



Adelaide Coastal Waters Study

Consolidated Stage 2 and 3 Research Plans

Prepared for

Adelaide Coastal Waters Study Steering Committee

Compiled by

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Limitations Statement

The sole purpose of this Approved Stage 2 and 3 Research Plan prepared by CSIRO's Environmental Projects Office (EPO) is to document and specify a scientific research and technical program to address management issues and concerns expressed by members of the Adelaide Coastal Waters Study Steering Committee, otherwise referred to as (the Study) stakeholders. Work has been carried out in accordance with the scope of services identified in the agreement dated 14 September 2002, between the Department for Environment and Heritage ('the Client') and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

The material presented in this document has been derived from the previously prepared Final Research Requirements Report (RRR) prepared for the client by CSIRO Environmental Projects Office in February 2002 and from proposals submitted by various research individuals and organisations following technical review of the suite of research proposals and overall research program. At the time of preparation, the scope of works documented here has the endorsement of the Client, on recommendation from the Technical Review Committee. The passage of time, or impact of future events, may require further exploration and re-evaluation of the research plan and/or proposed research methods nominated in this document.

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Foreword

These consolidated Stage 2 and 3 Research Plans have been compiled by the CSIRO Environmental Projects Office, as Project Managers engaged by the South Australian Environment Protection Authority (EPA) to manage the Adelaide Coastal Waters Study (ACWS). This is a significant document that identifies the components of research, scientific investigations and data analysis deemed appropriate to address the majority of priority Stakeholder issues. With the endorsement of the ACWS Steering Committee, the Plan is the operational document for Stages 2 and 3.

In compiling this document we have relied heavily on the goodwill and cooperation of the ACWS Scientific Committee and individuals and organisations submitting proposals to undertake the tasks specified in the Final Research Requirements Report. These scientists and committee members have devoted considerable time and effort to developing this detailed research plan and I would like to reiterate our gratitude for individuals' and organisations' efforts.

The process of arriving at an approved research plan has benefited from the input and advice from the South Australian EPA and members of its Technical Review Committee.

Following sign-off by the ACWS Steering Committee Executive Officer, contracts will be awarded for respective tasks. A commencement date is yet to be confirmed, however, it is anticipated that the two-year research program would commence during 2003 for implementation, synthesis and reporting during the second, third and fourth years of the Study.



Professor David Fox
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Adelaide Coastal Waters Study

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Executive summary

‘Clean water, diverse aquatic ecosystems and sandy beaches’

This simple statement articulates a vision for Adelaide’s metropolitan coastline. The Adelaide Coastal Waters Study (ACWS) was first conceived and subsequently scoped during the middle to late 1990s. Building on previous efforts and research, we are now on the verge of seeing this vision become a reality. This important report documents the essential research tasks that will enable the region’s managers to identify and implement the management actions necessary to achieve this ideal coastal vision.

The objective of the ACWS is to develop knowledge and tools to enable sustainable management of Adelaide’s coastal waters by identifying the causes of ecosystem modifications and the actions required to halt and reverse degradation.

The ACWS will focus on:

- seagrass loss;
- sea floor instability; and
- water quality degradation.

The ACWS will result in:

- new knowledge and understanding;
- options for management action;
- a program to assess effectiveness of management actions (including a monitoring program); and
- communication of results.

The ACWS objective provides a clear direction and focus for the study’s research program and tasks.

This document describes an integrated suite of research tasks designed to investigate issues associated with the ecosystem components identified above. Stakeholder contributions of approximately \$2.2 million in cash are intended to be matched by an equal in-kind investment from the research providers.

These consolidated Stage 2 and 3 Research Plans define the research program and individual research tasks to be implemented during the remainder of the current ACWS. These tasks are listed, with an upper limiting fee provided for each, in Table 1 below.

Synthesis and reporting tasks form Stage 3. The Project Managers recognise the importance of these activities; synthesis of results will commence early in Stage 2 and continue as a project management and ACWS Scientific Committee responsibility throughout Stages 2 and 3.

The Project Managers will, in consultation with the Client, communicate results to the stakeholders and scientific committee from the early stages of the ACWS and will implement an effective continuing communication strategy to encourage and maintain stakeholder, scientific and general community interest for the duration of the study.

Table 1 Titles and indicative costs of research, synthesis and reporting tasks recommended for implementation during Stages 2 and 3

Task code	Research/activity title	
Stage 2 Research Tasks		Task budget (\$'000)
Input Studies – Quantity and Quality		
IS 1	Quantification of diffuse and point source terrestrial, groundwater and atmospheric inputs to the coastal waters	315
Ecological Processes		
EP 1	Assessment of the effects of inputs to the Adelaide coastal waters on seagrass ecosystems and key biota	884.5
Remote sensing		
RS 1	Remote sensing study of marine and coastal features and interpretation of changes in relation to natural and anthropogenic processes”	185
Physical Processes and Modelling		
PPM 1	Coastal sediment budget	160
PPM 2	Physical oceanographic studies in the Adelaide coastal waters using high resolution modelling, in-situ observations and satellite techniques	430.5
Environmental Monitoring Program		
EMP 1	Environmental Monitoring Program – spatial/temporal design; statistical analysis; Quality assurance and control.	95
Total of indicative costs for recommended Stage 2 tasks		2,071
Stage 3 Synthesis and Reporting Tasks		Indicative costs per task (\$'000)
AMF 1	Development of Adaptive Management Framework	Project management responsibility
DST	Development of Decision Support Tools for management	
DST MM 1	Development of a coarse resolution management model for the Adelaide coastal waters	100
DST DB 1	Adelaide Coastal Waters Study database and spatial information system	Developed as costed project management responsibility

Introduction to the Adelaide Coastal Waters Study

Introduction

Over a number of years, there has been increasing concern about the effects of coastal and catchment development on the marine environment near Adelaide. Nutrients and other pollutants are introduced to nearshore waters from urban and rural runoff (particularly in the southern streams), sewage treatment plants and some industrial sources. The South Australian EPA and the Coast Protection Board have been particularly concerned about well documented seagrass loss and its impacts on biological and physical coastal processes, including sand movement, for over two decades. Stakeholders and coastal communities have also expressed concerns about algal blooms, aesthetic values, recreational use of the water, environmental health and biodiversity in marine habitats. However, understanding of the processes involved, the interrelationships among them, and how they would respond to management actions, is insufficient to support management decisions.

In response to these issues and management concerns, the South Australian EPA has initiated this large-scale, integrated study of the Adelaide coastal waters to determine options for the ecologically sustainable management of this important area.

Need for an integrated study

Agencies responsible for management of Adelaide coastal waters are collectively concerned about a number of issues that interact strongly with one another. The issues include:

- seagrass loss;
- coastal erosion;
- water quality degradation;

and a general uncertainty about the extent of these problems, their possible consequences (direct and indirect) and what should be done about them.

Because of large-scale modification of the coastal drainage and the impacts of a large modern city in a naturally low nutrient marine environment, the following issues must be considered:

- water and sediment quality as they affect: recreational use of the beaches; natural ecosystems (for example, seagrass systems), key species and human activities (for example, fishing); and toxic microalgal blooms in estuaries and macroalgal blooms;

- the high costs of improved sewage treatment and catchment management, and uncertainty about the harm or benefits of the available options to the coastal waters ecosystem. Such options include: improved treatment of sewage; diversion of reclaimed water to terrestrial re-use; diversion of outfalls from catchments directly to the sea (bypassing estuaries); draining stormwater into constructed wetlands; and extending wastewater outfalls further offshore; and
- the potential effects of coastal erosion on beaches, property, and seagrass loss; the high costs of the strategies adopted to ameliorate coastal erosion; and uncertainty about the ecological costs or benefits of those strategies. The Office of Coast and Marine (OCM) and the South Australian Coast Protection Board (CPB) have made substantial progress investigating these issues.

The Adelaide coastal ecosystem typically has the potential for large-scale interaction between seagrasses, beach and nearshore morphology, benthic biota, nutrients and toxicants and water quality. Lack of understanding of these interactions can be costly, in both ecological and economic terms. It is not possible to specify the full effects of particular management actions because the system is presently not sufficiently well understood, and so it is not possible to evaluate the costs and benefits of major decisions. However, it is possible to significantly reduce the risks associated with major decisions through the improvement of system understanding and through integrative modelling and adaptive management.

The major reasons for proposing the ACWS as a large-scale study are to establish an *integrated* understanding of the system and to provide knowledge in a context that permits better informed management decisions. An integrated view of the ecosystem will allow the community and managers to assess ecological priorities along with practical, economic and social objectives and to determine suitable trade-offs without initiating unintended or irreversible (and possibly costly) damage in a seemingly unrelated part of the ecosystem. In other places, large-scale studies have been valuable in providing context, integration and synthesis. Examples include the Port Phillip Bay Environmental Study in Victoria, the Perth Coastal Waters Study and the Southern Metropolitan Waters Study in Western Australia and the Brisbane River and Moreton Bay Wastewater Management Study in Queensland.

The ACWS is based on the broad principles of adaptive management, which recognise that there is always some uncertainty in our knowledge of the system. Accordingly, the system is managed to produce information that will reduce uncertainty. The process will initiate an ongoing partnership between management and science.

Study stakeholders

The key stakeholder organisations include: SA Water; the South Australian EPA; Transport SA; the Patawalonga, Torrens and Onkaparinga Catchment Water Management Boards (CWMBs); Primary Industries and Resources SA; the Coast Protection Board; Mobil Refining Australia; and TXU Torrens Island. As funding partners to the study, they are equally represented on the ACWS Steering Committee. Other non-funding organisations represented on the Steering Committee include the Local Government Association, the Conservation Council (SA) and the South Australian Fishing Industry Council.

Stage 1 process

Stage 1 of the ACWS commenced in March 2001. It was essentially the design phase of the study. The process of developing an approved research program began with a series of stakeholder interviews. A workshop of the ACWS Scientific Committee followed, providing an opportunity for local research providers to investigate the stakeholder issues and to nominate a research program that would integrate existing knowledge and build on it through focused research tasks. The study's Research Requirements Report was submitted for Steering Committee consideration late in 2001. The scope of tasks and the research program were agreed during March 2002. In late 2002, CSIRO called for proposals from researchers to undertake the tasks specified in the February 2002 report as the first in Stage 2.

Stages 2 and 3

Stage 2

Stage 2 is the research stage, when activities presented in attachments to this report will be undertaken. While the duration of these activities is somewhat dependent on the start date, our initial assessment is that these tasks will require two full calendar years to complete (including two summer periods) and that results will be synthesised and reported during Stage 3. The conceptual model proposed for the study will be evaluated and further refined in the light of information and understanding as it emerges during Stages 2 and 3.

The presentation of technical reports from each research task will denote the completion of Stage 2.

Stage 3

Stage 3 will commence concurrently with Stage 2 and comprise integrated modelling, synthesis of results and communication of these results to interested scientific and wider communities and stakeholders. It will involve analysis of field data and samples, finalisation and calibration of models and use of the models to assess the impact of management actions. It will culminate in the production of the final study report.

Stage 3 will also involve the establishment of an adaptive management framework that will be used to underpin future decision making and environmental management. The adaptive management framework may include experimental process studies in parallel with the monitoring tasks (to be defined through an iterative refinement process during Stage 2 and Stage 3), as the data sets available during Stage 3 will be limited to historical data and that derived through Stage 2 research, survey and monitoring tasks.

The study area and coastal systems

This section presents:

- a definition and brief description of the study area, including a summary of the principal anthropogenic influences;
- a hypothesised conceptual model of the coastal system; and
- a synopsis of what we still need to know about the Adelaide coastal waters system, and important interactions, as the basis for proposed research tasks.

The study area

The study area extends along the eastern side of Gulf St Vincent, South Australia, from Port Gawler, at the discharge of the Gawler River, in the north, to Sellicks Beach in the south. The seaward boundary is nominally 20 kilometres from the high water mark. The landward boundary is not strictly defined, but the study encompasses the catchments of the contributing streams and rivers discharging into the coastal waters. The Port Adelaide River and the associated Barker Inlet wetlands system are considered within the study area as an important source of input to the coastal system, but there will be no detailed ecological process assessments made in this region, nor will there be any assessment of marine or estuarine habitat type and health, whereas such assessments will be made in the four zones identified in the description of task EP 1. Similarly, the Patawalonga Basin and the Onkaparinga River estuary are excluded from the study area, but their effects on the coastal waters will be taken into account in the same manner as for the Port Adelaide River area.

The study area is indicated pictorially in Figure 1. It can be seen that the major contributing flows enter the coastal waters from the Torrens, Patawalonga and Onkaparinga rivers. Flows from these sources arise in both rural and urban areas. Less substantial flows arrive from the Field River and Gawler River. Flows into the Port Adelaide River and associated wetlands surrounding and connected to the Barker Inlet are predominately derived from urban runoff. Rural runoff is particularly prevalent in the southern areas, where it enters rivers and streams that discharge into the ocean.

The conceptual ACWS model and hypothesised system status

Water quality decline, particularly as indicated by seagrass loss, is the overriding issue of concern for Adelaide's coastal managers. Seagrass has declined along the Adelaide coastal waters, Port Adelaide River and Barker Inlet Estuary and there have been increases in algal, phytoplankton and *Ulva* growth. This is typical of a sheltered waterway's response to eutrophication. The loss of seagrass might originally have been triggered by a nutrient imbalance; however, the causes of continuing seagrass loss may be more closely related to physical processes. The Seagrass Restoration Workshop at SARDI (South Australian Research and

Development Institute) Aquatic Sciences (May 2001) proposed a similar theory of causal factors.

There is ample experience, gained from similar studies conducted in Australia and elsewhere, that additions of nitrogen through land-based discharges have caused the majority of the disturbances we see today. The issue for the ACWS is to identify the features of the system that are peculiar to the Adelaide area and Gulf St Vincent. The ACWS needs to determine the relationship between seagrass loss and sand movement and how these changes might be controlled. The study needs to look at ecosystem response using integrated resources.

While causes of continuing decline are uncertain, it is reasonably safe to assume that the movement from a seagrass-dominated nearshore area to one where brown algal blooms and *Ulva* growth predominate follows a predictable model of response to increased nutrient loads. A hypothesised conceptual model of the Adelaide coastal waters system (Figure 2) was proposed as a reasonably accurate interpretation/prediction of the pressures and responses experienced along the metropolitan coastline.

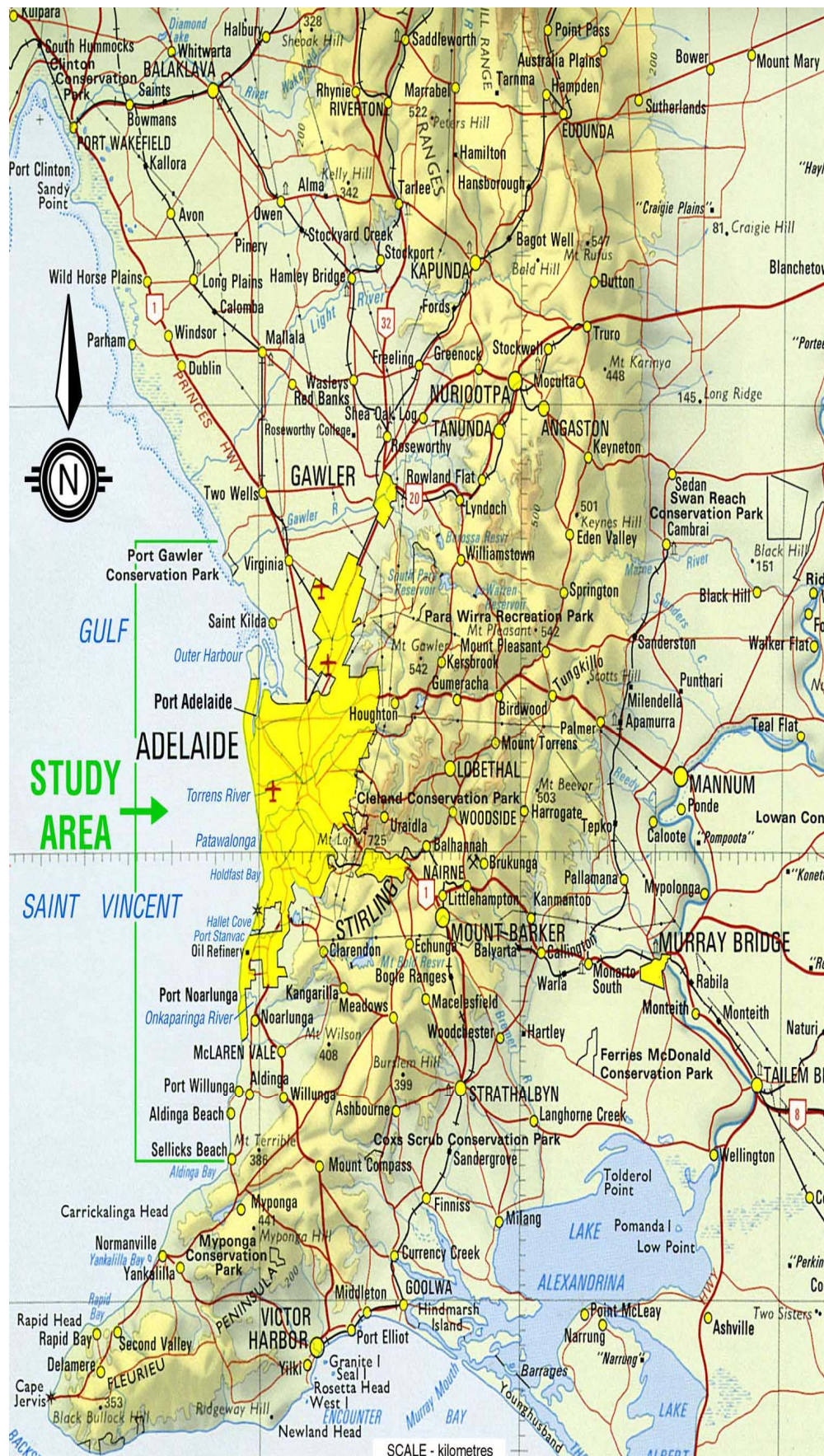


Figure 1. Study area for the Adelaide Coastal Waters Study.

Note: The seaward boundary is nominally 20 kilometres from high water mark. Port Adelaide River excluded.

The conceptual model

A conceptual model of the Adelaide coastal waters system has been proposed to provide an informal, descriptive picture (Bill Dennison, University of Queensland, personal communication, December 2001). It incorporates a number of key state variables, processes and interactions, according to current understanding, and highlights the complexity of the system. The model confirmed knowledge gaps and assisted in the specification of detailed research tasks to be undertaken. This model will be continually refined as we increase our understanding of the coastal system and driving processes.

Adelaide Coastal Waters

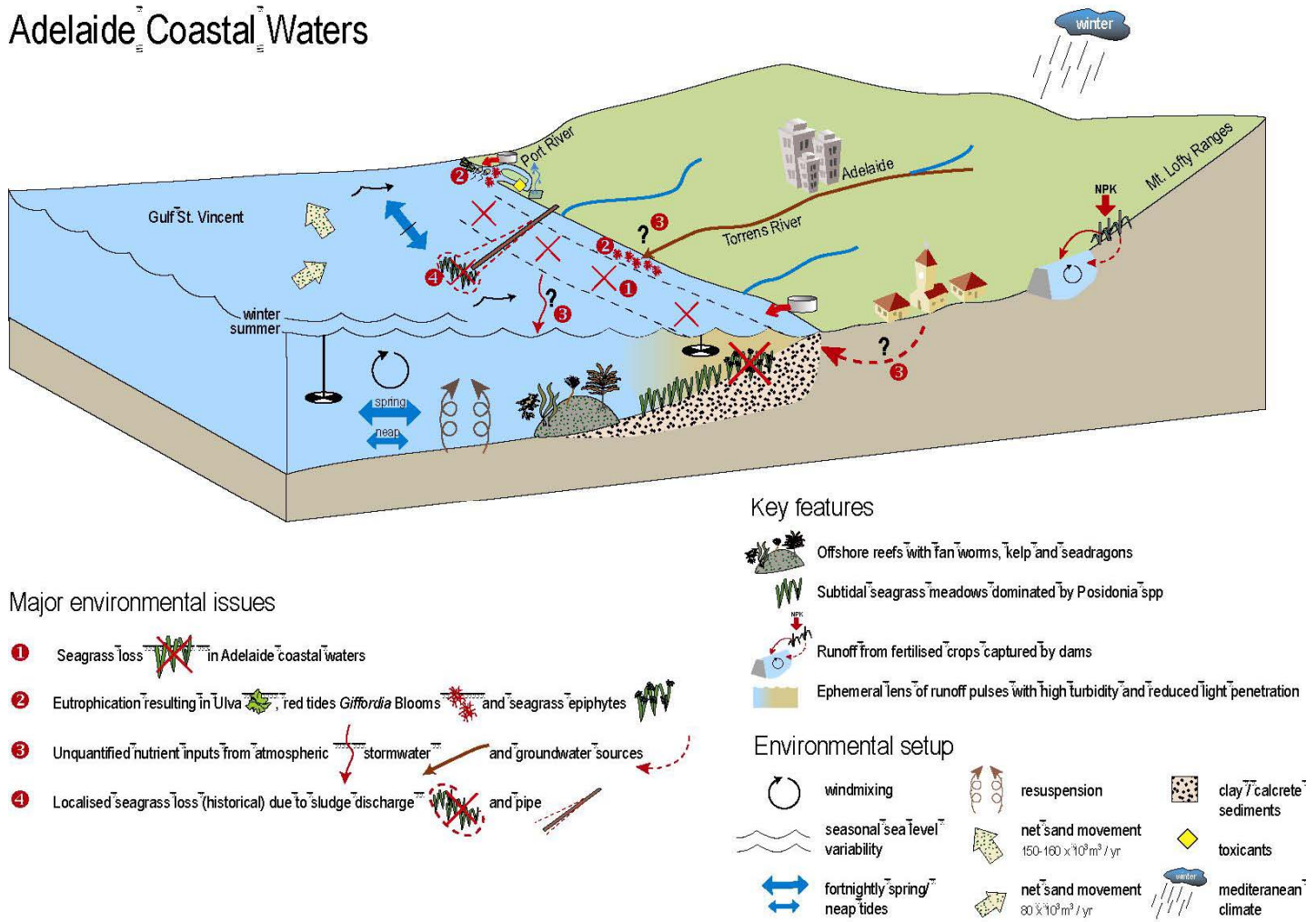


Figure 2: Conceptual model of the Adelaide coastal waters systems

It was suggested that significant combined nitrogen and phosphorus loads from all catchment and discharge sources have been entering the coastal waters and that the results are highly typical for this level of disturbance. Given the effects of this level of disturbance, questions raised included how to determine the relative inputs of diffuse sources and whether the nitrogen loads can be controlled at source and/or stored and re-used (instead of entering the nearshore as discharges).

