in SP/S. | PHCC/Birds Australia | Largely volunteers. Any funding is opportunistic. | Ramsar criteria 3,4,5,6 | Annual assessment against LAC. Annual reporting by PHCC body (via Ramsar Tech. Advisory Group). LAC exceedences trigger management response request by PHCC. |
| **Dolphins** | | | | | |
| Behavioural observations & counts | na | na | na | na | na |
| **Food web** | na | na | na | na | na |

**Table 1b:** Summary of the environmental and biotic sampling regimes proposed by the Peel-Harvey Catchment Council (PHCC) for the Peel-Harvey Estuary in the *Monitoring and Evaluation Guide for the Peel-Yalgorup Ramsar Site* (Hale, 2008).

| Peel-Yalgorup Ramsar Site Monitoring & Evaluation guide | | | | |
|---|---|---|---|---|
| **Key Ecosystem Components** | **Monitoring program** | **Monitoring agency** | **Performance & Evaluation** | |
| | | | **Limits of Acceptable Change (LAC)** | **Actions** |
| **Abiotic components** | | | | |
| **Estuarine surface water quality/hydrology** | | | | |
| Physical water quality | 6 sites (3 each in Peel Inlet & Harvey Estuary), monitored monthly. In-situ profiles in deeper waters. All monitoring to meet ANZECC & APHA standards. | DoW | | Annual assessment against LAC. Annual reporting by PHCC body (via Ramsar Tech. Advisory Group). LAC exceedences trigger management response request by PHCC. |
| *Dissolved oxygen* | X | " | 70% – 80% saturation | " |
| *pH* | X | " | > 7 | " |
| *Salinity* | X | " | < 30 ppt in winter in centre of Peel Inlet & Harvey Estuary. < 3 ppt at Harvey R. mouth in winter. | " |
| *Conductivity* | na | na | na | na |
| *Temperature* | na | na | na | na |
| *Turbidity &/or Secchi depth* | na | na | na | na |
| *Total suspended solids* | na | na | na | na |
| *Light penetration* | na | na | na | na |
| *Biological Oxygen Demand* | na | na | na | na |
| Hydrology | | | | |
| *Tidal state* | na | na | na | na |
| Nutrients | 6 sites (3 each in Peel Inlet & Harvey Estuary), monitored monthly. In-situ profiles in deeper waters. All monitoring to meet ANZECC & APHA standards. | DoW | | Annual assessment against LAC. Annual reporting by PHCC body (via Ramsar Tech. Advisory Group). LAC exceedences trigger management response request by PHCC. |
| *Total P* | X | " | < 30 µg/L (maximum) | " |
| *Filtered reactive phosphorous* | na | na | na | na |
| *Total N* | X | " | ? | " |
| *Total oxidised N* | na | na | na | na |
| *Total kjeldahl N* | na | na | na | na |
| *NH3* | na | na | na | na |
| *Bioavailable inorganic nutrients (PO4, NH4, NO3, NO2)* | X | " | < 10 µg/L (median) | " |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Performance & Evaluation | |
|---|---|---|---|---|
| | | | Limits of Acceptable Change (LAC) | Actions |
| *Total C* | na | na | na | na |
| **Ground water quality/hydrology** | | | | |
| Water levels | na | na | na | na |
| Salinity | na | na | na | na |
| pH | na | na | na | na |
| **Subtidal sediment** | | | | |
| Sedimentology | | | | |
| *Grain size* | na | na | na | na |
| *Organic matter content & biomass* | na | na | na | na |
| *Moisture content* | na | na | na | na |
| *Redox potential* | na | na | na | na |
| Nutrients | | | | |
| *Total P* | na | na | na | na |
| *Total N* | na | na | na | na |
| *Total organic carbon* | na | na | na | na |
| *Bioavailable inorganic nutrients (PO4, NH4, NO3, NO2)* | na | na | na | na |
| Non-nutrients | | | | |
| *Polyaromatic hydrocarbons* | na | na | na | na |
| *Organochlorine pesticides* | na | na | na | na |
| *Bioavailable metals* | na | na | na | na |
| Sediment/water interchange of contaminants | na | na | na | na |
| **Bathymetry** | na | na | na | na |