It was postulated that approximately 15–20 µg/L of chlorophyll a would be found in the Port Adelaide River system and approximately 5–10 µg/L would be found in coastal waters. Concentration peaks would be expected in January and February.

Coastal waters off Adelaide are relatively exposed and nearshore dynamics (for example, advection of water) are predicted to dominate the natural coastal processes. There is also likely to be a northerly bias to plume dispersions and associated impacts, as the nutrients entering the coastal waters would be moved along and onshore by the predominant south-westerly winds. Residence time in the nearshore areas would also be relatively high if the offshore tidal exchange rates are low, as predicted. Residence time is likely to be as important as loads of nitrogen and other contaminants in determining ecosystem degradation levels. It was suggested that the scientific community does not fully understand how effective seagrass beds are at providing denitrification services.

It is conjectured that a hysteresis effect in nitrogen loads and ecosystem response may operate. If true, the reduction in nitrogen loads required to restore ecosystem function would be many times greater than the original increase which resulted in the disturbance. This hypothesis requires investigation and, if substantiated, would have profound implications for future management of the coastal waters.

Questions to emerge at this stage of discussions include:

- what are the physical mechanisms that lock coastal waters into nearshore areas?;
- how can any hysteresis be proved and then quantified?;
- how far is the study area from being a healthy environment for seagrass? (to answer this question, it would be necessary to identify and evaluate a similar location—for example, Port Hughes on Spencer Gulf's east coast);
- what are denitrification efficiencies in a healthy environment?; and
- does salinity stratification occur?

To address these questions, we need to know more about denitrification processes, in order to understand better what happens in a healthy area and what happens in a disturbed area.

It was proposed that we need information on:

- denitrification processes (including the role of seagrass meadows);
- salinity impacts; and
- effects of light (reduction) and re-suspension of sediments (recalling the suggestion that sediments are likely to be carbon limited). This would require the use of benthic chamber assessment of the microphytobenthos.

It was also proposed that stormwater inputs would bring in high organic carbon loads and contribute to pelagic-benthic coupling. Atmospheric deposition was identified as an additional source of nutrients to coastal waters. The question proposed here is—how important are atmospheric fallout and enriched groundwater inflows as contributors to the coastal waters' eutrophication?

The importance of the ecosystem services (for example, denitrification processes) provided by microphytobenthos and fauna in the sediments was suggested to be considerable. They are likely to play a substantial role in increasing the capacity of receiving waters to assimilate nutrient enriched discharges.

What we know about Adelaide's coastal systems

The CSIRO scoping study report, prepared by CSIRO Marine Research in 1997, provided a comprehensive review of existing knowledge and information gaps at the time of preparation. The Draft ISP of July 2001 built upon the considerable knowledge base and highlighted key research findings that emerged during the intervening years. These two previously prepared documents should be referred to in order to determine what is known about the Adelaide coastal system. The following section details the current information gaps; the ACWS has been designed to address these information gaps.

Current information gaps

Physical circulation dynamics

Long-term observational data sets are required to provide forcing data for realistic simulations of the physical circulations (and sediment movements). For coupled ecological–physical modelling, data sets of years to decades may be required.

Adequate measurements are needed to calibrate model performance with respect to circulation and the distributions of important water.

Catchments and inputs

It is necessary to know ranges and variability of loads, from long-term monitoring stations within the catchments and associated with treated effluent discharges, and to obtain a firmer understanding of nutrient inputs from groundwater sources and atmospheric fallout, to enable an accurate nutrient budget to be developed for the coastal waters study area.

Nutrient cycling

It is essential to understand better the interaction between physical transport, on the one hand, and nutrients, turbidity, plant growth and sediment biogeochemistry, on the other. There is a real need to quantify the magnitude (spatial and temporal) and the impacts of nutrients, and the potential importance of cycling through macrophytes and sediments in changing effective flushing times in the system. The relative importance of nitrogen and phosphorus as coastal contaminants in the study area is uncertain. However, similar studies in sheltered coastal waters with high freshwater inputs have indicated that phosphorus may also be a significant contaminant and result in coastal water quality and ecosystem degradation.

It is uncertain to what extent the turbid plumes from local and intermittent stormwater events affect water quality offshore over the remaining seagrass beds in the long term. There are also insufficient data on sediment nutrients and organic

content, and on exchanges between the sediment and the water column, to quantify these effects.

Past work on seagrass dynamics has concentrated on the major sites of seagrass loss in the vicinity of effluent or sludge outfalls. The role of subtle broad-scale changes in water quality is unclear. Better characterisation of broad, alongshore gradients in water and sediment quality, and their relation to existing nutrients and sediment loads, and better understanding of interactions between sediment and water quality are required. Knowledge of these processes will also contribute to the understanding and management of the Port Adelaide River, reef systems, mangroves and intertidal seagrass areas.

Sediment dynamics

A framework/method is needed for relating short-term variable processes with long-term changes.

It will be necessary to relate wind-wave conditions with observed rates of sediment transport, thereby providing a refined understanding of long shore transport processes (however, the Office of Coast and Marine and the Coast Protection Board continue to address these issues as regular organisational tasks).

The effects of benthos (seagrass) on sediment transportability is a key knowledge gap, and it will be essential that ground truth measurements in seagrass areas are made in the sediment budget.

Toxicant dynamics

A major gap is evident in the level of relevant chemical and toxicological data for the study area. Some analytical surveys of Adelaide's stormwater and wastewater treatment plant (WWTP) discharges have been carried out, but these have generally been restricted to nutrients, trace metals, bacteria, oil and grease, pH, salinity and suspended solids. Very few data are available for organic contaminants. There may be an opportunity to link the findings of chemical spatial surveys to validate physical transport and dispersion modelling.

It will be important to quantify inputs from a range of sources and to assess temporal variability, concentrations and pools and fluxes in the water, sediments and biota. While there are reasonable data, it will be essential to interpret existing data with a particular focus on determining the links between concentrations and effects.

One of the major study tasks will be to characterise stormwater and wastewater discharges and, through risk assessment, determine the constituents of greatest concern and potential impact.

Seagrass and sediment dynamics

A field study of wave attenuation and model experiments on the effects of seagrass on wave refraction and currents would be required to resolve whether beach topography and frictional effects of seagrass can alter wave and current patterns.

Process studies of sand transport in the seagrass meadows and exchange with the beach are needed to evaluate the importance of beach morphology for sand stability in the seagrass meadows.

The critical size of seagrass patches should be examined, and experiments designed to test the hypothesis that seagrass patches are now too small to be viable.

Seagrass community structure

Focused experiments are required to test a number of hypotheses related to seagrass community structure. These hypotheses relate to seed productivity and recruitment success, variability in preferential conditions between seagrass species, theory of successional changes and predator/food web theories.

Study design and research program

This section provides an overview of the issues to be addressed by the study and highlights the study objective and anticipated outcomes. The section also outlines the process adopted to scope, develop and integrate the suite of Stage 2 research tasks specified as attachments to this document.

Scope of the study issues

An iterative process of consultation and review with the study stakeholders resulted in a suite of issues being identified in the Stakeholders Requirements Report. The ACWS Scientific Committee subsequently reviewed and discussed the relevance of these issues and the context in which they might be addressed by the study. The issues, presented under the headings listed below, highlight significant gaps in the current knowledge base and in the confidence of managers and stakeholders to manage the coastal systems. The stakeholder issues presented in the Stakeholders Requirements Report represent the scope of the study issues.

The focus areas for the study are:

- nutrients (in sediments and/or water column);
- pollutants (transport and fate of heavy metals, pesticides, ammonia);
- ecotoxicology;
- salinity—dispersion and interactions/impacts modelling;
- seagrass dynamics/ecology;
- algal blooms;
- water quality—objectives/standards, assimilative capacity and maximum contaminant loads;
- indicators of disturbance and health; and
- coastal processes and sediments.

Table 2 below presents stakeholder issues to be addressed by the study (determined through Stage 1 consultation) and their relative priority, and indicates which task(s) will address particular issues.

Study objectives

The objective of the ACWS is to develop understanding and tools to enable sustainable management of Adelaide's coastal waters, by identifying the causes of ecosystem modifications and the actions required to halt and reverse degradation.

The study will focus on:

- seagrass loss;
- seabed instability; and
- water quality degradation.

Study outcomes

The study will result in:

- new knowledge and understanding;
- options for management actions;
- a program to assess effectiveness of management actions (including monitoring program); and
- communication of results.

Table legend:

- *Critical issue*—**will** be addressed;
- *Important issue*—**expected** to be addressed but has external dependencies (for example, other research, other data, other people/providers) and other uncertainties (for example, results of co-dependent task(s) whose outcomes cannot be anticipated in advance) that preclude us from providing absolute guarantee;
- *Interesting issue*—Not central to ACWS, but will be investigated **if time and resources permit**;
- *Side issue*—outside of current scope of ACWS and **will not be** addressed.

Table 2 Table of issues to be addressed by the ACWS, the relative priority of each and the research tasks potentially contributing to issues' resolution.

Issue ID #	Common research theme area and specific issues	Comments/priority	Addressed by Research Task(s)
3.2.1 Nutrients (in sediments and water column)			
3.2.1.1	What is the fate of nutrients (nitrogen and phosphorus) and what are their respective impacts on the receiving marine environment and ecosystem functions?	Critical Issue —the study requires a sound nitrogen budget that considers point source, diffuse, atmospheric and groundwater inputs.	EP 1, RS 1, PPM 2
3.2.1.2	What are the relative contributions of all contaminant inputs to the system and how do these compare to the impacts of WWTP sourced nutrients in terms of significance of effects?	Critical issue to be addressed in nitrogen budget	IS 1, RS 1, PPM 2
3.2.1.3	How does stormwater's contribution to nutrients in the Gulf compare in significance to discharges from the wastewater treatment plants? Is nitrogen the only nutrient input of concern?	Critical issue to be addressed in nitrogen budget	IS 1, IS 1, PPM 2
3.2.1.4	The Environmental Improvement Programs (EIPs) for the coastal WWTPs are designed to result in the target reduction of nitrogen in discharge waters from 30 mg/l to 10 mg/l. What impact will this have on the seagrasses?	Critical issue —question is, what effect will this reduction have?	EP 1, RS 1, PPM 2
3.2.1.5	How important are any denitrifying processes in sediments along Adelaide's coastline in assimilating discharged nutrients?	Critical issue	EP 1
3.2.1.6	How effective are the Barker Inlet wetlands at reducing the nitrogen loads to coastal waters and the Port Adelaide River?	Side issue —may potentially be considered in relation to coastal denitrification process studies	
3.2.2 Pollutants (transport and fate of heavy metals, pesticides, ammonia)			
3.2.2.1	Are there other parameters of concern in the coastal waters in addition to or instead of nutrients?	Critical issue —study to identify additional parameters	IS 1, EP 1
3.2.2.2	What are the pollutant loads entering the coastal waters from all sources?	Critical issue —to be addressed in parallel with 3.2.1.2	IS 1
3.2.2.3	Is nitrogen/ammonia toxicity an issue for seagrass—is toxicity directly related to concentration?	Critical issue —as knowledge on issues exists (relating to trigger loads)	EP 1
3.2.2.4	What are the effects of heavy metals on marine ecosystems (including reefs)?	Interesting issue —of lower priority, as knowledge exists already	EP 1, RS 1
3.2.2.5	Are there any latent effects of DDT and other pesticide use on seagrass? (Biota likely to be better indicators than seagrass)	Important issue —need to link with current Adelaide University studies (Dr Brian Williams)	EP 1
3.2.2.6	What is the bioavailability of heavy metals? Are metals locked up in the Gulf St Vincent sediments?	Interesting issue —answer would emerge from tissues sample reconnaissance and from Pat Harbison's sediment work Linked to all issues in 3.2.7	EP 1, RS 1, PPM 1
3.2.3 Ecotoxicology			
3.2.3.1	What is the relative toxicity and fate of each of the various stormwater contaminants (for example, rubber, hydrocarbons)?	Critical issue —to be addressed as part of storm water characterisation process	EP 1
3.2.3.2	Is it pollution load or concentration that is important in water quality management?	Critical issue —to be addressed broadly in study	[EP 1], PPM 2
3.2.4 Salinity—dispersion and interactions/impacts modelling			
3.2.4.1	What is the impact of low salinity levels on seagrass communities (and different species within communities)?	Critical issue —initially requires strategy to confirm that salinity drop is real	EP 1, RS 1, PPM 1, PPM 2

Issue ID #	Common research theme area and specific issues	Comments/priority	Addressed by Research Task(s)
3.2.4.2	What is the cumulative impact of the low salinity and high turbidity discharges from the various coastal stormwater outlets on seagrass health?	Critical issue	EP 1, RS 1, PPM 2
3.2.4.3	What are the interactions with the larger body of water in Gulf St Vincent and do these have any effects on the coastal waters?	Critical issue	PPM 2
3.2.5 Seagrass dynamics/ecology			
3.2.5.1	Why have we lost, and why do we continue to lose, nearshore seagrass?	Critical issue —requires historical analysis and examination of current pressures	EP 1, RS 1, PPM 2
3.2.5.2	Is seagrass loss due to freshwater inputs, nutrients, increased turbidity, other pollutants, other effects including coastal processes or a combination of all of the above?	Critical issue —answer will illuminate issue above	EP 1, RS 1, PPM 2
3.2.5.3	Are seagrasses sensitive to salinity changes—what is the tolerance range of Adelaide’s seagrass species?	Critical issue —to be addressed as in 3.2.4 / salinity loggers	EP 1, RS 1, PPM 2
3.2.5.4	Is the relatively recent trend to discharge freshwater directly to the Adelaide coastline causing significant disturbances to inshore seagrass?	Critical issue —may confirm current understanding of cause and effect relationship(s)	EP 1, RS 1, PPM 1, PPM 2
3.2.5.5	What effects will seagrass loss and associated seabed behaviour have on the active beach zone? What implications will this have regarding the CPB’s coastal management responsibilities?	Important issue —will require linkage with OCM and CPB	RS 1
3.2.5.6	Is the loss of seagrass linked to increased coastal sand losses and accelerated erosion rates?	Important issue —will require linkage with OCM and CPB	RS 1
3.2.5.7	Is seagrass loss progressive or episodic (for example, driven by storm events or high stormwater discharge)?	Critical issue	RS 1, PPM 2
3.2.5.8	Is the seagrass loss we see a result of heavy chemical and pesticide/herbicide use in the catchments and coastal zones during past decades (for example, 1960s to 1980s)?	Important issue —to be addressed as in 3.2.3	EP 1
3.2.5.9	Is the loss of seagrass linked with loss of coastal dunes for sand replenishment and wave energy attenuation?	Important issue —requires linkage with OCM and CPB	RS 1
3.2.5.10	Is it possible to get the seagrasses back, and what effect will this have on coastal processes, sand dynamics and movement?	Important issue —requires linkage with studies by SARDI Aquatic Sciences and by OCM and CPB	RS 1, PPM 1
3.2.5.11	Is re-colonisation of seagrass dependent on the existence of a residual seagrass root mat?	Important issue —requires linkage with studies by SARDI Aquatic Sciences and by OCM and CPB	RS 1, PPM 1
3.2.5.12	Are nutrients from WWTP outfall discharges the only cause of epiphytism on seagrass and is epiphyte loading the sole cause of smothering and demise of affected plants/communities?	Critical issue —to be addressed in related seagrass and nutrient studies	RS 1, EP 1
3.2.5.13	Does the time of year when discharges occur make an important difference to their effects on the marine environment(s)?—for example, is it sustainable to discharge in winter but not during summer algal growth periods?	Important issue —to be addressed in light of a better understanding of the system(s)	EP 1, PPM 1, PPM 2
3.2.6 Algal blooms			
3.2.6.1	What is the link between nutrient discharges and brown algal blooms (particularly <i>Giffordia</i>)?	Important issue	EP 1
3.2.6.2	Is <i>Giffordia</i> causing the nuisance brown algal blooms?	Interesting issue —linked to issue above	EP 1
3.2.6.3	What is the cause of the <i>Ulva</i> growth apparently smothering the reefs between the Onkaparinga River and Seaford?	Interesting issue	EP 1
3.2.6.4	What are the algal blooms (sea lettuce— <i>Ulva</i> sp—and other organisms occurring as red tides) in the Port Adelaide River caused by?	Side issue	
3.2.6.5	Are there any factors other than or in addition to nutrient enrichment contributing to algal blooms (for example, temperature, salinity and/or turbidity)?	Critical issue	EP 1, RS 1, PPM 2
3.2.7 Water quality—objectives/standards, assimilative capacity and maximum contaminant loads			
3.2.7.1	What are the relative contributions of stormwater flows and wastewater discharges to environmental disturbance?	Critical issue —to be addressed through analysis of CWMB and/or SA Water data, nitrogen budget and outcomes of EP 1	[IS 1]
3.2.7.2	What are the principal agents of concern in stormwater? Are pesticides, suspended solids, nutrients, heavy metals or unknown inputs/interactions creating the most significant environmental degradation?	Critical issue —to be addressed in related research	IS 1, EP 1, PPM 1
3.2.7.3	In the absence of reasonably achievable stormwater quality standards for urban stormwater, what contaminant loads can sustainably be assimilated by the marine environments?	Important issue	EP 1
3.2.7.4	What are the relative impacts of the different outfalls along the coast in terms of assimilative capacity? Are discharges in deeper fast flowing water less detrimental than those in shallow slow moving water? Is relocating discharges from Port Adelaide River to Bolivar a good idea?	Critical issue —to be addressed through circulation and ecosystem modelling (see also MFP Study)	IS 1, EP 1, RS 1, PPM 2

Issue ID #	Common research theme area and specific issues	Comments/priority	Addressed by Research Task(s)
3.2.7.5	Is road runoff a significant and unsustainable threat to the coastline? If so, what is the extent of the impact and what can we do about it (for example, road runoff diversions and soakage swales to minimise marine discharge)?	Critical issue —to be addressed in stormwater characterisation and risk assessment. Details of management options likely to be restricted by resources.	
3.2.7.6	Are there any distinguishable constituents (soluble/insoluble) in stormwater runoff that are of particular environmental concern? How should these constituents be managed (for example, segregation, treatment before disposal, or diversion and re-use)?	Critical issue —to be addressed in storm water characterisation and risk assessment. Details of management options likely to be restricted by resources.	RS 1
3.2.7.7	How significant are the effects of turbid water discharge plumes on coastal biota (seagrass, macroalgae)?	Critical issue —to be addressed in related research (refer to 3.2.5)	EP 1, RS 1, PPM 1, PPM 2
3.2.7.8	What is the relative contribution of road runoff to any turbidity induced impacts?	Critical issue —to be addressed in storm water characterisation and risk assessment	IS 1, EP 1
3.2.7.9	Are the treated effluent discharges the only cause of the coastal water decline?	Critical issue —to be addressed broadly across the study	RS 1
3.2.7.10	Will the SA Water EIP nutrient input reductions make stormwater pollution and associated impacts relatively more or less significant in years to come?	Important issue —to be addressed through overall loading balance assessment and once degradation drivers are identified (EP 1)	
3.2.7.11	Are coastal and catchment wetlands (for holding and retention) the most effective method to treat urban stormwater before release to coastal waters?	Interesting issue	
3.2.7.12	What are the important issues that the Comprehensive Catchment Water Management Plan(s) should be looking at? How should the CWMBs invest their limited funds?	Critical issue —to be addressed through storm water characterisation and risk assessment processes	
3.2.7.13	What should drive management objectives for the Torrens, Patawalonga and Onkaparinga Rivers, given that it is not practicable to follow the ANZECC (Australian and New Zealand Environment and Conservation Council) Guidelines?	Critical issue —to be addressed through storm water characterisation and risk assessment processes	EP 1
3.2.8 Recreational water quality and environmental health			
3.2.8.1	What is a reasonable protocol, for coastal metropolitan local government councils, to manage recreational water contact along the coastal foreshore to minimise health risks?	Side issue	
3.2.8.2	At what level of health risk is it reasonable to allow the resumption of public swimming following stormwater pulses?	Side issue	
3.2.8.3	Will the provision of effluent holding tanks and effluent pump-out facilities on recreational boats result in an appreciable improvement in coastal water quality?	Side issue	
3.2.9 Indicators of disturbance (health)			
3.2.9.1	Are there other indicators of marine environment disturbance in addition to seagrass decline/loss?	Critical issue	EP 1, RS 1
3.2.9.2	Will the study attempt to quantify marine species biomass along the coastal waters as an indicator of disturbance?	Interesting issue	EP 1, RS 1, PPM 1
3.2.10 Coastal processes and sediments			
3.2.10.1	What is the effect of large-scale sand dredging in terms of re-mobilisation and denitrification processes?	Important issue —to be addressed through development of sediment budget	PPM 1, PPM 2
3.2.10.2	Are there any suitable areas for the dumping of dredge spoil within the study area?	Interesting issue —would need to integrate with consultancy task (Halliburton KBR)	RS 1, PPM 2
3.2.10.3	What is the effect of the Port Adelaide River system on the Gulf St Vincent and nearshore coastal waters?	Important issue —may be addressed through hydrodynamic modelling task	
3.2.11 Marine habitats—status of reefs, estuary, inlets, wetlands, mangroves			
3.2.11.1	What is the sensitivity of mangroves to hypersaline and high temperature water discharges?	Side issue	RS 1
3.2.11.2	What will be the likely cumulative impact of the current and proposed power generating plants along the Port Adelaide River? Is there likely to be incremental increase in ambient Port Adelaide River temperatures and, if so, what effects will this have on algal dynamics and survival of other marine organisms (including undesirable introduced marine pests)?	Side issue	PPM 2
3.2.11.3	What is the status of the various reef systems along the Adelaide coastline (including the Port Adelaide River estuary mangroves and areas potentially affected by oil spills from the Port Stanvac oil refinery)? What are the principal causes of any identified degradation?	Side issue	RS 1
3.2.11.4	What impact is <i>Ulva</i> growth having on reef and mangrove systems along the coastline and Port Adelaide River?	Side issue	RS 1
3.2.11.5	Are current stormwater discharges further degrading Barker Inlet and its disturbed/natural ecosystems?	Side issue	
3.2.11.6	What is the capacity of the Port Adelaide River and Barker Inlet receiving environment to assimilate industrial process, treated wastewater and stormwater discharges?	Side issue	

Issue ID #	Common research theme area and specific issues	Comments/priority	Addressed by Research Task(s)
3.2.11.7	What is the relative impact of stormwater nitrogen loads and discharges on the Barker Inlet system, compared to effluent incursions from the nearby Bolivar WWTP?	Side issue	IS 1 (in part), RS 1
3.2.11.8	How can degradation of the Barker Inlet be stopped? What is the 'safe' discharge level, where no further degradation is expected and where rehabilitation can occur (enhanced or natural)? Is natural rehabilitation of the degraded ecosystem possible?	Side issue	
3.2.11.9	Are any of the observed disturbances to local Port Adelaide River/Angas Inlet mangroves a result of climatic/natural variation and not ambient water temperature changes?	Side issue	RS 1

The ACWS research program

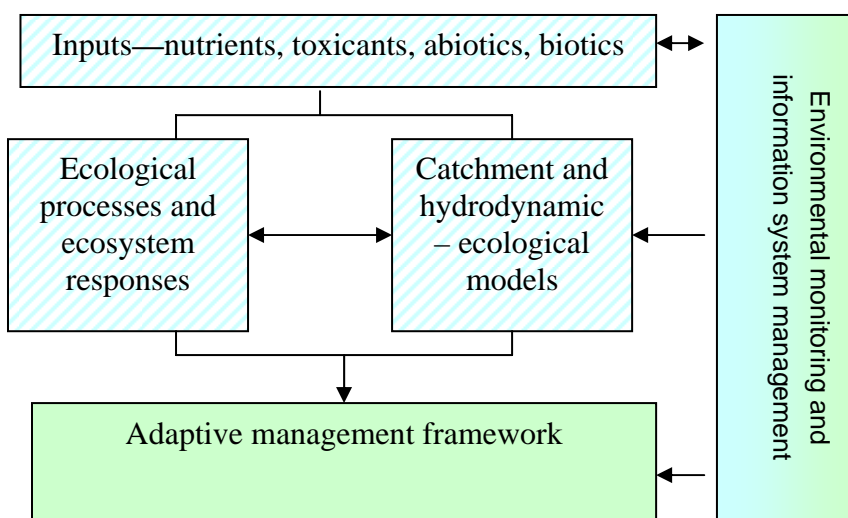
This section presents the individual research tasks constituting the Stage 2 research plan. It also shows how the tasks will be scheduled to allow for successful integration of previous and current research and for the results emerging from proposed tasks to be used as inputs to subsequent and dependent tasks.

Coordination and research management

There will be a high-level coordination and research management task with the objectives of overseeing the linkages between tasks and the appropriate consideration and application of statistical design and analysis in research and monitoring tasks. The coordination task will also include overseeing data collection and ensuring that appropriate quality assurance and quality control procedures and standards are maintained throughout the study.

Stage 2 research tasks

Conceptually, the research tasks specified in this Approved Stage 2 and 3 Research Plan fit within a number of functional areas. The relationship between these functional areas is presented in Figure 3 below.



Hatched = Stage 2 task. Solid = predominately Stage 3 task.

Figure 3, Stage 2 research task components, Stage 3 synthesis tasks and interrelationships

The majority of research tasks are to be supported by focused environmental monitoring and data collation, with task results being collated, managed and disseminated within an integral environmental information system. Through integration, all tasks will contribute to the adaptive management framework.

The research and synthesis tasks to be implemented during Stages 2 and 3 are presented in Table 3 below.

Table 3 Research tasks for the Adelaide Coastal Waters Study

Task code	Research/activity title
Stage 2 Research tasks	
Input studies—quantity and quality	
IS 1	Quantification of diffuse and point source terrestrial, groundwater and atmospheric inputs to the coastal waters
IS 1—SP 1	Stormwater flows from major and minor catchments: audit and monitoring
IS 1—SP 2	Audit of the quality and quantity of effluent discharging from WWTPs to the marine environment
IS 1—SP 3	Groundwater discharge to the coastal environment: flow quality and quantity assessment
IS 1—SP 4	Wetfall and dryfall input directly into the coastal zone
Ecological processes	
EP 1	Assessment of the effects of inputs to the Adelaide coastal waters on seagrass ecosystems and key biota
Environmental information systems	
RS 1	Remote sensing study of marine and coastal features, and interpretation of changes in relation to natural and anthropogenic processes
Physical processes and modelling	
PPM 1	Coastal sediment budget
PPM 2	Physical oceanographic studies in the Adelaide coastal waters, using high resolution modelling, field observations and satellite techniques.
Environmental monitoring program	
EMP 1	Environmental monitoring program—spatial/temporal design; statistical analysis; quality assurance and control
Stage 3 Synthesis and reporting tasks	
AMF 1	Development of adaptive management framework
DST	Development of decision support tools for management
DST MM 1	Development of a coarse resolution management model for the Adelaide coastal waters
DST DB 1	ACWS database and spatial information system

Tasks in the program have been designed to quantify and characterise inputs to the coastal and offshore waters from stormwater/catchment flows, treated effluent discharges, and groundwater and atmospheric sources. Tasks have subsequently been scoped to assess the impacts of these inputs on seagrass ecosystems and species assemblages, coastal processes, and sediment and nutrient budgets. Tasks incorporate field and remote collection of essential information to inform both ecological assessment tasks and process studies and the hydrodynamic-ecological modelling of inputs, system forces and responses. It is considered important to obtain an accurate baseline during this study against which the effectiveness of management efforts can be assessed. Therefore, there is a requirement, involving considerable effort, to obtain a spatial perspective through mapping of the current situation.

Stage 3 tasks remain fundamentally unchanged from those proposed in the ACWS Scoping Study Report, approximately four years ago. It is as important now as it was then for the design and implementation of the ACWS to recognise and support an adaptive management framework, and to develop a suite of decision support tools to provide managers with the best information available to guide management decision making.

Implementation program for Stage 2 research tasks

The components of the Stage 2 research program are strongly linked. Links, dependencies and contributions are discussed under the headings of the individual research tasks. Task IS 1 is to proceed in stages, with field monitoring and data collection activities to be defined following an intensive literature and data review.

The timing of, and linkages between, the various Stage 2 and 3 tasks are presented pictorially in Figure 4 below. This Gantt chart highlights the key activities to be presented for each task and defines specific milestones, where one task's outputs are required for the implementation of one or more dependent tasks. For example, the selection of sites for field survey and sampling locations will not be attempted until a reliable habitat base map of the study area is provided as an outcome of task RS 1.

Coordination and exchange of results between study tasks will be facilitated through a quarterly scientific meeting and the co-production of a quarterly newsletter for wide distribution. The first of these coordination meetings will, importantly, provide an opportunity for all researchers undertaking coastal waters based studies, surveys and assessments to share information on site selection, data needs and individual field programs (to enable sharing of resources and greater efficiencies).

The two-year field program represents the minimum period to ensure scientific rigour in obtaining the information required about the nutrient and toxicant status of the coastal waters. It will allow for the assessment of spatial and temporal variability in parameters and key processes (biomass changes, chemical flux and partitioning). Assessment of this variability is fundamental to the evaluation of parameter trends and the resolution of functional integrated models that will support the development of long-term management options for the coastal waters.

Outputs of research tasks

Outputs from the various research tasks will be dependent on the activities undertaken, but will generally include a scientific report including any data and its interpretation. Expected outputs are discussed under the heading of each individual research task.

Results from individual tasks will be integrated and incorporated into models to provide a capacity to make predictions (for example, about the ecological effects of reducing nutrient loads) that can assist management decision making. It is envisaged that, following the study, the models will be maintained and (predominantly) used by the South Australian EPA.

The series of outputs from the research tasks will be synthesised into a comprehensive Final Report that will integrate individual findings and the key outcomes documented in the technical reports. This Final Report will be a valuable resource for the region's managers and stakeholders.

All data will be incorporated into a comprehensive database that will allow efficient future recovery of information for use in the long-term management of Adelaide's coastal waters. A study-specific spatial/environmental information system will be developed for data and information management. It will be designed for subsequent integration with existing State management data storage and presentation tools (that is, the Coastal Atlas and the South Australian EPA's Environmental Data Management System).

Modelling

The hydrodynamic and numerical models to be applied in the study were selected as they incorporate the following fundamental features:

- the ability to model, accurately, transport of a scalar quantity in a flow field on a fixed grid;
- the ability to model, accurately, turbulence under a full range of hydrodynamic conditions;
- the proper modelling of the flooding and drying of intertidal flats with absolute mass conservation; and
- resolution to fit different scales and purposes.

Study deliverables

The ACWS study will deliver:

- predictive models for waves, circulation and transport of dissolved and particulate constituents for the Adelaide coastal waters and Gulf St Vincent;
- a sediment dynamics model for the study region that includes sediment re-suspension, deposition and transport, and that couples with the physical transport and nutrient cycling models;
- a nutrient cycling model for the study region that couples primary production and other key biogeochemical processes with the physical transport and sediment dynamics models;
- an assessment of the existing toxicant concentrations in the water column, sediments and biota, together with their sources and likely impacts (this is a simpler aim than those for the effects of nutrients and sediment dynamics above, because we start from a much more limited knowledge base about toxicants; addressing dynamics and impacts of toxicants might be proposed as a follow-up study if results indicate it is a serious issue);

- a suite of decision support tools that will assist managers in visualising and assessing the output of other models, in terms of prospective management actions and the risks associated with those actions;
- an ongoing program to monitor key water quality and ecosystem parameters, and to provide measurements needed to use and/or assess management actions and the management tools described below; and
- a database of historical and study data with graphical interface on the Worldwide Web and on CD-ROM.

Appendix A Proposed Stage 2 and 3 research tasks

CONTENTS OF APPENDIX A

STAGE 2 RESEARCH TASKS:

INPUT STUDIES:

- IS 1

ECOLOGICAL PROCESSES:

- EP 1

REMOTE SENSING:

- RS 1

PHYSICAL PROCESSES AND MODELLING:

- PPM 1
- PPM 2

ENVIRONMENTAL MONITORING PROGRAM:

- EMP 1

STAGE 3 SYNTHESIS AND REPORTING TASKS:

ADAPTIVE MANAGEMENT PROGRAM

- AMF 1

DECISION SUPPORT TOOLS

- DST MM 1
- DST DB 1

Input studies ***IS 1 — Quantification of diffuse, point source, groundwater and atmospheric contaminant inputs***

Task description

IS 1 is an integrated program of studies to determine both the quantity and quality of stormwater, wastewater, groundwater and atmospheric fallout entering the coastal study area.

This study comprises four sub-programs:

- sub-program 1: ‘Stormwater flows from major and minor catchments: audit and monitoring’;
- sub-program 2: ‘Audit of the quality and quantity of effluent discharging from wastewater treatment plants (WWTPs) into the marine environment’;
- sub-program 3: ‘Groundwater discharge to the coastal environment: flow quantity and quality assessment’; and
- sub-program 4: ‘Wetfall and dryfall input directly into the coastal zone’.

The task will be initiated by an intensive literature and data review that builds upon the substantial review work commenced during Stage 1 of the study, by and for a number of organisations represented on the ACWS Scientific Committee. During the first three months of the study, available data will be further compiled, interpreted and presented for incorporation and use in the ecological assessment and hydrodynamic modelling tasks. The literature and data review will identify information gaps and inconsistencies and allow a program of research to be identified, approved and implemented to fill these gaps.

The degree of effort allocated to any of the four sub-programs described below will be wholly dependent on the outcomes of the literature and data review.

This suite of sub-program tasks should seek to identify the drivers for management of the Torrens River, Patawalonga catchment system and Onkaparinga River, as the ANZECC Guidelines can’t reasonably be achieved in a system heavily influenced by contaminated stormwater inputs.

Data management

Proponents of all sub-programs within the IS 1 task are required to assist the project managers to provide the client with a database in GIS Arcview or ArcInfo format containing all new data collected for the study.

The database shall come complete with metadata down to the Page 0 and Page 1 ANZLIC levels. Data and metadata are to be provided in MS Access format in line with the ANZLIC Metadata Page 0 and Page 1 levels. Metadata complying with

these standards is to be provided to the project managers for each data set developed in the course of Task IS 1.

Data provided by task proponents shall be in a format that requires minimal editing for compatibility with the EPA's Environmental Data Management System. Guidelines for database formatting will be provided to all proponents by the project managers at the commencement of the study and must be consistently applied.

Sub-program 1: stormwater flows from major and minor catchments: audit and monitoring

Task description

This project will conduct a thorough audit and compilation of existing data, current and historical, for:

- major catchments;
- minor catchments; and
- stormwater drains;

in order to identify gaps and determine the quality of these data. It is anticipated that there are many gaps in the present data, particularly with respect to the minor catchments and drainages discharging directly into the coastal zone. Following the audit, where required, selected catchments and stormwater drains will be monitored and sampled.

Stormwater flows and peak flows will be monitored, sampled and analysed for their loads of nutrients, inorganic species, suspended solids (sediment load), heavy metals, organics and microbiological indicators. This will contribute to the understanding of the relative importance of various diffuse sources of pollutant and nutrient load to the coastal environment. In addition, sediment samples from Gulf St Vincent will be analysed for the same suite of indicators as the stormwater sediments. This will be coordinated with the sediment mapping and characterisation program.

Issues to be addressed

Issues to be addressed by this research task include the following (from the Stakeholders Requirements Report).

3.2.1 Nutrients (in sediment and water column)

3.2.1.2 What are the relative contributions of all contaminant inputs to the system and how do these compare to the impacts of WWTP-sourced nutrients in terms of significance of effects?

3.2.1.3 How does stormwater's contribution to nutrients in the Gulf compare in significance to discharges from the wastewater treatment plants? Is nitrogen the only nutrient input of concern?

3.2.7 Water quality—objectives/standards, assimilative capacity and maximum contaminant loads

3.2.7.2 What are the principal agents of concern in stormwater? Are pesticides, suspended solids, nutrients, heavy metals or unknown inputs/interactions creating the most significant environmental degradation?

3.2.7.4 What are the relative impacts of the different outfalls along the coast in terms of assimilative capacity? Are discharges in deeper fast flowing water less detrimental than those in shallow slow moving water? Is relocating discharges from Port Adelaide River to Bolivar a good idea?

3.2.7.8 What is the relative contribution of road runoff to any turbidity induced impacts?

Rationale

The audit will provide data to inform modelling of catchments and provide historical insight regarding the status of inputs before seagrass decline. The present input load will aid prediction of its likely impact on coastal ecosystems. Little water

quantity and quality monitoring has been done on small catchments and stormwater drainages that flow directly into the coastal zone. Water monitoring of non-storm and storm flows has been done to varying degrees in all the major catchments. Detailed and accurate sampling of peak stormwater flows requires special effort and equipment, because weekly or even daily flow data will generally miss peak flows. This is especially relevant because Adelaide's catchments are generally small and, as a consequence of urbanisation, topography and drainage density, the response time of streams to major storm events is rapid. Furthermore, the small catchments and stormwater drainages targeted as part of this project only flow during storms. In addition, monitoring and sampling instruments have limited capacity, or can become disabled, during peak storm events. Thus, special care and instrumentation is needed to collect such data. In addition, the dispersal and transformation of these inputs in the coastal zone is critical to an understanding of the nutrient budget (EP 1).

Linkages and dependencies

This study will quantify the stream loads into the coastal zone and the dispersal of the solid fraction in the coastal zone, with an emphasis on peak stormwater flow events.

This project is linked with tasks RS 1, PPM 2 and DST MM 1.

Current status

The minor catchments and direct stormwater discharges are relatively small, and have largely been ignored in the planning assessment of coastal impacts. Nonetheless, the areas drained are significant and the volumes and concentrations entering the coastal zone may be very significant. At present, both the input loads and the dispersal of inputs are poorly understood.

The determination of loads from major catchments has commenced; however, the period of time over which the data are available varies between catchments. The frequency of data collection, specifically with regard to contaminants other than nutrients, needs addressing.

Information gaps

- Some information on the location of smaller drainages and potential flow volumes exists in municipal planning documents. However, actual flow and concentration data is only known for Christies Creek.
- The concentration and distribution of heavy metals, and of organic matter and its nutrient load, are poorly known for the surface sediment in Gulf St Vincent.
- Interpretation is required of total load data (nutrients, sediment, and chemical and microbiological contaminants) with respect to both major and minor coastal discharge and loads.

Task outcomes

Outcomes expected from this task include:

- determination of the relative inputs from major and minor catchments and small drainages to the overall input to the coastal zone (quantity and quality);

- assessment of the influence of land use/management and the degree of urbanisation on input loads of nutrients, sediments and contaminants (organic and microbiological);
- concentrations of nutrients, heavy metals and microbiological indicators and their distribution in the coastal zone;
- support for management strategies to aid in reduction of stormwater loads; and
- information to support the development of management strategies within and between catchments.

Task outputs

Outputs expected from this task include:

- meta-analysis of existing data, with specific reference to loads discharged to the coastal zone;
- information to allow modellers to hindcast and forecast daily loads of parameters for each discharge point to the Adelaide coastal waters;
- detailed report presenting results;
- characterisation of different parts of the coast in terms of catchment and drainage inputs;
- database against which to judge the efficacy of future integrated catchment management strategies, as measured by reductions in stormwater sediment, nutrient and contaminant loads to the coastal environment;
- spatial database with which to map the dispersal of sediment loads from input sources and to assist in estimating the likely impact on ecosystems; and
- contribution of data to ACWS management model (DST MM 1).

Methodology

Review of existing data and literature

Stage 1 of the ACWS acknowledged that there was likely available a significant body of information regarding the quality and, probably to a lesser extent, quantity of stormwater flowing from the major catchments into the coastal zone. It is anticipated that the quantity, quality and value of the available data will have improved following the formation of the respective catchment water management boards (CWMBs). An inventory of existing material held by various organisations (for example, CWMBs and the then Department of Environment and Natural Resources), including consultancy and university project reports, was compiled by Flinders University as ‘in-kind’ support and made available to Stage 1 of the ACWS. This phase of the sub-program will review, collate and interpret data available for both major and minor catchments. The data will be collated and reviewed to permit both a historical interpretation of the likely impact of stormwater upon seagrass (hindcasting) and forecasting of future effects; however, we are unable to indicate how far back in time reliable stormwater quality and/or quantity (Q/Q) data are available. During this phase of the project, where possible,

information regarding past, present and future land use within the catchments, including changes in urbanisation, will also be collated.

Following the collation and interpretation of the existing data—‘needs analysis’—a detailed program to address the information gaps within minor and major catchments will be formulated. This will be completed in time for the field research program to be implemented for storm events in 2003.

Determination of the relative inputs from major and minor catchments and small drainages to the overall input to the coastal zone (quantity and quality)

Study area

The Torrens, Patawalonga and Onkaparinga will be the major catchments studied. Representative minor catchments and drainages into the coastal zone will be selected following the literature and data review. Selection will consider factors such as size of catchment, land use and urbanisation, and riverine, piped or channelled discharge. Also, to facilitate comparison, drainages with and without gross and suspended solids removal systems (for example, hydrocyclones) will be selected.

It is anticipated that seasonal Q/Q data will largely be available for the major catchments, particularly for recent years. The focus of the proposed study will be determination of Q/Q of stormwater entering the coastal zone from minor and major catchments and stormwater drainages during major storm events.