| **Catchment (river) monitoring** | 3 primary LMU's on Murray, Serp. & Harvey rivers. LMUs sample at fixed intervals (weekly data downloads) | DoW | | |
| Physical water quality | | | | |
| *Dissolved oxygen* | na | na | na | na |
| *pH* | na | na | na | na |
| *Salinity/conductivity* | na | na | na | na |
| *Temperature* | na | na | na | na |
| *Turbidity &/or Secchi depth* | na | na | na | na |
| *Total suspended solids* | LMUs every 1-2 weeks | DoW | ? | ? |
| Hydrology | | | | |
| *River flow* | Measured consistently at LMUs | " | ? | ? |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Performance & Evaluation | |
|---|---|---|---|---|
| | | | Limits of Acceptable Change (LAC) | Actions |
| Nutrients | | | | |
| *Total P* | LMUs every 1-2 weeks | " | ? | ? |
| *Filtered reactive phosphorous* | na | na | na | na |
| *Total N* | X | " | ? | ? |
| *NH3* | na | na | na | na |
| *Nitrates/nitrites* | na | na | na | na |
| *Total & dissolved organic carbon* | na | na | na | na |
| **Social & environmental drivers** | | | | |
| Regional population level | na | na | na | na |
| Landuse in catchment | na | na | na | na |
| Total foreshore developed | na | na | na | na |
| Loss of adjacent wetlands (claimed for land development) | na | na | na | na |
| Loss of riparian vegetation | na | na | na | na |
| Canal development & extent/location of dredging | na | na | na | na |
| Index of total recreational use of estuary & catchment | na | na | na | na |
| Median value of urban property | | | | |
| Number & size of confirmed fish kills | na | na | na | na |
| Level of public complaint about health of estuary | na | na | na | na |
| **Key habitats** | | | | |
| **Benthic plants (seagrass & macroalgae)** | Map macrophyte cover/ comp$^{n}$ throughout PHE from Quickbird/ IKONOS imagery. Validate with ground-truthing. Repeat annually in SP/S. | University/consultant. DEC may provide remote-sensing support | insufficient data | Annual assessment against LAC. Annual reporting by PHCC body (via Ramsar Tech. Advisory Group). LAC exceedences trigger management response request by PHCC. |
| **Littoral & fringing vegetation** | Map veg$^{n}$ cover/ comp$^{n}$ throughout PHE from Quickbird/ IKONOS imagery. Validate with ground-truthing & assess historical transects. Repeat every 1-5 years in SP. | University/consultant. DEC may provide remote-sensing support | insufficient data | " |
| **Shallow flats** | na | na | na | na |
| **Integrated habitats** | na | na | na | na |
| **Supporting biological components** | | | | |
| **Phytoplankton** | 6 sites (3 each in Peel Inlet & Harvey Est.), monitored monthly (surface & bottom waters). All monitoring to meet ANZECC & APHA standards. | DoW | | Annual assessment against LAC. Annual reporting by PHCC body (via Ramsar Tech. Advisory Group). LAC exceedences trigger management response request by PHCC. |
| Chlorophyll *a, b, c* & pheophytin | X | " | < 10 $\mu$g/L (median) | " |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Performance & Evaluation | |
|---|---|---|---|---|
| | | | Limits of Acceptable Change (LAC) | Actions |
| Species abundance | na | na | na | na |
| Biomass | na | na | na | na |
| **Macrophyte wrack** | na | na | na | na |
| **Key faunal components** | | | | |
| **Fish, crabs & prawns** | | | | |
| Abundance, lengths and weights of all species | 7 sites in PHE (those sampled in 1979-81). Repeat annually in SP/S. | University/consultant. | insufficient data | Annual assessment against LAC. Annual reporting by PHCC body (via Ramsar Tech. Advisory Group). LAC exceedences trigger management response request by PHCC. |
| Biology of key species (growth, age, reproduction &/or diet) | na | na | na | na |
| Interchange of key species between estuary & ocean | na | na | na | na |
| Commercial fishers | As is | DoF | ? | ? |
| Recreational fishers | na | na | na | na |
| **Small benthic macroinvertebrates** | | | | |
| Species abundance & biomass | na | na | na | na |
| **Waterbirds** | | | | |
| Total counts of each species (inc. life cycles stages where possible) | Counts of Red-necked Stints, Sharp-tailed sandpiper (Aug-Apr) & Comorants (Aug-Oct) at zones within PHE &/or in fringing veg$^{n}$ on an annual basis. | Birds WA | Peel-Yalgorup supports >1% of pop$^{n}$ in 3 out of 5 yrs/ insufficient data. | Annual assessment against LAC. Annual reporting by PHCC body (via Ramsar Tech. Advisory Group). LAC exceedences trigger management response request by PHCC. |
| **Dolphins** | | | | |
| Behavioural observations & counts | na | na | na | na |
| **Food web** | na | na | na | na |

**Table 1c:** Summary of the environmental and biotic sampling regimes proposed for the Peel-Harvey Estuary under this proposed science strategy.

| Peel-Harvey Estuary Science Strategy | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Key Ecosystem Components** | **Monitoring program** | **Monitoring agency** | **Cost** | **Performance & Evaluation** | | | |
| | | | | **Drivers** | **Health indices & Report card** | **Mitigation strategies** | **Coupled model** |
| **Abiotic components** | | | | | | | |
| **Estuarine surface water quality/hydrology** | | | | X | | Independent audit of reporting & performance every 5 years | X |
| Physical water quality | 19 sites (5 in each the Peel Inlet & Harvey Est. & 3 in each the lower Murray, Serpentine, Harvey rivers) monitored 1-2 weekly in surface waters in shallows & at depth profiles in deeper waters. | DoW | $450 000/yr * | | | | |
| *Dissolved oxygen* | X | " | | | | | |
| *pH* | X | " | | | | | |
| *Salinity* | X | " | | | | | |
| *Conductivity* | X | " | | | | | |
| *Temperature* | X | " | | | | | |
| *Turbidity &/or Secchi depth* | X | " | | | | | |
| *Total suspended solids* | X | " | | | | | |
| *Light penetration* | X | " | | | | | |
| *Biological Oxygen Demand* | X | " | | | | | |
| Hydrology | | | | | | | |
| *Tidal state* | As is, plus 10 extra pressure & temperature recorders (providing a network of 15 sea-level monitoring sites) | DoT/ University/Consultant | $25 000/10yr | | | | |
| Nutrients | 19 sites (5 in each the Peel Inlet & Harvey Est. & 3 in each the lower Murray, Serpentine, Harvey rivers) monitored 1-2 weekly in surface waters in shallows & at depth profiles in deeper waters. | DoW | *part of above surface WQ costs | | | | |
| *Total P* | X | " | | | | | |
| *Filtered reactive phosphorous* | X | " | | | | | |
| *Total N* | X | " | | | | | |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Cost | Performance & Evaluation | | | |
|---|---|---|---|---|---|---|---|
| | | | | Drivers | Health indices & Report card | Mitigation strategies | Coupled model |
| *Total oxidised N* | X | " | | | | | |
| *Total kjeldahl N* | X | " | | | | | |
| *NH3* | X | " | | | | | |
| *Bioavailable inorganic nutrients (PO4, NH4, NO3, NO2)* | X | " | | | | | |
| *Total C* | X | " | | | | | |
| **Ground water quality/hydrology** | Reassess after 2010 MGWAP implementation completed | DoW | Dependent on MGWAP | X | | | X |
| Water levels | X | " | | | | | |
| Salinity | X | " | | | | | |
| pH | X | " | | | | | |
| **Subtidal sediment** | Measure at representative n° of sites throughout PHE (inc. near major drains) in spring & summer. | DoW | | X | | | X |
| Sedimentology | | | | | | | |