Methods—stormwater sampling

Two ISCO automatic water samplers and two ISCO bubble flow meters are available as ‘in-kind’ support to the project. The water samplers may either be operated on a timed sampling basis or integrated with the flow meters to conduct flow-proportional sampling over the range of the hydrograph for a specific storm event. They can be installed in manholes in stormwater pipes. The potential for samplers to be linked to existing flow monitoring systems, to enable flow-proportional sampling in the major catchments, will be explored. The flow-proportional configuration will be employed to study specific peak flow events. Resolution of water quality over a specific event will be dependent upon the nature of the storm event, which influences the number of flow-proportional samples collected. Limitation on resources may mean that some flow-proportional samples have to be flow-composited prior to analysis, with a consequent loss of resolution. The samplers will be used to determine Q/Q differences within and between catchments during storm events. Complementary manual sampling procedures include grab sampling, using students dispersed along catchments over the duration storm events; obviously, this will have limited application. Major storm events will be selected following consultation with the Bureau of Meteorology.

Concentrations of nutrients, heavy metals and microbiological indicators, and their distribution in the coastal zone

It is envisaged that the fate of pollutants (nutrients, suspended solids, heavy metals and microbiological indicators), together with the movement of the freshwater plume in the coastal environment, will be determined for a few specific storm events. This will provide information relevant to EP 1 and require significant integration with PPM 2.

Insufficient resources will be available to conduct a detailed sampling (for example, coastal transects) and analytical program to map contaminants in the surface sediments of the coastal zone. Some limited sampling and analysis of surface sediments relative to major terrestrial input sources, and informed by tracking the plume caused by specific storm events, will be conducted. In addition, selected sediment samples collected during EP 1 studies will be analysed for contaminants. An alternative strategy is to determine the quantity and quality of terrestrial inputs and then use this information as inputs to the hydraulic models of sediment transport within the coastal zone. The model output can then be used to target sample predicted convergent or dispersive sediment zones for contaminant content. This would have the additional benefit of partially validating model predictions. The sediments collected from these sites would be analysed for the suite of contaminants indicated below and for sterols (faecal and plant) and ^{15}N as potential markers of the origin of the terrestrial inputs.

Nitrogen availability is one of the major factors regulating primary production in many aquatic and coastal environments (Herbert, 1999). These regions commonly receive large anthropogenic inputs of nitrogen that can cause eutrophication. Stable isotopes of nitrogen have been used extensively to trace the principal sources of nitrogen in aquatic systems, to identify the trophic level of organisms and to identify areas where nitrogen cycling is occurring (Michener & Schell, 1994; Macko & Ostrom, 1994; Fourqurean et al., 1997; Kendall, 1998). Recent studies have shown that microbial organisms (biofilms on aquatic surfaces) reach isotopic steady state with dissolved ammonia within days (Hamilton et al., 2001). Thus, microbial biomass in aquatic systems records the isotopic ratio of ammonia in the aquatic system. It can therefore be used as a record of the nitrogen isotopic ratio, and hence as a trace of the most mobile and reactive form of nitrogen. Microbial biomass is much easier and less expensive to analyse for stable isotopes of nitrogen than are dissolved species of nitrogen (ammonium, ammonia, nitrate and nitrite). Microbial biomass will also give a time average over several days of the isotopic ratio and have less variation than dissolved species of nitrogen. This pilot project would trace sources of nitrogen in selected sub-catchments by analysing the stable isotope ratio of nitrogen in various forms of organic matter (aquatic plants and microbes and sediment) as well as analysing stable isotope ratios of dissolved nitrogen species (ammonia and nitrate). Organic matter in sediments in estuary settings, as well as near shore, will be analysed, in order to establish the level of terrestrial input and the degree of mixing between marine and terrestrial nitrogen sources.

Analysis of sterols (faecal and plant) may provide the means to distinguish between sources of contamination of terrestrial inputs to the coastal zone. Coprostanol, a hydrogenated metabolite of cholesterol that is present in uniquely high concentration in human faeces, has been successfully used to trace human sewage and to estimate the extent of sewage contamination in aquatic environments (Goodfellow et al., 1977; Hatcher et al., 1977; Escalona et al., 1980; Dureth et al., 1986; Laureillard & Saliot, 1993; Chan et al., 1998). Furthermore, aquatic levels of coprostanol in marine and estuarine environments appear to correlate well with levels of sewage-derived thermotolerant coliforms and enterococci (Leeming & Nichols, 1996). Thus the determination of coprostanol is likely to be useful as a complementary or surrogate measure to existing microbiological standards of water quality. Plant sterols might also offer an opportunity to identify inputs from specific catchments. The faecal sterol profile of the Torrens and Patawalonga catchment water and sediment has been the focus of a recent study (Suprihatin et al., 2002); however, no measurements have been made of the presence or persistence of these sterols in the Adelaide coastal environment.

Analytical procedures

Where possible, *Standard methods for the analysis of water and wastewater* (American Public Health Association, 1992) will be employed. The proponent will undertake to conduct the research with due diligence. Good laboratory practice shall be conducted throughout the study.

The analytical method employed will be selected on the basis of cost-effectiveness, sensitivity, reliability and reproducibility, with due regard to the likely relevant toxic concentration. The following analyses will be conducted.

1st tier :

- Suspended solids (GFC filtered, 105°C/24h) including suitable controls for variable salt concentration.
- Nutrients soluble and particularly, where relevant:
 - nitrogen: organic nitrogen, TKN (Keljtec System), NH₄-N (spectrophotometric or steam distillation), oxides of nitrogen (NO₂/NO₃ distinguished where relevant);
 - phosphorus (spectrophotometric); and
 - carbon total, inorganic and organic, using Shimadzu total organic carbon analyser.
- Heavy metals, copper, lead, zinc, cadmium and mercury by a variety of methods including ICP-AES (Lucas Heights), atomic adsorption spectroscopy (Flinders) and potentiometric stripping voltametry (Flinders).

2nd tier

- Microbiological, total coliforms and *E. coli* by Colilert™, enterococci by Enterolert™.
- Potential tracers of the origin of terrestrial inputs in the coastal environment:
 - ¹⁵N using stable isotope MS (CSIRO Land and Water); and
 - sterol profiling using GC-MS (Environmental Health, FUSA).
- Herbicides and pesticides analysis will be conducted following consultation with the Mt Lofty Watershed Protection Office regarding usage rates, consideration of their persistence and toxicology and identification of analytical laboratories, for example, CSIRO Land and Water.

Data management and reporting

All new data for the study will be in GIS Arcview/ArcInfo format. Metadata will meet national metadata framework standards, where more general information is recorded at the highest level (Page 0, ANZLIC core metadata elements).

Additional information relevant to particular sub-programs at the jurisdictional, organisational or thematic level will be recorded at Page 1 level and be consistent with corresponding metadata elements in the ISO (International Standards Organisation) Standard. Data and metadata will be supplied to the client and overall data manager in MS Access format. The data will be managed and stored in accordance with the Statement and Guidelines on Research Practice issued jointly by the National Health and Medical Research Council (NHMRC) and the Australian Vice-Chancellors' Committee (AVCC) in 1997, and will be consistent with the Australian Guidelines for Water Quality Monitoring and Reporting (2000).

References

- American Public Health Association, 1992. *Standard methods for the examination of water and wastewater*, 18th edn. APHA, Washington DC.
- Chan, K-T, Lam, MHW, Poon, K-F, Yeung, H-Y & Chiu, TKT, 1998. 'Application of faecal stanols and sterols in tracing sewage pollution in coastal waters.' *Water Resources* 32:225–235.
- Dureth, S, Herrman, R & Pecher, K, 1986. 'Tracing faecal pollution by coprostanol and intestinal bacteria in an ice-covered Finnish lake loaded with both industrial and domestic sewage.' *Water, Air and Soil Pollution* 28:131–149.
- Escalona, RL, Rosales, MTL & Mandelli, EF, 1980. 'On the presence of faecal steroids in sediments from two Mexican harbors.' *Bulletin of Environmental Contamination and Toxicology* 24:289–295.
- Fourqurean, JW, Moore, TO, Fry, B & Hollibaugh, J, 1997. 'Spatial and temporal variation in C:N:P ratios, ¹⁵N and ¹³C of eelgrass *Zostera marina* as indicators of ecosystem processes, Tomales Bay, California, USA.' *Marine Ecology Progress Series* 157:147–157.
- Goodfellow, RM, Cardoso, J, Eglinton, G, Dawson, JP & Best, GA, 1977. 'A faecal sterol survey in the Clyde estuary.' *Marine Pollution Bulletin* 8:272–276.
- Hamilton, SK, Tank, JL, Raikow, DF, Wollheim, WM, Peterson, BJ & Webster JR, 2001. 'Nitrogen uptake and transformation in a midwestern U.S. stream: a stable isotope enrichment study.' *Biogeochemistry* 54:297–340.
- Hatcher, PG, Keister, LE & McGillivray, PA, 1977. 'Steroids as sewage specific indicators in New York Bight sediments.' *Bulletin of Environmental Contamination and Toxicology* 17:491–498.
- Herbert, RA, 1999. 'Nitrogen cycling in coastal marine ecosystems.' *FEMS Microbiology Reviews* 23:563–590.
- Laureillard, J & Saliot, A, 1993. 'Biomarkers in organic matter produced in estuaries: a case study of the Krka estuary (Adriatic Sea) using the sterol marker series.' *Marine Chemistry* 43:247–261.
- Leeming, R & Nichols, PD, 1996. 'Concentrations of coprostanol that correspond to existing bacterial indicator guideline limits.' *Water Resources* 30:2997–3006.

Macko, SA & Ostrom, NE, 1994. 'Pollution studies using stable isotopes.' In Lajtha, K & Michner, R (eds), *Stable isotopes in ecology and environmental science*.

Michener, RH & Schell, DM, 1994. 'Stable isotope ratios as tracers in marine aquatic food webs.' In Lajtha, K & Michner, R (eds), *Stable isotopes in ecology and environmental science*.

Suprihatin, IE, Fallowfield, HJ, Bentham, RH & Cromar, NJ, 2002. 'Determination of faecal pollutants in Torrens and Patawalonga catchment waters in South Australia using faecal sterols.' Submitted to *Water Science and Technology*.

Work plan

- 1 Completion of detailed literature review (months 1–3).
- 2 Nomination of required monitoring and data collection strategy and program.
- 3 Identification of suitable sites for study, focusing on segments of the coastline that have similar hydrologic properties.
- 4 Flow-proportioned sampling campaign using automatic samplers during background and peak flow events.
- 5 Analysis of water samples and calculation of loads from flow volumes.
- 6 Development of regression models for loads from each catchment.
- 7 Analysis of Gulf St Vincent sediment for heavy metal concentration, organic matter characterisation and microbiological indicators.

Quality control and assurance

Where possible, *Standard methods for the analysis of water and wastewater* (American Public Health Association, 1992) will be employed. The University undertakes to conduct the research with due diligence. Good laboratory practice will be conducted throughout the study. The data will be managed and stored in accordance with the Statement and Guidelines on Research Practice issued jointly by the NHMRC and the AVCC in 1997, and will be consistent with the Australian Guidelines for Water Quality Monitoring and Reporting (2000).

Sub-program 2: audit of the quality and quantity of effluent discharging from wastewater treatment plants (WWTPs) into the marine environment

Task objectives

The objectives of this task are:

1. to compile existing data on the quality and quantity of effluent discharging into marine and riverine environments from Adelaide's WWTPs;
2. to analyse and interpret existing data on the quality and quantity of effluent and to develop an understanding of the relationships between flow and loads discharging into marine and riverine environments from Adelaide's WWTPs;
3. to identify the constituents that are currently not being monitored in WWTP discharges and that may be of concern to seagrass and marine health (that is, identify gaps in the current WWTP monitoring program);
4. to provide details of WWTP nutrient loads to the nitrogen budget project and to develop an understanding of relationships between flow and loads; and
5. possibly, depending on the results of efforts to identify additional constituents of concern to seagrass that are not currently monitored, to inform and direct a review and possible expansion of the existing WWTP monitoring program.

Issues to be addressed

Issues to be addressed by this research task include the following (from the Stakeholders Requirements Report).

3.2.1 Nutrients (in sediments and water column)

3.2.1.2 What are the relative contribution of all contaminant inputs to the system and how do these compare to the impacts of WWTP sourced nutrients in terms of significance of effects?

3.2.1.3 How does stormwater's contribution to nutrients in the Gulf compare in significance to discharges from the wastewater treatment plants? Is nitrogen the only nutrient input of concern?

3.2.2 Pollutants (transport and fate of heavy metals, pesticides, ammonia)

3.2.2.1 Are there other parameters of concern in the coastal waters [WWTP discharges] in addition to or instead of nutrients?

3.2.2.2 What are the pollutant loads entering the coastal waters from all sources [WWTPs]?

3.2.11 Marine habitats

3.2.11.7 What is the relative impact of stormwater nitrogen loads and discharges on the Barker Inlet system, compared to effluent incursions from the nearby Bolivar WWTP?[addressing the Bolivar WWTP aspect only]

Rationale

The basic premise of the ACWS is the need to identify the sources of nutrients and other pollutants entering the marine environment, and the daily to seasonal/yearly variability of flows, before embarking on targeted management strategies.

Previously, WWTPs have been targeted as the principal cause of declining marine water quality and of seagrass and mangrove dieback (Neverauskas, 1987; Bayard,

1992). This was one of the factors that led to the implementation of Environmental Improvement Programs (EIPs) at a number of WWTPs in the Adelaide metropolitan area at a cost of about \$210 million (State of the Environment Report for South Australia, 1998). The question now being asked is, what proportion of the marine environment demise can be attributed to WWTPs and what is the relative contribution from other sources? There also needs to be an improved understanding of the importance of daily, seasonal and inter-annual variability of flows and of concentration of discharges. This project (an audit of WWTP outputs) is thus fundamental to the basis of the entire ACWS. The findings of this project (as they relate to stakeholder issue 3.2.1.3) will thus provide information necessary for the completion of a number of other key tasks (relating to stakeholder issues 3.2.1.2, 3.2.2.1, parts of 3.2.2.2 and 3.2.11.7), including the compilation of a nitrogen budget. Conversely, not implementing the proposed research task would preclude the completion of tasks to deal with issues 3.2.1.2, 3.2.2.1, 3.2.2.2 and of the nitrogen budget (a critical issue).

In addition to an audit of the existing WWTP discharge data, the project will consider the adequacy of the existing monitoring program. The Environment Protection Authority of South Australia (EPA) currently monitors annual volumes of effluent discharge and certain other water quality parameters for only those WWTPs that exceed a specific threshold quantity. WWTPs in Water Protection Areas are licensed (and monitored) if they exceed 100 equivalent persons per day, whereas those outside of Water Protection Areas are only monitored if they exceed 1000 equivalent persons per day. Furthermore, the parameters measured vary between WWTPs. Where gaps in the data set are identified, selective monitoring will be implemented to provide information about pollutant loads from WWTPs as a whole.

Linkages and dependencies

This project may be undertaken simultaneously with tasks concerned with stakeholder issues 3.2.1.2, 3.2.1.3 and 3.2.2.2 (which relate to pollutant loads from sources other than WWTPs).

The findings of this project will provide an input to the nitrogen budget (EP 1).

The findings of the task(s) to resolve stakeholder issue 3.2.2.1 (that is, to identify other parameters of concern in the coastal waters in addition to or instead of nutrients) will achieve a number of objectives for this project.

This project will require cooperation with the organisations currently monitoring WWTP discharges, particularly where monitoring programs need to be extended or additional constituents analysed. Cooperation with those already monitoring WWTP discharges will be cost- and time-effective.

Current status

Much of the data needed for this audit are readily available because the EPA requires discharges from licensed WWTPs to be monitored (albeit to a varying extent) in terms of quality and volumes of discharges. There is, however, a need for this information to be collated and evaluated to provide the total pollutant load output from WWTPs as a whole.

Information gaps

While data for a number of individual WWTPs are available, the information is not dealt with in a coherent way and a need exists for it to be collated.

Not all discharges from WWTPs are monitored to the same extent (in terms of the water quality parameters measured), so a need for additional analyses is likely. There may also be significant variations in flows and concentrations of discharges. Seasonal variation may also result in a higher concentration of contaminants in discharge flows during the dry summer months.

Certain parameters critical to the health of seagrass and other marine life, and which have not been monitored in WWTP discharges, may need to be monitored. EP 1 will inform the selection of parameters to be monitored.

To determine the relative contribution of specific pollutant loads from WWTPs, compared to other sources of those pollutants, may require adjustments or additions to the existing EPA water quality monitoring program. For example, certain heavy metals may not be routinely measured in WWTP discharges but may be found in high concentrations in road runoff. In order to determine the relative contributions of sources of such pollutants, those heavy metals may need to be measured in WWTP effluent.

Task outcomes

Outcomes expected of this task include the following.

- Information will be produced on the type and proportion of pollutants (nutrients, heavy metals, pesticides and endocrine disruptors) from WWTPs relative to other sources, and their variability. This information will be necessary for the completion of tasks relating to stakeholder issues 3.2.1.2, 3.2.2.1, 3.2.2.2 and 3.2.11.7.
- Results will provide an input to the nitrogen budget task.
- This information will provide a basis for appropriate management decisions. That is, once sectors (WWTPs, road runoff, stormwater discharges) have been identified as key contributors of particular pollutant types, management strategies can target those sources specifically (as opposed to many expensive 'blind' pollution control mechanisms currently being implemented without knowledge of their efficacy).

Task outputs

Outputs expected of this task include:

- meta-analysis of existing data, with specific reference to WWTP effluent loads discharged to the coastal zone;
- new data set for contaminants (daily flows and loads);
- collated and evaluated information in final sub-program 2 report;
- characterisation of different parts of the coast in terms of catchment and drainage inputs;

- database against which to judge the efficacy of WWTP management strategies to reduce effluent, suspended solids, nutrient and contaminant loads to the coastal environment;
- contribution of data to ACWS management model (DSS MM 1); and
- a scientific basis for the ongoing monitoring of WWTP discharges.

Methodology

This study will comprise, mostly, collation of existing data and literature review. This will require the fieldworker to visit WWTPs to gain access to their reports and data files, recording/copying files for later analysis. The collation and analysis of existing data will occur over a two-month period, with a final report of the sub-program 2 findings produced at the end of this period.

Work plan (including details of monitoring)

This is to be determined after the completion of objectives 1, 2 and 3 of this research task. Monitoring may involve expanding the current monitoring program of WWTPs (presently conducted for EPA) to include additional necessary parameters, or establishing monitoring where none currently exists.

Initially, there will be a period of consultation with the agencies (SA Water and EPA) holding the WWTP quality and quantity data to secure the release of such data to this project.

Once access has been gained to the existing data, there will be a period of transfer and data conversion where the WWTP data is converted to a format that is compatible with proponent's software. This period is necessary to ensure that the format of the final documentation is in a format that is commonly accessible by other sub-programs in IS 1. The format of data output will be determined in liaison with other sub-programs in IS 1.

To determine loads of pollutants from individual WWTPs, water quality data will be examined together with rates of discharge. Particular emphasis will be placed on total discharge of nutrients (nitrogen, ammonia, total soluble phosphorus), suspended solids and chlorophyll. Where data are available, the discharge of heavy metals, pesticides and endocrine disruptors will also be determined.

Where gaps in the water quality and quantity data are identified, it may be necessary to supplement existing data with a new data collection program aimed solely at filling the gaps. Where flow data are unavailable, flow measurement-composite sampling equipment may need to be installed for a short period. Where chemical variables are not compatible with other sub-program requirements (for example, a WWTP may give total nitrogen, whereas a second WWTP may give nitrogen as nitrate), or not comparable with other WWTP water quality data, supplemental water quality analyses will be required.

The period covered in this survey will to a certain extent be determined by the records available for both flow and water quality. Ideally, sub-program 2 would plot changes in nutrient discharges on a timeline, to enable the superposition of activities/processes (relevant to other programs) that may be related to nutrient discharge to the marine environment. For example, WWTP upgrades could be marked on the timeline together with any major land use changes within the

catchment, stormwater developments and the area of extent of noted seagrass dieback. The period of data examined in sub-program 2 will be determined, in consultation with the program manager, by the timeframe of the activities/processes data.

Timing

- Consultation with SA Water and EPA for WWTP data release (one month).
- Collation and conversion of data into a format compatible with other sub-programs, analysis of existing data and calculation of flows and loads (four months).

The duration of the study examining existing data will be five months. Following this collection and analysis period, a report will be written and submitted within a month. Thus, completion of the final report is expected to be six months from receipt of funds. If, however, additional sampling is required, the duration of sub-program 2 will need to be extended according to the extent of sample collection, water analysis and flow monitoring required (possibly a further two months).

Spatial coverage

All WWTPs within the study area that discharge directly or indirectly into the marine environment along the east coast of Gulf St Vincent will be included. In addition to the WWTP discharging directly into the marine environment, a number of WWTPs that are realistically expected to have an impact on inland riverine, estuarine and other aquatic systems that ultimately discharge into the marine environment will also be monitored.

Resources required to implement task

The successful completion of sub-program 2 is subject to access to WWTP data. It is assumed that appropriate clearance for access to WWTP files containing water quality and discharge data can be negotiated by the Management Committee of the ACWS.