| *Grain size* | Repeat every 10 yrs | " | $20 000 /10yr | | | | |
| *Organic matter content & biomass* | Repeat every 3 yrs | " | $300 000/3yr | | | | |
| *Moisture content* | " | " | | | | | |
| *Redox potential* | " | " | | | | | |
| Nutrients | | | | | | | |
| *Total P* | " | " | | | | | |
| *Total N* | " | " | | | | | |
| *Total organic carbon* | " | " | | | | | |
| *Bioavailable inorganic nutrients (PO4, NH4, NO3, NO2)* | " | " | | | | | |
| Non-nutrients | | | | | | | |
| *Polyaromatic hydrocarbons* | " | " | | | | | |
| *Organochlorine pesticides* | " | " | | | | | |
| *Bioavailable metals* | " | " | | | | | |
| Sediment/water interchange of contaminants | Repeat every 5 yrs | " | $100 000/5yrs | | | | |
| **Bathymetry** | Undertake high-resolution depth-soundings throughout PHE using acoustic (sonar) techniques. Repeat every 20 yrs. | DoT | $50 000/20yr | X | | | X |
| **Catchment (river) monitoring** | As is | DoW | *part of above surface WQ costs | X | | | X |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Cost | Performance & Evaluation | | | |
|---|---|---|---|---|---|---|---|
| | | | | Drivers | Health indices & Report card | Mitigation strategies | Coupled model |
| Physical water quality | | | | | | | |
| *Dissolved oxygen* | X | " | | | | | |
| *pH* | X | " | | | | | |
| *Salinity/conductivity* | X | " | | | | | |
| *Temperature* | X | " | | | | | |
| *Turbidity &/or Secchi depth* | X | " | | | | | |
| *Total suspended solids* | X | " | | | | | |
| Hydrology | | | | | | | |
| *River flow* | X | " | | | | | |
| Nutrients | | | | | | | |
| *Total P* | X | " | | | | | |
| *Filtered reactive phosphorous* | X | " | | | | | |
| *Total N* | X | " | | | | | |
| *NH3* | X | " | | | | | |
| *Nitrates/nitrites* | X | " | | | | | |
| *Total & dissolved organic carbon* | X | " | | | | | |
| **Social & environmental drivers** | | | | | | | |
| Regional population level | Dependent on inter-agency coordination | See Table 1a | Dependent on inter-agency coordination. | X | | | |
| Landuse in catchment | " | " | " | X | | | |
| Total foreshore developed | " | " | " | X | | | |
| Loss of adjacent wetlands (claimed for land development) | " | " | " | X | | | |
| Loss of riparian vegetation | " | " | " | X | | | |
| Canal development & extent/location of dredging | " | " | " | X | | | |
| Index of total recreational use of estuary & catchment | " | " | " | X | | | |
| Median value of urban property | " | " | " | X | | | |
| Number & size of confirmed fish kills | " | " | " | X | | | |
| Level of public complaint about health of estuary | " | " | " | X | | | |
| **Key habitats** | | | | | | | |
| **Benthic plants (seagrass & macroalgae)** | Map macrophyte cover/ comp$^{n}$ throughout PHE from Quickbird/ IKONOS &/or hyperspectral imagery. Validate with ground-truthing. Measure biomass throughout PHE, inc. at sites sampled historically. Repeat every 3 yrs in SP/S. | University/consultant. DEC may provide remote-sensing support | $100 000/3yr | X | X | | X |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Cost | Performance & Evaluation | | | |
|---|---|---|---|---|---|---|---|
| | | | | Drivers | Health indices & Report card | Mitigation strategies | Coupled model |
| **Littoral & fringing vegetation** | Map veg$^{n}$ cover/ density/comp$^{n}$ throughout PHE from Quickbird/IKONOS imagery (same imagery as above). Validate with ground-truthing. Measure biomass throughout PHE, inc. at sites sampled historically. Repeat every 3 yrs in SP/S. | " | $50 000/3yrs | X | X | | X |
| **Shallow flats** | Map throughout PHE from Quickbird/ IKONOS imagery (same imagery as above). Validate with ground-truthing. Repeat every 3 years in SP/S. | " | (part of above costs) | X | X | | |