Project management and reporting

1. Appropriate prior notification from the project management team of the anticipated start date to the project is required (where the start date is defined as a time when funds have been received by the researchers). This will enable timely project management and apportioning of time in the context of other duties. Continuous delays over a number of months and uncertainties in a possible start date for the project would make time management difficult.
2. A suitably qualified person is immediately available to start work on sub-program 2. This means that, once the funds have been received for the project, work will be able to commence without any delay.
3. The manager of sub-program 2 will communicate with the program manager on a monthly basis (over three months) for the purpose of update and information exchange on the progress of the project. The overall IS 1 program leader will be responsible for communicating with the Scientific Steering Committee.

4. Ten per cent of the sub-program 2 manager's time, over a period of five months, will be allocated to the project.

Quality control and assurance

- The ability to quantify the nutrient loads being discharged from the WWTPs will depend on that data being available and permission being granted to access the data.
- The quality of the data collected will be determined by the quality of the records available for access from the WWTPs. It is possible that the chemical variable analysed may be in different forms at different WWTPs (for example, total nitrogen versus nitrate ion only).
- The format of WWTP data needs to be compatible with Flinders University software. Some difficulties/delays may be encountered in the conversion process.
- If there are inadequacies in the available data, these will be identified as a finding of the study, and appropriate recommendations will be made to rectify the problem. The quality of the sub-program 2 data may have consequential implications for the sub-programs into which it feeds information.
- Any gaps in record collection will be identified.
- Where gaps in the data are identified, a supplementary sampling program will be conducted, subject to the availability of equipment and adequate funds.

Sub-program 3: groundwater discharge to the coastal environment: flow quantity and quality assessment

Task description

This task is considered a priority, as it will support the determination of both the relative contribution of inputs to marine environment and the role of potentially nitrogen-rich groundwater in the denitrification processes.

Task objectives

The objectives of this task are:

- to determine the likely groundwater discharge (quantity and quality as well as spatial distribution) to the coastal environment from aquifers underlying the Adelaide plains; and
- to compare quantity and quality of groundwater discharge with other inputs to coastal environment (for example, stormwater, river loads and sewage) and to establish its relative importance.

Issues to be addressed

Issues to be addressed by this research task include:

- the volume and rate of groundwater discharges to the study area;
- the spatial distribution of sources and discharge points;
- the quality of the upwelling discharge (is it fresher than seawater? is it likely to be contaminated in any way?);
- the chemical properties of the groundwater discharges; and
- the quantity and quality of groundwater discharge in comparison with other inputs to the coastal environment (answers are needed in order to assess its relative importance in shaping the coastal environment).

Rationale

A number of groundwater aquifers underlie the Adelaide plains at varying depths. These are recharged in the Mt Lofty Ranges for the most part, with less input likely along the traverse between the Ranges and the coastline. Topography tends to control water table elevations in aquifers that, in turn, control groundwater flow directions. All evidence suggests that groundwater is recharged in the Ranges and discharges out to sea. Previous research supports this claim in a weakly qualitative way. However, the precise spatial distribution of this discharge, as well as its quantity and quality, remain unclear. Preliminary calculations suggest that the volumes of groundwater discharge are not trivial. Aquifers of reasonable thickness are capable of transmitting significant quantities of water. Given the length of the discharging feature, and thus its likely area, it may be anticipated that volumes of groundwater discharge are substantial.

Linkages and dependencies

This task will contribute to the study's understanding of inputs to the coastal waters. The groundwater contribution must be quantified, as it potentially represents a very significant volume of outflow to the coastal system.

Current status

A number of previous works relate to this task. Gerges (1999), an unpublished PhD thesis, examines the hydrogeology of the Adelaide aquifer systems. It does not provide details of the discharging volumes, nor their position in the coastal environment. It would, however, provide a basis for defining further work to be carried out, and basic background data needed in this project. Dillon et al. (1995) addressed aspects of water quality in Adelaide's aquifers, and Martin (1998) has included estimates of groundwater discharge to the coast from the Willunga Basin.

Information gaps

While there is some basic information available pertaining to the water quality present in the Adelaide aquifer systems, this is largely salinity data only. Neither the precise discharge volumes nor the precise nature of the discharge locations are known.

Task outcomes

Outcomes expected of this task include:

- data pertaining to quantity and quality of groundwater discharge to the coastal environment;
- interpretation of the significance of the results for nutrient loads to coastal waters and, where applicable, implications for marine sediment processes (chemical and biological); and
- supporting information for construction of a nutrient budget for the coast environment.

Task outputs

The expected output is a report on the methods employed and results, including all data sets.

Methodology

Very little is known about the rates, volumes and quality of groundwater discharge into Adelaide's coastal environments. First, the investigation will focus on estimating the volumetric discharge and quality of groundwater within the coastal aquifer, which will, in turn, allow assessment of the relative importance of groundwater discharge and nutrient fluxes into the Gulf. Second, delineation of the location and quality of submarine discharge in the coastal area will be addressed by integrating existing survey data with other data from the Adelaide coastal water project, and by conducting small-scale field experiments.

Without a very extensive geophysical and chemical onshore and offshore monitoring program, which would be very costly, it is likely that this project would

not determine the precise discharge locations or contaminant loads. A plan could be devised should this aspect of the work be deemed suitable, and critical to other parts of the project. The proposed project involves an examination of existing data, combined with a small-scale field project to make some initial direct measurements at a selected site.

Background on methods

Several approaches can be used to define the submarine groundwater discharge (SGD) in the coastal environment, operating at different scales and looking at different components of the system:

- regional scale groundwater balances and groundwater flow net analysis;
- piezometric transects at the beachfront (Ullman et al., 2002);
- seepage measurements using meters positioned on the sea floor (Corbett et al., 1999; Burnett et al., 2002); or
- measurement in sea floor seepage, or in sea surface water, of tracers such as radon and radium, which are usually present in higher concentrations in groundwater than in sea water (Corbett et al., 1999).

The advantage of the regional scale groundwater balance and flow net approach is that it leads to regional estimates of potential groundwater discharge based on readily available data. However, it relies on accurate estimation of hydraulic conductivity and hydraulic gradients in the nearshore zone, and has been shown to compare poorly with other methods (Burnett et al., 2002). In some areas, uncertainty in the water balance may be high if the volume of SGD is small compared to the other water budget terms. Groundwater chemistry may also undergo numerous reactions in the nearshore zone, so that regional groundwater quality may not represent the quality of groundwater discharge.

Seepage meters measure SGD directly (both quantity and quality), but observations are local and difficult to extrapolate to spatially variable hydrogeological settings along the coastline. Piezometric transects at the beachfront allow site-specific seepage meter measurements to be linked to the regional groundwater flow net analysis, and also permit measurement of groundwater quality in the nearshore zone. However, it has been shown that biological activity in the freshwater–seawater mixing zone increases nutrient loads in discharging groundwater (Ullman et al., 2002; Miller, 2002), so processes occurring in the sediments have to be explored.

Measurement of tracers within shallow marine waters potentially leads to an integrated measurement of groundwater seepage into the water column, as local scale variations in SGD are smoothed through the water column.

The quality of submarine groundwater discharge can be estimated from the quality of the groundwater in the coastal aquifer or at the seepage location. Again, measurement of water quality in the coastal aquifer is based on the assumption that the groundwater discharging in the coastal environment retains the characteristics of the groundwater in the aquifer.

Approach

Sub-task 1—literature study

Stratigraphic information from existing bore records and ocean floor surveys will be assessed to determine the likely areas of discharge of the different aquifer systems (that is, distances offshore).

Estimates of groundwater discharge to the coast for the different aquifers will be made using flow net analysis, using existing data on the hydraulic head distribution near the coast. Groundwater chemistry in bores near the coast will be accessed from the DWLBC database and used to estimate possible solute fluxes. Some of the existing reports which provide information directly relevant to this task include Gerges (2001), Gerges (1999) and Dillon et al. (1995).

Sub-task 2—regional groundwater survey

Existing water quality data (especially nutrient and heavy metal data) are unlikely to be sufficient for determination of groundwater solute loads, and historical data will need to be complemented by a sampling program. Approximately 30 bores will be sampled and analysed for nutrients and heavy metals, as well as dissolved radium and radon (see below). Estimates of net nutrient and heavy metals fluxes will be derived using the estimated groundwater fluxes.

Sub-task 3—site investigation

The location of the field site for direct measurement of groundwater discharge will be selected based on the findings of sub-tasks 1 and 2. It is anticipated that the site would be chosen from those identified as having the highest rate of groundwater discharge based on the regional analysis.

Near-coastal mini-piezometer nests will be installed in a transect along the beachface. Water level and salinity will be monitored through tidal cycles, and samples will be collected for nutrient, heavy metal and radon analysis.

Seepage meter measurements will be made.

Geophysical methods will be used to map the interface between the relatively fresh water discharging to the ocean and the saline ocean water. This mapping will assist in locating the piezometer network (described above).

Offshore measurements of water chemistry will be obtained using electrical conductivity and temperature loggers operating from a boat. Measurements will be obtained in a transect from the beachfront to approximately three kilometres offshore (or as determined in sub-task 1). Samples will be collected for analysis of radon, radium and nutrients.

Sub-task 4—collation and integration

Results of sub-tasks 1, 2 and 3 will be collated and incorporated into simple models to provide estimates of groundwater discharge quantity and quality. Results from seawater chemistry transects obtained in sub-task 3 will be integrated with results from the coastal water sampling program planned for PPM 2.

References

- Burnett, B, Chanton, J, Christoff, J, Knotar, E, Krupa, S, Lambert, M, Moore, W, O'Rourke, D, Paulsen, R, Smith, C, Smith, L & Taniguchi, M, 2002. 'Assessing methodologies for measuring groundwater discharge to the ocean.' *EOS* 83(11):117–123.
- Corbett, RD, Chaton, J, Burnett, W, Dillon, K, Rutkowski, C & Fourqurean JW, 1999. 'Patterns of groundwater discharge into Florida Bay.'
- Dillon, PJ, Pavelic, P, Rattray, KJ, Schultz, M, Winkler, IG, Ragusa, SR, Stanger, G & Armstrong, D, 1995. 'The quality of water in the Upper Quaternary aquifer at three selected sites in the Adelaide metropolitan area.'
- Gerges, N, 1999. 'The geology and hydrogeology of the Adelaide Plain metropolitan area.' PhD thesis, Flinders University.
- Gerges, N, 2001. 'Northern Adelaide Plains groundwater review.' Department of Water Resources, report 2001/013.
- Martin, RR, 1998. 'Willunga Basin—Status of Groundwater Resources 1998.' Primary Industries and Resources SA, Report DME 429/94.
- Miller, DC, 2002. 'Ecological consequences of estuarine groundwater discharge at Cape Henlopen, Delaware Bay, USA.' Submitted to *Groundwater*.
- Ullman, W, Chang, B, Miller, DC & Madsen, J, 2002. 'Groundwater mixing, nutrient diagenesis, and discharges across a sandy beachface, Cape Henlopen, Delaware (USA).' Submitted.

Work plan and milestones

Months 1–4

- Collect and compile available data that relate to submarine groundwater discharge to the Adelaide coastal waters. Obtain preliminary estimates of discharge quantity and quality based on existing data.
- Carry out regional groundwater sampling to address gaps identified in literature survey.
- Construct a potentiometric surface, using available and collected data, for water table elevations in unconfined aquifers and hydraulic head variation in confined aquifers.
- From the potentiometric surface, aquifer hydrogeologic properties and water quality data, establish the flow rates, and approximate discharges to the coast (quantity and quality).

Milestone 1. Complete sub-tasks 1 and 2 (end of month 4).

Months 5–10

- Select site for detailed field study, based on results of sub-tasks 1 and 2. Organise permissions with councils and Aboriginal groups, as required.

- Carry out geophysical survey to determine likely location of freshwater–saltwater interface.
- Carry out field programs involving mini-piezometers, seepage meters and offshore chemistry profiling for sub-task 3.

Milestone 2. Complete sub-task 3 (end of month 9).

Months 11–12

- Complete laboratory analysis of field samples collected in site investigation and interpretation of collected data.
- Write final report.

Milestone 3. Complete sub-task 4 and provide final report to EPO.

Quality control and assurance

Where possible, the *Standard methods for the analysis of water and wastewater* laid down by the American Public Health Association in 1992 will be employed. The data will be managed and stored in accordance with the Statement and Guidelines on Research Practice issued jointly by the NHMRC and the AVCC in 1997, and will be consistent with the Australian Guidelines for Water Quality Monitoring and Reporting (2000).

Sub-program 4: wetfall and dryfall input directly into the coastal zone

Task description

This project will conduct a thorough audit and compilation of existing data, as well as the analysis of existing suspended sediment samples, to evaluate the contribution to coastal waters of dissolved and solid loads from atmospheric sources.

Task objective

The objective of this task is to determine the relative contribution from atmospheric sources of nutrients and other contaminants to the coastal waters.

Issues to be addressed

Issues to be addressed are found within the following focus areas of the Stakeholders Requirements Report.

3.2.1 Nutrients (in sediment and water column)

3.2.7 Water quality—objectives/standards, assimilative capacity and maximum contaminant loads

Rationale

The direct input of dissolved and solid material from atmospheric sources to coastal waters is largely unknown. However, it might be significant given the severity of wind and dust conditions in the Adelaide area. Specifically, strong northerly winds with visible dust loads occur several times a year, especially during late spring and early summer. These dust-laden winds are commonly followed directly by cool fronts that produce rainfall. The questions addressed by this project are how background rates of wetfall and dryfall compare with the large northerly events just described, and what component of the dissolved and solid input to the coastal zone is contributed by atmospheric sources (stakeholder issue 3.2.1.2).

Linkages and dependencies

Sample collection for background flux rates and storm flux could be coordinated with physical oceanography data collection (PPM 2).

It will also be essential to link with and integrate existing air pollution monitoring/modelling activities for the Adelaide region.

Current status

Data on the dissolved concentrations of rainwater are available from a Flinders University PhD thesis. However, data collection for this thesis was land-based. Data on suspended sediment in the air column have been collected by the EPA for the Adelaide area. The data are reported as mass of sediment per cubic metre and only the data on lead have been analysed. There are numerous studies of soils and ocean sediment elsewhere in the world in which the wetfall and dryfall components of the solid and aqueous loads have been evaluated. Atmospheric fluxes estimated from these studies could be applied to the Adelaide area, given appropriate local baseline data.

Information gaps

The contribution of wetfall and dryfall to Adelaide coastal waters is largely unknown.

Task outcomes

The expected outcomes of this task include:

- assessment of the relative contributions to coastal waters from atmospheric sources (wetfall and dryfall), compared with other sources;
- assessment of the seasonal variation of this source; and
- identification of the sources of this input: for example, agricultural, industrial or natural.

Task outputs

The expected outputs of this task include:

- meta-analysis of existing data and comparison of other studies to the Adelaide area;
- report presenting detailed results, with data divided into seasonal components; and
- contribution of data to ACWS management model and adaptive management framework.

Methodology

The significance of wind-blown dust in the marine realm has been noted for some time (Darwin, 1846). However, both the quantification of its input and the realisation of its impact are only recent (Prospero, 1999; Shinn et al., 2000). The data collection and data analysis proposed here will provide a first approximation of the quantities and composition of dryfall and wetfall input to the Adelaide coastal zone. A quantitative assessment of pre-European and pre-Indigenous dust accession levels in the Adelaide area, as has been done elsewhere from sediment cores (Pye, 1987; Busacca et al., 1998), is outside the funding limits of the ACWS.

In the Adelaide area, the EPA has collected suspended sediment from the air column for approximately the past 20 years. Also included in this data set are suspended sediment samples from the Port Pirie area. These samples are from high volume dust samplers which trap dust on glass fibre mats. These samplers record a volume of air sampled, so that mass of suspended sediment per volume of air can be calculated. Suspended sediment samples have been continuously collected over this 20-year timeframe, for each site at a frequency of one day in every six. Each sampling period is 24 hours. The samples are archived in Adelaide under constant humidity conditions and at least one-half to three-fourths of each sample remains. The samples have been analysed for mass and lead (Rob Mitchell, EPA scientist, personal communication, 2002). Our group has preliminary approval to use one third of these samples for the analyses described here.

Our plan regarding these dust samples is to compile existing data on mass per volume and lead concentration over the years of record and evaluate this data to arrive at yearly average dust masses collected, as well as to identify dust storm events. Selected samples will be acid digested and analysed using ICP-AES (induction coupled plasma atomic emission spectrometry), in order to determine the concentration of major and trace elements. The sample masses on the glass fibre mats are insufficient in mass to analyse using XRF (x-ray fluorescence). Thus, all samples will be analysed using ICP-AES, because of the low sample mass and for data consistency. ICP-AES analysis of one hundred and eighty samples is planned: eight samples per year of the 20-year record and 20 water column and water pan samples (see below). Eight samples per year is thought to be a reasonable number to cover the variation in dust mass as well as to include at least two dust events per year. Analysing samples over the 20-year record period will ensure that some of the largest dust events are included in the database, as well as giving a time average of dust flux. Our group has routinely had samples analysed using ICP-AES at CSIRO Lucas Heights Science and Technology Centre. Detection limits are on the order of 0.02 mg/L for most elements. We anticipate that this level of detection will be sufficient for the concentrations of elements present in dust samples. Elements to be included in the planned ICP-AES analysis are Al, Ba, Be, Ca, Co, Fe, K, Mg, Mn, Mo, Na, P, Pb, S, Si, Sr, Ti and V.

Volatile ionic species, such as nitrate and other NO_x species, ammonia, chloride and sulphate, will need to be collected from water-filled pans during dust storm events, since the archived dust samples will have lost a large part of their volatile components. Thus, collection of samples during dust storm events, or dusty northerly weather patterns, will be made on-site at Flinders University, using collection pans containing de-ionised water. These collection pans will be set out for 24-hour periods during dusty storm events with associated rainfall. Ten samples will be collected this way. The de-ionised water is needed to help trap aerosols and hold volatile components. Analyses of these samples will be compared to analyses of Kayaalp (2001), from which a subtraction will need to be assigned for sea-derived components (chloride, sulphate, bromide and sodium). The pan samples will be analysed using similar acid digest methods and ICP-AES analytical techniques, as well as by anion chromatography. Anion chromatography can be done in the Earth Sciences hydrology laboratory at Flinders University and in the Environmental Health laboratory at Flinders University.

Quantitative XRD mineralogy of ten suspended sediment samples is planned, in order to determine the type and percentage of clay minerals, iron oxide and other mineral constituents of the dust. The ten samples will span the 20 years of dust records, and will be selected from the highest mass samples.

Sampling water column profiles during dust storm events will be attempted. We anticipate, however, that wave motion will stir up sediment from the shore and obscure dust that has settled into the water. For this reason, we plan two boat trips using the relatively inexpensive Flinders University vessel, in order to take samples far enough away from the shore zone so that shore and bottom sediment mixing is minimised. Two water profiles will be made, with four to six samples taken for each.

Acid digestion of mineral and organic material for cations and non-volatile anions will involve standard methods of evaporation and hydrochloric and nitric acid digestion.

We have consulted CSIRO Atmospheric Research, through Dr John Gras (Aerosol and Pollutant Exposure Team), about possible collaboration. Dr Gras has agreed in principle to collaborating with this project as the need arises. We plan to involve Dr Gras, and other relevant personnel at CSIRO, in reviewing the project findings.

References

Busacca, A, et al., 1998. 'Effect of human activity on dustfall: a 1,300-year lake core record of dust deposition on the Columbia Plateau, Pacific Northwest U.S.A.' In *Conference Proceedings: Dust Aerosols, Loess Soils and Global Change*, Washington State University, Pub. No. MISC0190.

Darwin, C, 1846. 'An account of the fine dust which often falls on vessels in the Atlantic Ocean.' *Quarterly Journal of the Geological Society of London* 2:26–30.

Kayaalp, AS, 2001. 'Application of rainfall chemistry and isotope data to hydro-meteorological modelling.' PhD thesis, Flinders University.

Prospero, JM, 1999. 'Long-term measurements of the transport of African mineral dust to the southeastern United States: implications for regional air quality.' *Journal of Geophysical Research*, 104(D13):15,917–15,927.

Pye, K, 1987. *Aeolian dust and dust deposits*. Harcourt Brace Jovanovich, New York.

Reheis, MC, 1997. 'Owens (dry) Lake, California: a human-induced dust problem.' U.S. Geological Survey Website, <<http://geochange.er.usgs.gov/sw/impacts/geology/owens/>>, accessed 22 August 2003

Shinn, EA, Smith, GW, Prospero, JM, Betzer, P, Hayes, ML, Garrison, V, and Barber, RT, 2000. 'African dust and the demise of Caribbean coral reefs'. *Geophysical Research Letters* 27(19):3029–3032.

Work plan

1. Completion of a detailed literature review.
2. Analysis of existing high volume air sampler data archived at EPA for nutrients such as phosphorus and nitrate.
3. Identification of suitable sites for study, with focus on selected jetties for measurements during storms and offshore transects to be coordinated with physical oceanographers.
4. Sampling during typical weather patterns, including the strong northerly winds of late spring. Sampling would consist of water depth profiles as well as rainfall collection.
5. Analysis of dissolved and suspended sediment in water samples.
6. Integration with other coastal input research project results.

Quality control and assurance

All new data for the study will be in GIS Arcview/ArcInfo format. Metadata will meet national metadata framework standards, where more general information is recorded at the highest level (Page 0, ANZLIC core metadata elements). Additional information, relevant to particular sub-programs at the jurisdictional, organisational or thematic level, will be recorded at Page 1 level and be consistent with corresponding metadata elements in the ISO Standard. Data and metadata will be supplied to the client and overall data manager in MS Access format. The data will be managed and stored in accordance with the Statement and Guidelines on Research Practice issued jointly by the NHMRC and the AVCC in 1997.

Ecosystems processes EP 1—Assessment of the effects of inputs to the Adelaide coastal waters on seagrass ecosystems and key biota

Relative priority

This is a priority task because of the high importance placed on seagrass ecosystems by the stakeholders and because of the number of stakeholder issues it will address. The task should be implemented from the commencement of Stage 2, as results from this will provide inputs to related hydrodynamic–ecological models.

Task description

This task represents a critical step in linking the observations of pollutant loads and inputs to Gulf St Vincent with a range of ecosystem effects, measured at various temporal and spatial scales.

The task will require field observations and measurements in combination with experimental research (field and laboratory based), to determine the tolerances of seagrass ecosystems to various levels of inputs and disturbance, including nutrients, toxicants and abiotic factors (freshwater, sediments, and so on).

It is also necessary to measure biomarkers for a variety of species that act as sentinels of toxic effects and to identify indicator species for adverse effects of nutrients and other abiotic factors (freshwater, sediments, and so on). These biomarkers and indicator species are to be selected for potential use in an ongoing monitoring program to determine the effects of various management decisions, such as reduction in nutrient load discharged, toxicants or freshwater inputs.

Objectives

The objectives of the ***field*** component of this task are to:

- identify, through field observations and measurements, changes in seagrass ecosystems (Table 4) that correlate with the various inputs to Gulf St Vincent;
- quantify nitrogen and phosphorus cycles and nutrient fluxes within the relevant seagrass ecosystems (Table 4) and locations (Figure 5); and
- determine metal and chemical content (stable isotope ratios) in biota of sediments within the relevant ecosystems (Table 4) and locations (Figure 5) (note: re-suspension and transport of toxicants will not be addressed by this task, but this objective will link into IS 1 and PPM 1).

The objectives of the ***experimental*** component of this research task are to include one or more of the following (depending on priority factors as determined by IS 1 and field monitoring).

- Determine the effects of nutrients on the physiology and ecology (abundance, growth and mortality) of plants and animals within the relevant seagrass-dominated ecosystems (Table 4).
- Determine the effects of toxicants on the physiology and ecology (abundance, growth and mortality) of plants and animals within the relevant seagrass-dominated ecosystems (Table 4).
- Determine the effects of abiotic inputs (freshwater, turbidity and sedimentation, and so on) on the physiology and ecology (abundance, growth and mortality) of plants and animals within the relevant seagrass-dominated ecosystems (Table 4).



Figure 5: Geographical boundaries of four zones nominated for Adelaide’s coastal waters.

Table 4: Focus ecosystems within each of the four Adelaide coastal waters zones.

Ecosystem	Priority	1 Northern section (including Bolivar)	2 Outer Harbour to Henley Beach	3 Henley Beach to Hallett Cove	4 Hallett Cove to Sellicks Beach
Intertidal seagrass	2	X			
Shallow subtidal seagrass	1	X	X	X	X
Deep subtidal seagrass	3	X	X	X	X
Pelagic	1	X	X	X	X

Issues to be addressed

Issues to be addressed by this research task include the following from the Stakeholders Requirements Report (July 2001), as the stakeholder requirements for the ACWS have underpinned the development of this task specification.

3.2.1 Nutrients (in sediment and water column)

3.2.1.1 What is the fate of nutrients (nitrogen and phosphorus) and what are their respective impacts on the receiving marine environment and ecosystem functions?

3.2.1.4 The EIPs for the coastal WWTP's are designed to result in the target reduction of nitrogen in discharge waters from 30 mg/l to 10 mg/l. What impact will this have on the seagrasses?

3.2.1.5 How important are any denitrifying processes in sediments along Adelaide's coastline in assimilating discharged nutrients?

3.2.2 Pollutants (transport and fate of heavy metals, pesticides, ammonia)

3.2.2.1 Are there other parameters of concern in the coastal waters in addition to or instead of nutrients?

3.2.2.3 Is nitrogen/ammonia toxicity an issue for seagrass—is toxicity directly related to concentration?

3.2.2.4 What are the effects of heavy metals on marine ecosystems (including reefs)?

3.2.2.5 Are there any latent effects of DDT and other pesticide use on seagrass? (Biota likely to be better indicators than seagrass)

3.2.2.6 What is the bioavailability of heavy metals? Are metals locked up in the Gulf St Vincent sediments?

3.2.3 Ecotoxicology

3.2.3.1 What is the relative toxicity and fate of each of the various stormwater contaminants (for example, rubber, hydrocarbons)?

3.2.4 Salinity—dispersion and interactions/impacts modelling

3.2.4.1 What is the impact of low salinity levels on seagrass communities (and different species within communities)?

3.2.4.2 What is the cumulative impact of the low salinity and high turbidity discharges from the various coastal stormwater outlets on seagrass health?

3.2.5 Seagrass dynamics/ecology

3.2.5.1 Why have we lost, and why do we continue to lose, nearshore seagrass?

3.2.5.2 Is seagrass loss due to freshwater inputs, nutrients, increased turbidity, other pollutants, other effects including coastal processes or a combination of all of the above?

3.2.5.3 Are seagrasses sensitive to salinity changes—what is the tolerance range of Adelaide’s seagrass species?

3.2.5.4 Is the relatively recent trend to discharge freshwater directly to the Adelaide coastline causing significant disturbances to inshore seagrass?

3.2.5.8 Is the seagrass loss we see a result of heavy chemical and pesticide/herbicide use in the catchments and coastal zones during past decades (for example, 1960s to 1980s)?

3.2.5.12 Are nutrients from WWTP outfall discharges the only cause of epiphytism on seagrass and is epiphyte loading the sole cause of smothering and demise of affected plants/communities?

3.2.5.13 Does the time of year when discharges occur make an important difference to their effects on the marine environment(s)?—for example, is it sustainable to discharge in winter but not during summer algal growth periods?

3.2.6 Algal blooms

3.2.6.1 What is the link between nutrient discharges and brown algal blooms (particularly Giffordia)?

3.2.6.2 Is Giffordia causing the nuisance brown algal blooms?

3.2.6.3 What is the cause of the Ulva growth apparently smothering the reefs between the Onkaparinga River and Seaford?

3.2.6.5 Are there any factors other than or in addition to nutrient enrichment contributing to algal blooms (for example, temperature, salinity and/or turbidity)?

3.2.7 Water quality—objectives/standards, assimilative capacity and maximum contaminant loads

3.2.7.2 What are the principal agents of concern in stormwater? Are pesticides, suspended solids, nutrients, heavy metals or unknown inputs/interactions creating the most significant environmental degradation?

3.2.7.3 In the absence of reasonably achievable stormwater quality standards for urban stormwater, what contaminant loads can sustainably be assimilated by the marine environments?

3.2.7.4 What are the relative impacts of the different outfalls along the coast in terms of assimilative capacity? Are discharges in deeper fast flowing water less detrimental than those in shallow slow moving water? Is relocating discharges from Port Adelaide River to Bolivar a good idea?

3.2.7.7 How significant are the effects of turbid water discharge plumes on coastal biota (seagrass, macroalgae)?

3.2.7.8 What is the relative contribution of road runoff to any turbidity induced impacts?

3.2.7.13 What should drive management objectives for the Torrens, Patawalonga and Onkaparinga Rivers, given that it is not practicable to follow the ANZECC Guidelines?

3.2.9 Indicators of disturbance (health)

3.2.9.1 Are there other indicators of marine environment disturbance in addition to seagrass decline/loss?

3.2.9.2 Will the study attempt to quantify marine species biomass along the coastal waters as an indicator of disturbance?

Rationale

There are many different inputs affecting the status of marine ecosystems along the Adelaide metropolitan coast. Nutrients, toxicants, sediments (turbidity and sedimentation) and freshwater associated with these inputs have the potential to greatly influence the distribution and abundance of flora and fauna, as well as recruitment, growth, mortality and fecundity. Seagrasses are habitat forming and have been selected for intensive investigation in this task in recognition of their role as an indicator species, and a species whose dynamics have significant local

and broad-scale management implications. This research should focus not only on seagrasses, but also on a range of species of flora and fauna that use these habitats (for example, epiphytic algae, meiofauna, macrofauna, fishes and humans).

Comparative field studies will provide evidence to link (correlate) changes in seagrass-dominated ecosystems, or species within those ecosystems, with the effects of various inputs (for example, increased turbidity, sedimentation, low salinity, elevated toxicants) and other factors such as hydrodynamics and sediment erosion. Manipulative field or laboratory experiments on the above factors (nutrients, toxicants, turbidity, sediment movement and freshwater) will provide an indication of levels of these various inputs that are likely to affect assemblages. However, it needs to be recognised that not all of the above factors will necessarily require experimental investigation. Only factors that are shown to be strongly correlated with seagrass loss or other negative ecosystem effects would warrant further investigation.

Currently, there is very limited information regarding the biological impacts of pollution in the Adelaide coastal waters. The proposed task would provide the experimental data to help establish cause and effect relationships. If the manipulative part of this proposed research task is not implemented, it will not be possible to draw definitive conclusions about the tolerances of seagrasses, as an indicator for whole ecosystems within the metropolitan coastal waters of Gulf St Vincent, to various levels of turbidity, sediment movement, salinity and potential toxicants.

The knowledge generated from this task will be valuable for the management of the marine environment. The Scoping Study and the Initial Findings Report highlight the fact that there are some complex, coupled processes, physical, chemical and biological, that are insufficiently well understood to permit confident management decisions. In other situations (for example, Port Phillip Bay), those interacting processes have shown unexpected behaviour, with major management implications.

The Adelaide coastal waters differ sufficiently from other systems studied in that there is major uncertainty about these processes, and therefore there is a need for studies of the way the ecosystem functions in terms of:

- nutrient cycling and fluxes in the sediments and water column;
- the role of benthic infauna (bioturbators) in sedimentary fluxes; and
- nutrient cycling through macrophytes and microphytobenthos.

Rationale for ecotoxicological assessment

Previous studies indicate that stormwater, sewage and industrial discharges are sources of nutrients, sediments and other pollutants such as heavy metals, pesticides and hydrocarbons. The concentrations of heavy metals such as cadmium, of copper, of mercury and of some herbicides have been reported to be high enough to affect marine ecosystem health.

Major river catchments discharge directly into the Adelaide coastal waters. Heavy metals and some pesticides have been detected in the stormwater and sediment samples from some catchments. Suites of bioassays have indicated impacts on some freshwater organisms due to the bioavailability of these toxicants (studies

conducted for Patawalonga and Onkaparinga Catchments). No studies have been undertaken to investigate the impacts of these toxicants on the marine environment. Currently, there is also not enough information available on the impacts of effluents discharged from WWTPs into the Adelaide coastal waters.

In this task, chemical analysis is required to identify different contaminants, such as heavy metals and organics, from various inputs into the Adelaide coastal waters. Ecotoxicological testing will complement the chemical assessment and identify the major sources of contamination. It will measure the impacts on selected organisms due to the bioavailability of contaminants. The bioassays will provide data on the integrated impacts of mixtures of pollutants and environmental variables such as turbidity, salinity and dissolved oxygen. Initial ecotoxicological investigations are needed to make a preliminary assessment of the spatial extent and severity of toxicity, and the relationships between toxicity and the concentration of contaminants in the Adelaide coastal waters. Use of biomarkers such as enzymes (EROD) from cytochrome P450 systems in fish liver will provide information on the impacts due to the presence of organic contaminants such as PCBs, dioxins and oil hydrocarbons. These contaminants are present at very low concentrations and can cause impacts even when below their detection limits.

Single-species toxicity tests are widely used to assess variability in the sensitivity to toxicants of different populations of species. Owing to the variation among species in their sensitivity to chemicals, a range of different effects, and to different degrees, may be expected when different species are exposed to the same concentration of a given chemical. It is therefore important to conduct bioassays with several species, perhaps from different trophic levels, to get better indication of the natural variability in the levels that cause an effect. Major errors could occur if the most sensitive species test is the sole source of information.

Previous studies have indicated sediment to be a source and sink of toxicants. In the proposed study, field surveys will be conducted to measure spatial and temporal variation in the benthic community composition. Sediment samples will also be analysed for nutrients, heavy metals and organic compounds. For the ecotoxicological component, we propose to conduct sediment toxicity testing with amphipods from all the sites selected for benthic community composition assessment. Sediment toxicity testing, along with benthic community composition and chemical analyses, will provide an integrated assessment of sediment quality in the marine environment. A 'sediment quality triad' approach, consisting of sediment chemical analyses, benthic community composition and measurement of toxicity, has been successfully used overseas in sediment assessments.

On this basis, ecotoxicological testing with a battery of bioassays should be utilised in this task to assess the effects of inputs to the Adelaide coastal waters. A suite of bioassays, with marine bacteria, algae, polychaete worm, scallop and sediment-inhabiting amphipod, may be considered for biological assessment of inputs to Adelaide's coastal waters.

Linkages and dependencies

This task requires integration with the input study tasks (IS 1), the mapping of seagrass ecosystems, sediments and water column (RS 1), and field monitoring task (as component of PPM 2), to provide physical, chemical and biological data so that appropriate concentrations/levels of factors (nutrients, turbidity, toxicants, salinity, and so on) and selection of biological entities (ecosystems/organisms) can be used to ensure meaningful experiments.

This task represents a critical step in linking the observations of pollutant load and input into ecosystems with effects measured at various trophic levels, and with the whole ecology. The data generated by this task will be used to link system inputs and the transport of contaminants attached to suspended solids, through hydrodynamic modelling, with the effects of these inputs on ecological processes for the various ecosystems across the five regions (Figure 5). That is, this task will provide essential data and knowledge for the development and calibration of the physical processes and modelling task (PPM 2).

The task will also provide comprehensive and detailed data with which to compare the effects of a reduction in nutrient loads from WWTPs in the future. This is important because many of the ecological changes associated with a reduction in nutrient loading may take many years to become apparent.

Current status of knowledge

Nutrients

Globally, there is a plethora of information on the cycling of nitrogen and phosphorus within and between the sediment and water column. The overall view is that the cycling of these two crucial nutrients is ecosystem-specific. There have yet to be any studies in Gulf St Vincent or the local study area that have quantified how nutrients are cycled within and between the water column and the sediments.

Waters in Gulf St Vincent are generally regarded as oligotrophic, with very low natural levels of nitrate, phosphate and ammonia (Steffensen et al., 1995). In its pristine state, the Adelaide coastal system was presumably also oligotrophic. It now appears to be mesotrophic nearshore and eutrophic in the Port Adelaide River estuary, as a result of anthropogenic nutrient loads. Ultimately, except for the Port Adelaide River, there is insufficient knowledge of the nutrient system to allow confident management decisions.

Toxicants

There have been some studies on the effects of toxicants on a range of species in South Australia, but these do not cover the range of metals and organic chemicals found within each of the ecosystems listed in Table 4. Literature specific to toxicants in the study area includes:

- stormwater toxicity in the Patawalonga catchment (report by the University of South Australia—UniSA);
- pilot study on sediment-bound pesticide residues and ecotoxicological impacts in the Onkaparinga catchment (report by UniSA and CSIRO Land and Water);
- initial toxicity screening of road runoff (report by UniSA);
- loads in stormwater detention basins (report by UniSA);
- chemical data on some pollutant loads, by catchments and WWTPs;
- temperature effects, by Torrens Island Power Station (TXU Torrens Island); and
- PCBs and mercury, in dolphins and translocated mussels (EPA).

While some data are available relating to sediment and organisms' levels of pollutants (especially metals), these data relate to a variety of sampling sites (for example, Port Adelaide River – Barker Inlet, Gulf St Vincent, and so on), between which it may be difficult to draw associations/trends, or may not represent more recent sampling. There is also a paucity of data on levels of pesticides and other organics.

Techniques are available for, and local groups have published data for, metal analysis in sediments and biota, pesticide concentrations in soils and tissue samples (Edwards et al., 2001; Pisaniello et al., 2000; Cattani et al., 2001; Smith et al., forthcoming).

There are few biomarker studies in South Australian waters. These relate to a variety of sampling sites, between which it may be difficult to draw associations/trends. Biomarkers of exposure can include measuring pesticide and metal levels in tissues (Edwards et al., 2001) and the measurement of chemical-DNA adducts. South Australia has expertise in measuring cholinesterase activities in different tissues (Dyer et al., forthcoming). Local groups have also published data regarding biomarker analysis in fish and shellfish, and honours projects at Flinders University have examined other species and other locations. While many of the studies have examined wild fish and the like, other studies have examined similar endpoints in farmed tuna and shellfish off Port Lincoln (Soole et al., 1999).

Abiotic factors

There are relatively few studies on the impact of sediments (from turbidity, smothering and erosion) on seagrass ecosystems within South Australia. In addition to benthic flora and fauna, sediments continually re-suspended in the water column (that is, high turbidity) may also influence phytoplankton, zooplankton, meiofauna and macrofauna, but again there have been very few studies in South Australia. An assessment of the influence of sediment dynamics on seagrass will be a priority for this task.

There are no studies on effects of reduced salinity from freshwater input in South Australia. Worldwide, there are some correlative or descriptive studies and laboratory experiments, but no field or large-scale mesocosm experiments.

Information gaps

Nutrients

There does not appear to be any information on the nutrient or phosphorus cycle for the region.

Toxicants

There appears to be little information with regard to:

- biological assessment of the toxicity of effluent discharged from WWTPs (spatial and temporal data);
- temporal and spatial data on the toxicity of stormwater, road runoff and other inputs to the various ecosystems;
- relative contribution, in terms of toxicity, of various inputs into coastal waters;

- toxicity of sediment-bound contaminants in wetlands, mangroves and seagrass ecosystems;
- concentration data for organics in sediments, water column and biota;
- exposure pathways and metal concentrations/doses are poorly characterised for human health effects arising from the consumption of fish (recreational and commercial fisheries); and
- data regarding changes in biomarkers, over time, and associated with changes in pollutant load.

Abiotic factors

Studies on the effects of sediment movement (sedimentation and erosion), increased turbidity and low salinity on seagrass habitats have not generally been conducted within South Australian waters and are urgently needed to determine possible impacts of these factors. Where studies have examined these factors, data are generally observational/survey-based rather than experimental (that is, providing evidence of correlative rather than causal effects).

Task outcomes

Results from this task will include correlative data on how factors such as nutrients, sediments (turbidity, sedimentation and erosion), freshwater and toxicants affect seagrass ecosystems, and organisms within those ecosystems. There will also be manipulative, experimental results, demonstrating causal links between the different factors and seagrass communities. The experimental results will also be used to determine levels of turbidity, sedimentation, salinity and potential toxicants that may cause negative effects on different species.

Major sources of pollution of Adelaide coastal waters may be identified on the basis of biological assessment and the concentrations of contaminants in sediments (including seston), water column and selected biota measured from various sites.

The task will:

- define spatial and temporal patterns of fluxes and parameters associated with key nutrient transformations: for example, phytoplankton uptake, grazing, and regeneration, and storms;
- define spatial and temporal patterns of fluxes and parameters associated with key nutrient transformations: for example, re-mineralisation, nitrification and denitrification, burial in sediments, sedimentation to sediments, re-suspension from sediments and effects of bioturbators; and
- provide biomarker data for selected biota, to be compared with existing data and used as baseline, against which future changes in the management of pollutant load may be correlated and improvements quantified.

Modelling outcomes

The data and knowledge generated from these objectives will feed directly into the development of the hydrodynamic-ecological model for Adelaide coastal waters (PPM 2), by delivering calibrated model(s) of nutrient cycling with appropriate

spatial and temporal resolution, incorporating the key processes of physical transport and water column – sediment exchange, and biogeochemical transformations in water column and sediments.

Key assumptions and uncertainties in prediction of the fate of inputs (nutrients, sediments, freshwater and toxicants) in the marine environment and of effects on seagrass-dominated ecosystems will be identified, thereby providing a user interface to allow managers to assess the consequences of alternative actions.

Management outcomes

- Data to inform potential improvement in coastal water quality arising from various intervention and reduction strategies.
- Data to advise goal setting as part of adaptive management strategy.
- Data that may influence development of CWMBs' and WWTP operators' monitoring programs.

Task outputs

Outputs expected from this task include a technical and/or final report detailing concentrations of metals, pesticides and other organics in sediments and biota (and biomarker responses to pollutants in sentinel biota) at selected seagrass sites. It will identify locations of selected sites for ongoing monitoring.

In addition to the technical/final report, outputs should include publications for scientific journals, presentations to the stakeholders and popular articles for the general public.

Data management

Proponents of this task are required to assist the project managers to provide the client with a database in GIS Arcview or ArcInfo format containing all new data collected for the study.

The database shall come complete with metadata down to the Page 0 and Page 1 ANZLIC levels. Data and metadata are to be provided in MS Access format in line with the ANZLIC Metadata Page 0 and Page 1 levels. Metadata complying with these standards is to be provided to the project managers for each data set developed in the course of Task EP 1.

Data provided by task proponents shall be in a format that requires minimal editing for compatibility with the EPA's Environmental Data Management System. Guidelines for database formatting will be provided to all proponents by the project managers at the commencement of the study and must be consistently applied.

Methodology

Literature review

Timing

Up to three months. To be completed before any experimental work is started.

Activities

A comprehensive review of the current status of scientific knowledge relevant to EP 1, based on previous studies within Australia and overseas, using library resources at the South Australian Aquatic Sciences Centre and at Flinders and Adelaide Universities, as well as inputs from the research leaders.