| **Integrated habitats** | Map throughout PHE from Quickbird/ IKONOS imagery (same that as above) that has been classified & ground-truthed for each of the above benthic cover types. Repeat every 10 yrs. | " | $30 000/10yr | X | X | | X |
| **Supporting biological components** | | | | | | | |
| **Phytoplankton** | 19 sites (5 in each the Peel Inlet & Harvey Est. & 3 in each the Murray, Serpentine, Harvey rivers) monitored 1-2 weekly in surface waters in shallows & at surface & bottom waters in deeper areas | DoW | *part of above surface WQ costs | X | X | | X |
| Chlorophyll *a, b, c* & pheophytin | X | " | | | | | |
| Species abundance | X | " | | | | | |
| Biomass | X | " | | | | | |
| **Macrophyte wrack** | Measure beach wrack biomass/ comp$^{n}$ throughout PHE. Repeat annually in W. | University/consultant. | $20 000/yr | X | | | X |
| **Key faunal components** | | | | | | | |
| **Fish, crabs & prawns** | | | | | | | |
| Abundance, lengths & weights of all species | Monitor 32 shallow & 24 deep sites in basins, Murray & Serpentine rivers, channel & coastal waters every 3 years in SP/S. Monitor a subset of above sites every year in SP/S. | University/consultant. | $40 000/3yrs + $20 000 in every other year. | | X | | X |

| Key Ecosystem Components | Monitoring program | Monitoring agency | Cost | Performance & Evaluation | | | |
|---|---|---|---|---|---|---|---|
| | | | | Drivers | Health indices & Report card | Mitigation strategies | Coupled model |
| Biology of key species (growth, age, reproduction &/or diet) | Full biological data (growth, age, reproductive & gut composition) measured for key species every 3 yrs & analysed every 10 yrs. Limited biological data (age, sex & gonad stage) recorded annually from a subsample of key species at above subset of sites. | " | $30 000/3 years + $3000 in every other year+ $5000 every 10 yrs | | X | | X |
| Interchange of key species between estuary & ocean | Tagging study of key species. Repeat every 10 yrs. | | $200000/10yr | | | | X |
| Commercial fishers | As is, in addition to age composition data collected annually from inside & outside PHE. | DoF | $50 000/yr | X | | | X |
| Recreational fishers | Surveys of recreational shore & boat based fishers throughout PHE to measure catch & effort data & length & age $comp^n$ of catches for key species. Measure on random subsample of weekdays, weekends & time of day. Repeat every 5 years. | DoF | $500 000/5yr | X | | | X |
| **Small benthic macroinvertebrates** | | | | | X | | X |
| Species abundance & biomass | Monitor 32 shallow & 24 deep sites in basins, Murray & Serpentine rivers, channel & coastal waters every 3 years in SP/S. Monitor a subset of above sites every year in SP/S. | University/consultant. | $40 000/3yrs + $20000 in every other year | | | | |
| **Waterbirds** | | | | | X | | X |
| Total counts of each species (inc. life cycles stages where possible) | As is, in addition to part-time costs for coordinator to maintain data consistency. | As is | $15 000/yr | | | | |
| **Dolphins** | | | | | | | X |
| Behavioural observations & counts | Establish $n^o$s & community structure every 3 yrs | University/consultant. | $20 000/3yrs | | | | |
| **Food web** | Establish quantitative food web for estuary using traditional gut $comp^n$ (fish & birds) & stable isotope (fish, birds & their prey) methods. Repeat seasonally for 2 consecutive yrs every 10 yrs. | " | $400000/10yr | | | | X |

**Table 2:** Frequency of data collection for each of the ecosystem components of the Peel-Harvey Estuary under this proposed science strategy.