Personnel

Completion and coordination of the literature review will be the responsibility of Post Doctoral Fellow 1 under the direction of the research leaders, who will provide a synthesis of the relevant technical information, combined knowledge and expertise.

Outcomes and outputs

Literature review report.

Habitat ground-truthing

Timing

Approximately three field days, ideally no later than February 2003, dependent on weather and on completion of aerial photography and production of orthorectified base maps from task RS 1.

Activities

Video/diver inspection and verification of habitats and major features of significance identified on the base maps supplied by task RS 1.

Personnel

Field team comprising Post Doctoral Fellow 2 and technical staff (scientist, technician, casual divers as required). Technical training and quality control regarding video techniques and GIS analysis will be the responsibility of David Miller (SARDI). Input from the research leaders.

Outcomes and outputs

Habitats identified on base maps.

Field surveys

Timing

Over one full year starting at the beginning of 2003. Four trips in total scheduled for February, May, August and November 2003, dependent on weather and timing of autumn rains.

Activities

Quarterly sampling (February, May, August and November 2003) to determine water quality and associated biological activity (chlorophyll a, phytoplankton, faecal coliforms in the overlying pelagic ecosystem) within each designated ecosystem, by zone represented in Table 4. Minimum two sites per ecosystem, three samples per site.

Sampling to determine contaminant load in the sediments and associated infaunal composition in summer (February) and winter (August). Minimum two sites per ecosystem, five sediment cores per site.

Chamber experiments on sediment cores in summer (February) and winter (August) to determine nutrient fluxes (following benthic chamber methodology of Lauer, Cheshire, Tanner & Fairweather—SARDI/Flinders¹). Five sediment cores per site, two sites within each ecosystem. The high priority shallow seagrass – pelagic interphase (Tables 4 and 5) will be sampled in each of the four zones, whereas the lowest priority deep seagrass – pelagic interphase will only be sampled in a maximum of two zones (zones 1 and 3) because of the high expense of chamber work.

Personnel

Completion of the field survey will be the responsibility of Post Doctoral Fellow 2. The field team will comprise Post Doctoral Fellow 2 (and Post-Doctoral Fellow 1 as required) and technical staff (scientist, technician, casual divers as required).

Outcomes and outputs

Database of water quality, sediment contamination and associated biological ecosystems (pelagic, intertidal seagrass, shallow seagrass, deep seagrass). Report on results of chamber experiments and variation of nutrient flux between ecosystems.

Laboratory experiments

Timing

2004 (possibly mid-2003 for honours projects).

¹ Comparable studies on benthic physiology are currently being undertaken by Peter Lauer (SARDI/Flinders University) in areas around Port Lincoln. These data could be used as a basis for comparison and assessment of generality.

Activities

Series of relatively short-term aquarium experiments in the pool farm or constant environment room, measuring the physiological tolerances and survival of seagrass and key fauna in the context of one or more of: elevated levels of ammonia; reductions in salinity; toxicants (which ones, and their treatment levels, will depend on results from field survey components of EP 1 and IS 1). For example, the separate and interactive effects of a toxicant (such as glyphosate), low salinity and turbidity on seagrasses and select biota would be investigated using an experimental design such as that shown in Figure 6. In this experiment we envisage having two levels of toxicant (for example, 1x ambient, 2x ambient), two levels of low salinity and two levels of turbidity (turbid and clear water). There will be two replicate aquaria per treatment. Parameters (as for mesocosm experiments) will be measured regularly for up to several months. The results will be analysed using robust parametric statistics, for example, analysis of variance, multiple regression.

Personnel

Completion of the laboratory experiments will be the responsibility of Post Doctoral Fellow 1 and honours students, under the direction of the research leaders. Technical staff (scientist, technicians) as required.

Outcomes and outputs

These experiments will provide the first causal examination of the responses of seagrasses to various possible factors identified in the background material and literature review, albeit at a small-scale and necessarily under artificial (laboratory) conditions. Thus, they will serve as an early stage in the process of filtering many potential stressors into a smaller set considered to be of primary importance. This will provide the basis for a series of more expansive and expensive studies that scale up progressively through mesocosms to field experiments. Results written up and published in scientific journals and theses (honours students).



Figure 6. A replicated orthogonal design schema for a short-term aquarium experiment comparing the main effects of toxicant (two levels, for example, 1x ambient, 2x ambient), low salinity (two levels, for example, 30‰, 20‰), turbidity (with and without) and their interactions, on select biota (for example, seagrasses, molluscs, fishes, and so on).

Mesocosm experiments

Timing

2004 (seagrass and other biological material to be collected and established in mesocosms in the South Australian Aquatic Sciences Centre pool farm by mid- to late 2003, if possible).

Activities

Series of replicated treatments (examining both main effects and interactions) in mesocosms to measure the physiological (for example, photosynthetic efficiency, respiration, growth) and ecological (for example, community structure, reproduction, recruitment) effects of turbidity and/or freshwater and/or elevated nutrients and/or toxicants. Specific treatments to be determined depending on results from the field survey component of EP 1 and information about levels of toxicants entering the marine environment from IS 1. For example, the effects of nutrients and freshwater would be investigated by multiple treatments of each factor in an orthogonal design. We envisage having three levels of nutrient and two levels of reduced salinity equating to six experimental treatments (Figure 7). There will be two replicate mesocosms per treatment. The levels of the nutrient and salinity in treatments will be based on those found in the field surveys. Parameters (see above)² will be measured regularly for up to nine months (longer would be better but time constraints prohibit). The results will be analysed using robust parametric statistics, for example, analysis of variance, multiple regression.

Personnel

Completion of the field experiments will be a prime responsibility of Post Doctoral Fellow 1 and honours students, under the direction of the research leaders. Technical staff (scientist, technicians) as required.

Outcomes and outputs

Indications of possible effects that feed directly into the field experimentation (such laboratory-based demonstration will first allow us to fine tune duration and levels of field experiments). Also, indications of the effects of factors that would be virtually impossible to control over extended periods in the gulf. Results written up and published in scientific journals and theses (honours students).

² If the experiment involves fauna, physiological and biochemical measurements may include: respiration, histopathology (for example, fish gills and liver/hepatopancreas), cytochrome P450 enzymes (organochlorines and polynuclear aromatics), inhibition of acetylcholinesterase (organophosphates), carbamates, metallothionein induction (some heavy metals), ATPase inhibition (for example, osmoregulation). Ecological and behavioural measurements may include: survival, community structure, reproduction, recruitment biomass changes, food conversion efficiency, behavioural endpoints (for example, swimming activity).

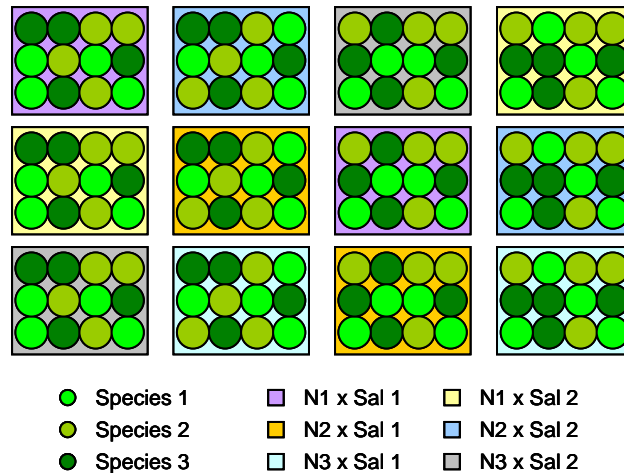


Figure 7. A replicated orthogonal design schema for a mesocosm experiment comparing the effects of three levels of nutrients (for example, 1x ambient NH_4 , 2x ambient NH_4 , 3x ambient NH_4) and two levels of low salinity (for example, 30‰, 20‰) on three species of seagrass (for example, *Posidonia sinuosa*, *Amphibolis antarctica* and *Heterozostera tasmanica*).

Field experiments

Timing

2004

Activities

Series of field experiments measuring the physiological (for example, photosynthetic efficiency, respiration, growth) and ecological (for example, community structure, reproduction, recruitment) response of seagrass and/or select biota to the effects of various treatments that are achievable under field conditions (for example, sedimentation, erosion, elevated nutrients and/or toxicants). Specific treatments to be determined depending on results from the field survey component of EP 1 and information on levels of toxicants entering the marine environment from IS 1. Methodologies may include: benthic chambers with injection units to apply doses of nutrients and/or toxicants and/or sediments; reciprocal transplants of seagrasses, that is, from control areas to areas exposed to various stressors (for example, high turbidity, nutrient input) and contrariwise; use of various exclusion devices such as cages and shades to control light, presence of grazers, and so on.

Personnel

Completion of the field experiments will be a responsibility of Post Doctoral Fellow 2. The team will comprise Post Doctoral Fellows, technical staff (scientist, technician, casual divers as required), PhD and honours students, with input from the named scientists.

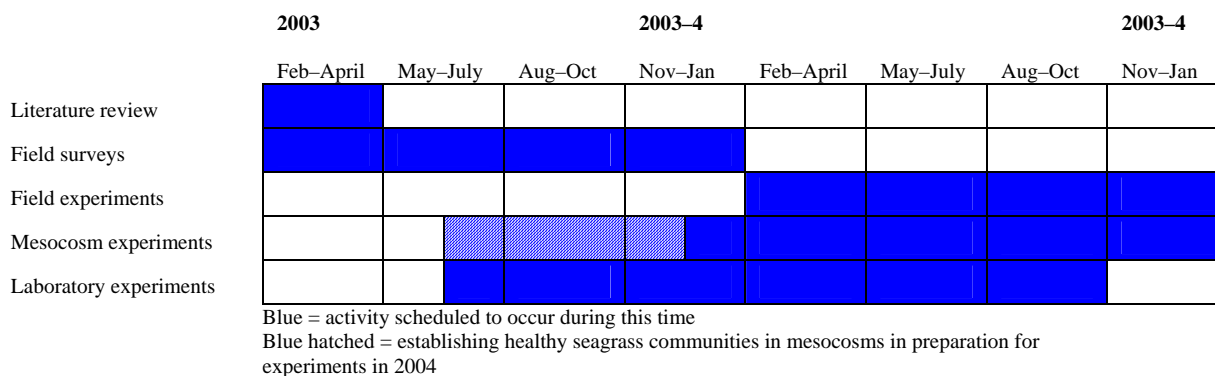
Outcomes and outputs

Causal relationships between seagrass performance (as measured through a variety of variables) and putative stressors (as previously suggested from significant results in mesocosm and laboratory experiments). Field validation of these effects is

crucial to eventual management recommendations. Results written up and published in scientific journals and theses (honours students³).

Work plan (amended)

The following work plan is indicative of the timing and relative effort to be apportioned to the key activities within the task. Variations to this work plan may be considered where greater efficiencies or enhanced outcomes may be anticipated from proposed variations.



Literature review

Three months have been allocated for a comprehensive review of the available data and literature (including international reports and publications) at the outset of this task, to fully assess the quality of previous research and identify any gaps. If there are studies elsewhere (for example, Perth Coastal Waters Study), it will be necessary to assess how applicable the results are to the Adelaide coastal waters. This will enable us to place any extremes for a given variable, measured during the field survey, in context with those measured historically along the Adelaide metropolitan coast and elsewhere.

Field surveys

The consideration and selection of field survey and sampling sites will necessarily utilise habitat base maps generated as an essential output from RS 1. It is also strongly recommended that site selection is coordinated with the proponents of other Stage 2 research tasks for comparable results, resource and cost efficiencies (Figure 5 in main document).

There will be a requirement for seasonal sampling and monitoring of:

- biological health assessment (BHA), to measure the current status of relevant ecosystems within the four zones (Table 5) (measurements include distribution and abundance, species richness, physiological and chemical indicators of health, and so on);

³ For example, honours theses at Adelaide University are written up as a scientific article following the format of a CSIRO journal and should be directly transferable (with some modification) to manuscript format.

- water and sediment samples from seagrass ecosystems (nutrients, heavy metals, organic compounds, and for bioassays on species representing different trophic levels); and
- stormwater, road runoff and WWTP effluent samples (for direct toxicity assessment).

Collections of biological samples will be required for:

- biochemical analyses (for example, King George whiting);
- bioavailability and bioaccumulation studies on algae, crustaceans, molluscs and fishes;
- water and sediment samples from seagrass ecosystems (nutrients, heavy metals, organic compounds); and
- stormwater, road runoff and WWTP effluent samples (freshwater).

Field experiments

It will be necessary to determine nitrogen and phosphorus cycles and fluxes in sediments, macrophytes (seagrasses and algae) and the water column using chamber experiments (see Table 5).

Manipulative experiments in the field will be required to examine effects of various factors on selected seagrass ecosystems or dependent biota.

- Field mesocosms will also need to be appropriately positioned and commissioned at selected sites (note comments on site selection above).

Mesocosm/laboratory experiments

Manipulative experiments will be required and may range from large-scale mesocosms, to simulate ecosystem and/or food web responses to a given factor(s) (for example, phytoplankton, seagrass and associated flora and fauna), through to smaller scale laboratory experiments designed to test tolerances of indicator species to a range of factors and/or interaction of factors.

Table 5: Spatial extent of field studies for each of the ecosystems and zones within the Adelaide coastal waters. C = Chamber assessment required, EHA = ecosystem health assessment required during the first year of the field studies. Priority has been assigned to each ecosystem on the basis of the need for information and the indication of impacts (1 = highest priority). Monitor refers to the need for ongoing close monitoring of the indicated ecosystem health.

Ecosystem	1	2	3	4	Priority	Monitor
	Northern section	Outer Harbour to Henley Beach (including Bolivar)	Henley Beach to Hallett Cove	Hallett Cove to Sellicks Beach		
Intertidal seagrass					2	X
Shallow subtidal seagrass ⁴	C, EHA	C, EHA	EHA	EHA	1	Y
Deep subtidal seagrass	EHA	C, EHA	C, EHA	C, EHA	3	X
Pelagic	C, EHA	C, EHA	C, EHA	C, EHA	1*	Y

Note: The sites for chamber work are targeted to high priority ecosystems due to the prohibitive cost of doing this work on a large spatial scale.

** Pelagic systems are a priority for ongoing close monitoring because of potential effects on human health, in terms of recreational beach use and consumption of fish and invertebrates.*

Quality control and assurance

- Chemical analyses of water samples will be provided by the Australian Water Quality Centre (AWQC) and sediment samples by CSIRO Analytical Services or the State Chemistry Laboratories Victoria (SCLV). Both AWQC and SCLV are accredited by the National Association of Testing Authorities.
- All data will be stored on a secure system with routine weekly backups off-site. Data entry will be double checked.
- Peer review of reports and scientific papers.

⁴ Shallow sub-tidal seagrass refers to seagrasses growing from Indian Spring Low Water down to a depth of approximately 10m.

Remote sensing RS 1 — Remote sensing study of marine and coastal features and interpretation of changes in relation to natural and anthropogenic processes

Task description

The task represents a workable, cost-effective, objective and systematic approach to providing answers to a large number of stakeholder and management issues.

The task will involve a remote sensing based study intended to map marine benthic features, document historical changes in features and investigate processes involved in environmental change. It will be based upon prior research conducted by the proponent and sub-consultants with a focus on developing methodologies and algorithms for the objective analysis of airborne hyperspectral imagery and aerial photography, using in particular the region of the Bolivar Wastewater Treatment Plant outfall as a pilot study area.

The task will require the application of a combination of remote sensing and interpretation techniques to the interpretation of airborne imagery, with validation of image features through appropriate field studies. It will also incorporate data sets from other tasks to allow interpretations of reasons for changes in marine benthic communities, particularly in relation to ambient water quality and impacts of land-based discharges and coastal processes.

The task will complement ecological, process and modelling studies and provide correlative information on anthropogenic and natural physico-chemical processes and ecosystem changes.

The task will also provide significant input to tasks EP 1, PPM 1, PPM 2 and EMP 1, and to the EPO. It will do this through provision, at an early stage, of base maps of benthic features, and also through provision of physical process data. Physical process data sets to which we plan to contribute include water circulation patterns in the near field of land-based discharges, historical changes in bathymetry sediment distributions and correlation of high resolution airborne imagery with lower resolution imagery such as Sea-viewing Wide Field-of-view Sensor data (PPM 2, sub-task 3).

The task specifies an initial twelve-month research and reporting program. The task team aims to produce significant deliverables in the first six months, with submission of a final report at the end of twelve months.

Subject to the availability of funding, the task could be extended to years 2 and 3 of the study and provide input to the Stage 3 synthesis of research findings and the design of long-term monitoring programs, once the immediate task study has been completed.

The task will provide essential support for and inputs to other research tasks, to achieve study integration through the provision of:

- maps of benthic and water column features, maps of changes over time in those features and databases of spatially referenced information;
- new remotely sensed data sets which will be interpreted to allow discrimination of major benthic species and water circulation features;
- maps of dispersion and dilution of plumes from land-based discharges;
- interpretations of temporal changes and how these might relate to the specific locations and natures of land-based discharges; and
- a remote sensing basis for long-term environmental monitoring of selected areas, to be continued after the completion of the study.

Task objectives

The objectives of the task are to provide high resolution and highly discriminatory mapping and interpretation of remotely sensed image features, focusing on seagrasses and sediments, but also providing information on mangroves, samphires, macroalgae, *Sabella* and reefs, where these can be reliably distinguished in the imagery. Mapping features additional to seagrasses and sediments would require little extra work within the areas covered by hyperspectral imagery.

Mapping and interpretation results will be applied to determine:

- historical changes in seagrass, sediment and other features;
- spatial variability in rates and patterns of changes;
- identification of changes related to specific land-based point discharges and coastal developments; and
- spatial and water circulation pattern relationships between losses of marine biota and distributions of water quality parameters, including heavy metals.

The study is expected to contribute in part to the following general ACWS aims (as originally presented in the Integrated Study Proposal of September 2001).

1. Result in an improved understanding of Adelaide's coastal systems (that is, hydrodynamic, biotic, abiotic, pelagic and sediment systems) and the relationships between different system components (the task contributes significantly here).
 - RS 1 will provide observational information on hydrodynamics of dispersion and dilution of plumes from selected land-based discharges (focusing on the Bolivar WWTP and using the in-kind contributions of Ball Aims, Defence Science and Technology Organisation and CSIRO). It will produce maps of biological communities and sedimentary features, and changes over time in those features, and through spatial referencing will suggest likely physical and temporal relationships between benthic and water column features and land-based influences.

2. Determine the overall water quality of the coastal waters, sediments and biota, in terms of nutrients, toxicants, freshwater, sediment and organic loads, and provide scientific information necessary for the development of long-term management options.
 - RS 1 will investigate near-field dispersion of wastewater plumes and how plume dilutions relate to pollutant concentrations in surrounding coastal waters.
3. Determine the impacts on, and the interactions between, the complex coastal waters systems, resulting from nutrient, toxicant, freshwater and sediment inputs from WWTPs and catchment inputs (the task contributes significantly here).
4. Identify historical and ongoing causes of ecosystem modifications (with a particular focus on seagrass dynamics) and the factors required to halt declines, reverse degradation and allow re-establishment (the task contributes significantly here).
 - RS 1 will demonstrate spatial and temporal correlations between changes in marine biotic and abiotic features, on the one hand, and land-based discharges and anthropogenic and natural influences on coastal morphology, on the other.
5. Determine the potential impacts of modifications to these input loads and concentrations.
 - RS 1 may not be able to confidently address this aim within the scope and duration of the study. The task will attempt to provide some suggestive, but not definitive, input to this aim by hindcasting of spatial and temporal observations and correlative data (this will be done to determine conditions when anthropogenic influences were not fundamental to changes in marine ecosystems) and also through provision of data for calibration of hydrodynamic and ecosystem models.
6. Determine the ongoing monitoring program necessary to ensure that the key ecosystem parameters identified in the study are sustainably managed.
 - RS 1 will provide a discriminatory, repeatable and cost-effective remote sensing basis for ongoing monitoring programs.

Study objective

The Adelaide Coastal Waters Study will focus on:

- seagrass loss;
- sea floor instability; and
- water quality decline.

Seagrass loss

It is crucial to the study to quantify seagrass loss through the production of historical maps of distributions of seagrasses and sediments, and this will be done by this task, using remotely sensed image interpretations. New airborne hyperspectral data sets using the CASI (Compact Airborne Spectrographic Imager) instrument and Quickbird II satellite imagery will improve upon the level of discrimination, of sediments and biotic features, presently achievable with the limited spectral resolution of aerial photography. A number of time intervals for aerial photography (late 1940s to the present time) are available, and these will be mapped to put some points on the 'seagrass decline curve' to provide a basis for prediction of likely future seagrass conditions.

It is recognised that some historical mapping of seagrasses in the Adelaide coastal region has already been conducted by the Department for Environment and Heritage (DEH). These data sets will be used in the task, on the assumption that they will be provided to the study at no cost. They will be re-investigated to determine whether better discrimination of seagrass and other benthic species cover and density is possible, given the new tools the RS 1 team has developed for image classifications as part of their in-kind contribution and as a result of their local knowledge of benthic ecosystems.

Mangroves and samphires may also be mapped as part of the image classification process, as it is anticipated that these classifications will arise as a consequence of seagrass mapping and therefore require little additional effort. Correlations between seagrass and other benthic species changes and their spatial relationships to land-based discharges will also be investigated.