| | Peel-Harvey Estuary Science Strategy | | | | | | |
|---|---|---|---|---|---|---|---|
| **Key Ecosystem Components** | **1-2 weeks** | **1-2 months** | **1 yr** | **3 yr** | **5yr** | **10 yr** | **20 yr** |
| **Abiotic components** | | | | | | | |
| **Estuarine surface water quality/hydrology** | X | | | | | | |
| **Ground water quality/hydrology** | | X | | | | | |
| **Subtidal sediment** | | | | | | | |
| Grain size and composition | | | | | | X | |
| Other physical variables and nutrient/ non-nutrient contaminants | | | | X (SP&S) | | | |
| Sediment/water interchange of contaminants | | | | | X | | |
| **Bathymetry** | | | | | | | X |
| **Catchment (river) monitoring** | X | | | | | | |
| **Social & environmental drivers** | | | | | | | |
| Regional population level | | | | | X | | |
| Landuse in catchment | | | | | X | | |
| Total foreshore developed | | | | | X | | |
| Loss of adjacent wetlands (claimed for land development) | | | | | X | | |
| Loss of riparian vegetation | | | | | X | | |
| Canal development and extent/location of dredging | | | | | X | | |
| Index of total recreational use of estuary & catchment | | | | | X | | |
| Median value of urban property | | | | | X | | |
| Number and size of confirmed fish kills. | | | X | | | | |
| Level of public complaint about health of estuary. | | | X | | | | |
| **Key habitats** | | | | | | | |
| **Benthic plants (seagrass and macroalgae)** | | | | X (SP/S) | | | |
| **Littoral and fringing vegetation** | | | | X (SP/S) | | | |
| **Shallow flats** | | | | X (SP/S) | | | |
| **Integrated habitats** | | | | | | X | |

| Key Ecosystem Components | 1-2 weeks | 1-2 months | 1 yr | 3 yr | 5yr | 10 yr | 20 yr |
|---|---|---|---|---|---|---|---|
| **Supporting biological components** | | | | | | | |
| **Phytoplankton** | **X** | | | | | | |
| **Macrophyte wrack** | | | **X (W)** | | | | |
| **Key faunal components** | | | | | | | |
| **Fish, crabs & prawns** | | | | | | | |
| Abundance, lengths and weights of all species | | | **X (SP/S)** - subset of sites | **X (SP/S)** | | | |
| Biology of key species | | | **X (SP/S)** - subset of sites & fish | **X (SP/S)** | | **X** (analysis) | |
| Interchange of key species between estuary and ocean | | | | | | **X** | |
| Commercial fishers | | | **X** | | | | |
| Recreational fishers | | | | | **X** | | |
| **Small benthic macroinvertebrates** | | | **X (SP/S)** - subset of sites | **X (SP/S)** | | | |
| **Waterbirds** | | | **X (SP/S)** | | | | |
| **Dolphins** | | | | **X** | | | |
| **Food web** | | | | | | **X** | |
| **Performance and Evaluation** | | | | | | | |
| **Reporting of biotic health indices and report cards** | | | **X** | | | | |
| **Audit of mitigation strategies (WQIP etc)** | | | | | **X** | | |
| **Model development & ongoing maintenance** | | | **X** | | | | |

**Table 3:** Annual cost, over a 10 year period, of this proposed science strategy for the Peel-Harvey Estuary. .

| Key Ecosystem Components | y1 | y2 | y3 | y4 | y5 | y6 | y7 | y8 | y9 | y10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Abiotic components** | | | | | | | | | | |
| **Estuarine surface water quality/hydrology** | $475,000 | $450,000 | $450,000 | $450,000 | $450,000 | $450,000 | $450,000 | $450,000 | $450,000 | $450,000 |
| **Ground water quality/hydrology** | (to be estimated once MGWAP completed) | | | | | | | | | |
| **Subtidal sediment** | | | $300,000 | | $100,000 | $300,000 | | | $320,000 | $100,000 |
| **Bathymetry** | $50,000 | | | | | | | | | |
| **Catchment (river) monitoring** (part of surface WQ costs) | | | | | | | | | | |
| **Social & environmental drivers** | | | | | | | | | | |
| **Key habitats** | | | | | | | | | | |
| **Benthic plants (seagrass and macroalgae)** | | | $100,000 | | | $100,000 | | | $100,000 | |
| **Littoral and fringing vegetation** | | | $50,000 | | | $50,000 | | | $50,000 | |
| **Shallow flats** | | | | | | | | | | |
| **Integrated habitats** | | | | | | | | | $30,000 | |
| **Supporting biological components** | | | | | | | | | | |
| **Phytoplankton** (part of surface WQ costs) | | | | | | | | | | |
| **Macrophyte wrack** | $20,000 | $20,000 | $20,000 | $20,000 | $20,000 | $20,000 | $20,000 | $20,000 | $20,000 | $20,000 |
| **Key faunal components** | | | | | | | | | | |
| **Fish, crabs & prawns** | | | | | | | | | | |
| Abundance, lengths and weights of all species | $20,000 | $20,000 | $40,000 | $20,000 | $20,000 | $40,000 | $20,000 | $20,000 | $40,000 | $20,000 |
| Biology of key species | $3,000 | $3,000 | $30,000 | $3,000 | $3,000 | $30,000 | $3,000 | $3,000 | $30,000 | $8,000 |
| Interchange of key species between estuary and ocean | | | | | | | | | | $200,000 |
| Commercial fishers | $50,000 | $50,000 | $50,000 | $50,000 | $50,000 | $50,000 | $50,000 | $50,000 | $50,000 | $50,000 |
| Recreational fishers | | | | | $500,000 | | | | | $500,000 |
| **Small benthic macroinvertebrates** | $20,000 | $20,000 | $40,000 | $20,000 | $20,000 | $40,000 | $20,000 | $20,000 | $40,000 | $20,000 |
| **Waterbirds** | $15,000 | $15,000 | $15,000 | $15,000 | $15,000 | $15,000 | $15,000 | $15,000 | $15,000 | $15,000 |
| **Dolphins** | | | $20,000 | | | $20,000 | | | $20,000 | |

| Key Ecosystem Components | y1 | y2 | y3 | y4 | y5 | y6 | y7 | y8 | y9 | y10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Food web** | | | | | | | | | $200,000 | $200,000 |
| **Performance and Evaluation** | | | | | | | | | | |
| **Development of biotic health indices & report card*** | | | | $250,000 | | | | | | |
| **Reporting of biotic health indices and report cards** | $25,000 | $25,000 | $25,000 | $25,000 | $25,000 | $25,000 | $25,000 | $25,000 | $25,000 | $25,000 |
| **Audit of mitigation strategies (WQIP etc)**** | | | | | | | | | | |
| **Data warehouse/management** | $30,000 | $30,000 | $30,000 | $30,000 | $30,000 | $30,000 | $30,000 | $30,000 | $30,000 | $30,000 |
| **Model development & ongoing maintenance** | $500,000 | $100,000 | $100,000 | $100,000 | $100,000 | $100,000 | $100,000 | $100,000 | $100,000 | $100,000 |
| **Senior Scientist** | $200,000 | $200,000 | $200,000 | $200,000 | $200,000 | $200,000 | $200,000 | $200,000 | $200,000 | $200,000 |
| **Funding Approaches** | | | | | | | | | | |
| Prefeasibility and study | $150,000 | | | $500,000 | | | | | | |
| **Annual Total** | **$1,558,000** | **$933,000** | **$1,470,000** | **$1,683,000** | **$1,533,000** | **$1,470,000** | **$933,000** | **$933,000** | **$1,720,000** | **$1,938,000** |
| **10 yr Total** | | | | | **$14,171,000** | | | | | |

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