Differences in the nature of changes in seagrass communities will also be investigated as it is known that the following processes and phenomena have occurred at different rates at different times and places:

- loss of seagrass density and cover;
- changes in species dominance;
- imbalances of erosion versus colonisation rates in blowouts;
- fragmentation of seagrass patches;
- establishment of seagrasses through propagules or rhizome growth; and
- epiphyte growth.

The existence of these different processes suggests that there are temporal and spatial differences in the balances between different environmental stressors. Multivariate statistical analyses of spatial and temporal data sets will be conducted to study the relationships between different stressors and their local and broader scale impacts.

Seabed instability

Quantification of historical changes in sediment distributions, and bathymetry derived from remote sensing studies (including spectral models of water depths),

should provide significant inputs to environmental process studies and give a better understanding of spatial and temporal dynamics of sea floor sediments.

Water quality degradation

The extent of water quality degradation due to land-based discharges will be examined using a number of tools, including, but not limited to, remote sensing and investigation and interpretation of wastewater and stormwater plume spectral characteristics. Chlorophyll, coloured organic substances and suspended sediments may be used as the plume tracers and serve as surrogates for the estimation of salinity, nutrient and toxicant dilutions in plumes. Decay coefficients for the non-conservative components of chlorophyll and total nitrogen have already been estimated for the Bolivar Wastewater Treatment Plant discharge plume dispersion field.

Issues to be addressed

The RS 1 Task will address specific stakeholder issues, and indeed some that the stakeholders may not have considered. These are summarised below.

Rationale

Remotely sensed data sets will be derived from available historical hyperspectral imagery and aerial photography and from proposed new aerial photography and state-of-the-art hyperspectral data from the airborne CASI instrument and the Quickbird II satellite instrument. We have already demonstrated through our pilot studies (as in-kind contributions) that it is possible to discriminate and map benthic biota, in many cases to species level. Some refinement of bio-optical models will be required as we investigate imagery outside our pilot study areas. The main research component of this task will not be development of image analysis methodologies and algorithms. Rather, multidimensional combinatorial analysis of diverse spatially referenced data sets will be used to determine whether differences in the spatial and temporal patterns of changes in benthic features can provide insights into the causes of such changes.

It is considered that hyperspectral images from airborne or satellite mounted instruments have potential for forming a basis for continuing monitoring programs, giving extensive spatial coverage, and high spatial and spectral resolution. The research into study-specific applications of hyperspectral data will provide a basis for selecting technologies and methodologies compatible with conducting environmental monitoring for many years into the future.

It is recognised that the costs of acquisition of current technology hyperspectral data are relatively high (approximately \$55,000), and a case is made for justifying this cost. Some satellite imagery, in particular that from the Hyperion and Quickbird II earth observation satellites, will be investigated, and image analyses will be conducted to determine whether satellite imagery can provide sufficient spectral and spatial resolution for the purposes of long-term management of coastal ecosystems. These are very new systems and their utility needs to be demonstrated.

The task will go beyond just mapping and providing spatial data sets. The spatial data investigations will provide, in the short term, feedback to other research groups. It is anticipated that this feedback could assist the conduct of adaptive research, for example, by focusing effort on issues which are demonstrated to have strong correlations between environmental stressors and ecosystem changes.

While aerial photography and remote sensing are powerful tools, there are limitations to their applicability. For example, remote sensing cannot effectively quantify and understand the spatially complex dynamics of reef ecosystems. There will also be little possibility of detailed discrimination of benthic species in aerial photography, although this may be possible with hyperspectral imagery, and re-calibration of aerial photography using the hyperspectral data will allow some degree of discrimination of features beyond just full seagrass cover and bare sediments.

Remote sensing, as a scientific discipline and a field of application of advanced technologies, has dramatically matured in the last ten years. Results that can be delivered now as a matter of course and in a timely manner would have been difficult or impossible to produce in large-scale coastal waters studies which are antecedent to this study, for example, the Port Phillip Bay Study and Perth Coastal Waters Study.

Linkages and dependencies

Linkages

The task will be linked to and provide essential inputs for tasks IS 1, EP 1, PPM 1, PPM 2 and EMP 1, and for project management, through the following aspects of the Task:

- assessment of impacts of freshwater, nutrients, suspended sediments and other pollutants on marine ecosystems and nutrient decay (through plume dispersion studies and inputs to numerical circulation models);
- studies of interactions between point sources and wider Gulf waters (through plume dispersion studies and inputs to numerical circulation models);
- investigation of mechanisms of loss of seagrasses (through studies of sediment movements, variability of patterns of changes and erosion–colonisation balances); and
- reporting on status of marine and coastal ecosystems (through provision of distribution maps and a historical perspective to elicit regions and types of critical changes).

Provision of data to, and receipt of data from, other research groups and CSIRO managers will be dependent upon the establishment of an effective information management system, in a time scale that is appropriate for the timelines for data analysis and delivery for each of the research teams.

The task will provide calibration information for hydrodynamics models proposed for PPM 2, at a very early stage, allowing modelling to commence prior to completion of field studies planned by the modellers. It will also provide data on the optical transmission and absorption properties of the water column, so that light intensities at the seabed under differing suspended sediment, chlorophyll and dissolved organics concentrations can be estimated. This will be a significant input to EP 1 and an important input to PPM 2.

A base map showing ground-truthing locations required for the task will be provided at a very early stage, so that other research groups can ensure that at least some of their field survey sites will coincide with this task's field sites.

Dependencies

The remote sensing studies will be dependent upon data derived from the following studies and data sets, some of which currently exist in part and all of which will be updated during the course of the study:

- ecological and hydrological field surveys;
- water quality studies, particularly those relating to wastewater and stormwater inputs, quality and dispersion;
- bathymetry;
- CSIRO studies to determine characteristic spectral reflectances for different plant species;
- CSIRO studies to remove effects of sun glint and the water column on spectral attenuation;
- DEH-provided time series maps of benthic features;
- wastewater plume dispersion mapping;
- independent studies of Gulf water's primary productivity using remote sensing;
- available supply of new and existing aerial photographic coverages from DEH;
- supply of new and existing hyperspectral data sets;
- supply of new and existing sedimentological and sediment geochemistry data sets;
- maps of *Sabella* distributions; and
- establishment of an environmental information management system to allow effective and timely sharing of data between research teams.

Task outcomes

Outcomes expected from this task include:

- an improved understanding of how environmental processes interact with marine and coastal features to produce changes over time in marine feature distributions, and how those changes have led to present conditions; and
- an environmental baseline methodology, as a basis for future monitoring and management of marine and coastal environments, that can make use of the proliferation of airborne and spaceborne sensors coming on line (six expected in the next two years) for aquatic environmental detection and monitoring purposes.

Task outputs

The primary, tangible deliverables of this task will include the following:

- a full study area base map showing major benthic features and RS 1 ground-truthing sample locations, to be provided in the first month to all other research teams so that they can select sample locations which will be, as far as possible, common to all research tasks;
- selected study area coverage maps of major benthic features from 1949 to 2002 at intervals of about 15 years, as far as possible (probably three or four in total)—benthic features will include seagrasses, discriminated to species where possible, macroalgae (especially *Ulva*), intertidal algal mats, *Sabella*, mangroves, samphire and sediment features (for example, sub-tidal sands, intertidal sands, beach ridges), and, to a limited extent, seagrass epiphytes;
- selected study area coverage maps of changes between times of acquisition of remotely sensed imagery (approximately two or three in total);
- selected study area bathymetry maps for the stated time periods;
- selected study area bathymetric change maps for the stated time periods;
- statistics of feature areas and changes for the stated time periods;
- high resolution maps (for selected areas) of benthic features for 1949 to 2002 (for six areas, resulting in 20 maps in total);
- high resolution change maps for the above (approximately 15 in total);
- statistics of feature area, changes and rates of change of feature boundaries, and cover percentages, for selected study areas as stated;
- maps of dilutions of photosynthetic pigments, dissolved coloured organic compounds, salinity and nutrients in wastewater treatment plant and stormwater discharge plumes (covering one to six time periods for a maximum of six locations—totalling perhaps 30 maps);
- guidelines for spatial data transfer, including metadata standards;
- bio-optical and related models to allow the reliable identification of benthic features using hyperspectral, remotely sensed imagery; and
- an interpretive report including:
 - descriptions and summaries of the data sets;
 - results of empirical correlation studies of changes in marine biotic and abiotic features, on the one hand, and land-based discharges and coastal development natures and histories, on the other;
 - identification of critical data gaps, and requirements for additional funding and resources to fill these gaps; and

- recommendations for a monitoring program and the most appropriate technologies for large-scale benthic feature mapping as an ongoing tool.

All data layers will be accurately geo-referenced and rectified to conform with spatial position accuracy defined by a reference base layer which will be based on high resolution ortho-photomap products. The rectification of spatial data provided by other research task teams will be dependent upon them supplying data sets which comply with ANZLIC data formats and transfer standards (see below).

As there will be ongoing interaction with other research teams, changes in some of the data layers are expected to occur as new hydrodynamic modelling, ecological and sediment dynamics results become available.

Data management

There is a need to manage the large data sets produced by this task. In particular, management of image and database formats, metadata standards and off-site backups of data will be required. Team members will provide assistance in developing standards for data transfer between the proponents of the task, guidelines for other research teams with regard to ANZLIC metadata standards and a common geodetic datum, and also provide an on-line computer system that will provide a backup for data produced by the project team.

Data security will provided by:

- use of hardware and software firewalls and up-to-date virus scanning software to ensure that any internet access will be protected from hacking; and
- off-site backups both by using on-line mirrored sites and by lodging CDs, mirrored hard disk drives and hard copies of data in a secure bank deposit box (weekly and monthly).

Methodology

To date, considerable effort and cost has been expended on:

- reviews of literature relevant to marine and coastal remote sensing and reviews of internet-based systems for data sharing;
- acquisition of remotely sensed data (aerial photography, airborne digital hyperspectral imagery and satellite hyperspectral imagery);
- fundamental research in remotely sensed image interpretation of biotic and abiotic features (seagrasses, macroalgae, microalgae, mangroves, samphires and sediments);
- development of methodologies for spectral corrections of remotely sensed data, including removal of sea surface reflection and water column effects (substantial work has been completed on mapping changes in marine and coastal features); and
- development of standards for spatial data set transfer protocols.

The project will commence with the production of base maps of the distributions of seagrasses and sediments (based upon the most recent aerial photography, 1998–2001). It is expected that these base maps (in hard copy form and georeferenced TIFF files) would be supplied to other research teams within one month of the project start-up. This delivery schedule assumes that EPO, through DEH, will provide the imagery as rectified digital data with a resolution of +/- 1 metre or better. It is expected that there will no costs incurred by the proponent of the task for the supply of recent or historical aerial photography by DEH.

Base maps of seagrasses and sediments will be provided with an accuracy sufficient for other research teams to define their field studies. These maps will be updated as more extensive historical and current remotely sensed data sets become available. This would happen concurrently with acquisition of new remotely sensed data (aerial photography, CASI hyperspectral and satellite coverages) which would be contemporaneous with field surveys to acquire information about seagrass species and other features and their specific spectral characteristics.

It is planned to acquire the new remotely sensed and field survey data within a month of start-up of the project (assuming that aircraft and airborne instruments will be available).

Once the new remotely sensed sets have been acquired it is expected that approximately eight months will be required to refine the image analysis techniques and provide objective and verifiable maps of benthic features for the study area. This is not a continuous eight-month research program, but its duration is set by the need to acquire further imagery six months after start-up of this phase. It is likely that the first part of this image component would be completed in about four months, and the second within about six weeks.

Indicative work plan

The indicative work plan is defined in relation to a scope of work, details of which are given below. Tasks and specific activities anticipated to be required are presented in Table 6 below.

Specific tasks to be carried out to ensure provision of data relevant to the needs of the study include:

- collation and spatial referencing of numerous data sets which currently exist, or which will be provided by other research tasks;
- acquisition of new remotely sensed imagery;
- classification of remotely sensed images to provide ecosystem, sediment and water circulation feature maps;
- data management ensuring quality assurance and control and data security for information supplied to other research teams; and
- supply of image data sets, in georeferenced TIFF format, on CDs to other research teams.

The interpretation of spatial and temporal data sets will require, in the following order:

- production, from existing aerial photography, of a base map to be supplied to other research teams, to assist with defining field survey programs;
- image spectral corrections to remove the effects of the water column, materials suspended in the water column, sea surface features and atmospheric effects (such corrections will provide a basis for discriminating species of benthic biota and concentrations of organic and suspended sediment tracers in plumes and bathymetry);
- image classification, including to species level where possible;
- production of change images and statistics so that rates and natures of changes for the whole study area, and for specific study sites, can be quantified; and
- preliminary combinatorial correlative studies of all spatial and temporal data sets, providing input for the quantification and ranking of different types of impacts for different times and places.

Table 6 Indicative schedule for completion of tasks and activities for RS-1

TASKS	MONTHS											
	2	3	4	5	6	7	8	9	10	11	12	
Compile existing mapping data sets												
Provide draft benthic feature base map												
Management of data sets and standards, software support												
Input data from other tasks												
Acquire hyperspectral data												
Acquire new aerial photography												
Image rectification and classification												
Ground-truthing/field studies												
Plume dispersion maps												
Produce change maps and statistics												
Interpret change maps in light of environmental conditions and processes												
Develop statistical metrics for relating changes to events and point discharges												
Project workshops												
Progress reporting												
Final reporting												

Note: CASI airborne hyperspectral data and Quickbird II data are planned for acquisition in month 1. The timeline bars in the Table do not represent full time input by team members. Input will vary from full-time during field studies to a minimum of about 0.2 days per week.

Parameters to be measured

- Spectral reflectances of image features, both in the field and in the laboratory, using field samples of benthos and sediments.
- Areas and rates of change of features, including seagrasses, algae and sediments.
- Bathymetry based upon water column attenuation of spectral bands.
- Salinity, nutrients, chlorophyll, dissolved organic material and suspended sediments in wastewater and stormwater plumes, based upon water samples collected during field surveys.
- Optical transmission and absorption properties of the waters in the study area.

Coverage and resolution

Existing aerial photography covers most of the study area at approximately five-yearly intervals, from 1949 to the present, and can be resolved at scales of between 30 centimetres and one metre. Because of budgetary constraints, it is planned to study five coverages in detail, although all coverages will be considered to determine which are likely to provide the most useful information for detection of seagrass loss events.

It is preferable that new aerial photography is obtained at a scale of 1:16,000, allowing sub-metre resolution. Such photography is flown at low altitude so that atmospheric effects are minimised. The preferred scenario is for two coverages, spaced six months apart, so that differences due to seasonal variability, for example, in epiphyte cover and water clarity, can be investigated.

Existing hyperspectral data sets cover areas from Gillman to Port Gawler and Brighton to West Beach at resolutions of about two to four metres. New, complete hyperspectral coverages are to be obtained for an area 40 kilometres by four kilometres at two-metre pixel sizes, extending from Marino to Port Gawler. This coverage will include most of the coastline where seagrasses occur and will extend seawards for a distance sufficient to cover most of the area where major changes in seagrass cover have happened.

Monitoring/survey measurement techniques

New aerial colour photography at 1:16,000 scale (resolvable to 50 cm pixel sizes) is expected to be supplied by the DEH as an in-kind or at least low cost contribution.

New airborne hyperspectral coverage will be obtained using the airborne CASI instrument. CASI is able to measure reflectances in up to 48 spectral bands, ranging from visible blue to short wave infrared, and for at least the visible blue to red part of the spectrum bands can provide information with a resolution of two metres. Details of the CASI instrument and its applications are provided in Attachment C. Quickbird II imagery with four spectral bands and 2.5 metre resolution will also be obtained at about the same time as the CASI instrument is flown. Further Quickbird image acquisition will be event-driven, for example, if there is a major rainfall event and stormwater plumes are discernible.

Ground-truthing of major image features will be conducted at the time of acquisition of new airborne imagery, so that data on water column properties can be used reliably for input to bio-optical models. This ground-truthing will involve terrestrial, intertidal and sub-tidal surveys, the latter requiring boat usage, and underwater surveys totalling some 8–10 days for the two planned field studies. Approximately 50 field sites will be surveyed. Seagrass, algae and surface sediment samples will be collected to allow identification of macrospecies and microspecies. Field investigations will be spatially positioned using Global Positioning System (GPS) to achieve positional accuracy of better than one metre.

Underwater still camera photographs will be taken at each site. The project team will also be able to acquire underwater video imagery using helmet mounted video cameras

Water samples will be taken at each dive site for laboratory analyses of chlorophyll, suspended sediments, salinity and major nutrients (nitrate, ammonia, TKN, soluble phosphorus).

Spectral reflectance and transmission calibration data for seagrasses, macroalgae, microalgae and the water column will be obtained in the field using hyperspectral radiometers. If possible, the project team will conduct these surveys contemporaneously with other research team field surveys. Where possible, the project team would like to time field surveys to coincide with those being conducted for EP 1 and PPM 1, to achieve some cost savings.

Image analyses, and spatial data storage and presentation, will be conducted using computer software including, but not limited to, TNTmips, TNTAtlas, ArcView, ENVI-IDL and Imagine. Appropriate computer hardware, capable of carrying out the necessary data processing, will be provided by the RS 1 Task team.

Project management and reporting

A strict program for meeting timelines and delivery of data sets will be adhered to. As the study proceeds the project team will regularly review, in consultation with the EPO, performance, deliverables and linkage/dependency issues.

The team leader will communicate with sub-consultants several times a week by phone and email connections to ensure that the scope of studies, data sharing, scope of deliverables and budgeting program are adhered to. Monthly project reports, detailing work conducted and time spent, will be submitted to the team leader. Progress reports, including summaries of the monthly team reports, will be submitted to CSIRO EPO every two months. MYOB software will be used to manage financial data. The team leader's accountants will also receive copies of monthly budget and time information (at no cost to the project) to review and manage the progress of the project.

A hyperindexed document control system is being established to ensure that versions of files, sources of data, dates of revisions, sources and destinations of emails and other communications are properly managed and are auditable. Reports will be provided in locked PDF format to ensure their immutability and security.

Quality assurance procedures

Remote sensing and other spatial data provided by all research teams will be stored and transmitted in forms compatible with the Australian Spatial Data Transfer Standard, to ensure compatibility with, and efficient incorporation into, the Environmental Information System. Data formatting standard information will be provided to all research teams at an early stage of the study to ensure they are compliant with this requirement.

Accuracy of image rectification will be assured by establishing differential GPS located ground control points at the times of field surveys and through the use of reference digital orthophotomap/cadastral data available through DEH.

Image interpretations will be checked against ground-truthing data, and further checked when ecological and water quality survey data sets are incorporated.

A qualified botanist will identify plant species collected during field surveys, and voucher specimens will be lodged with the Plant Biodiversity Centre of DEH.

There will be iterative validation of benthic feature maps, resulting from interaction with other research groups. We expect that there will be anomalies between early versions of our maps and field observations made, in particular, by the EP 1 and PPM 2 teams. Their observations will be accepted and incorporated into revised maps that have a level of accuracy acceptable to other research teams and the EPO. Formal risk analyses will be conducted to ensure that the accuracy of spatially continuous mapping based upon remote sensing is at least equal to or better than that based upon maps interpolated from discrete ecological, sediment and water quality sampling sites. The project team will also critically compare remote-sensing-based maps of wastewater and stormwater plume dispersion with numerical circulation models (PPM 2) to ensure that the models reflect reality with reasonable confidence.

Physical processes and modelling

PPM 1 Coastal sediment budget

Task description

This task specification has been developed in close collaboration with representatives of the South Australian Coast Protection Board (CPB) and the Department for Environment and Heritage's Office of Coast and Marine (OCM), so that ACWS task activities will complement CPB and OCM programs.

Coast Protection Board requirements for the ACWS

The South Australian Coast Protection Board is responsible for the management of Adelaide's metropolitan beaches, and is therefore a major stakeholder with specific interests in the ACWS. In recent years, the dynamics of the coastal beach system have been adversely affected by increased sand transport both onshore and offshore (depending on location). Sand from areas previously protected by healthy seagrass beds has entered the active beach zone, while at the same time changes to near shore bathymetry have altered coastal erosion rates.

The CPB is therefore interested in ensuring that this task provides essential information on:

- how much sand is entering the beach zone from offshore seagrass beds and denuded areas;
- sand sources and composition (type—for example, biogenic or siliceous);
- where the sand is coming on shore, its types, properties, rates and volumes.

This information will allow the CPB and OCM to better determine sand budgets along the metropolitan coast, and therefore to review and develop appropriate coast protection strategies.

Task objectives

The objectives of this task are to:

- 1 identify the components of the sediment grains on the sea floor throughout the entire study area;
- 2 determine the volumetric contribution of each component type at each site;
- 3 prepare a facies map for the sediments across the study area;
- 4 quantify the sources of the sea floor sediments and the volume derived from each source;
- 5 determine the relative time involved in the production of sand-sized grains from each source; and

- 6 trace experimentally the movement of sand from each source, through its sequence of temporary deposition sites, to its permanent accumulation site.

Links between objectives from the list above and other tasks are as follows.

- Objectives 1, 2 and 4: those sediments that have a terrestrial source will be studied in conjunction with task IS 1.
- Objectives 1, 2 and 4: those sediment grains that are biogenic will be studied in conjunction with tasks EP 1, in regards to calcareous epiphytes, and, to a lesser extent, task RS 1.
- Objective 6: the movement of sand from each source, through its sequence of temporary deposition sites, to its permanent accumulation site, will be conducted in conjunction with task PPM 2 and the CPB.

Issues to be addressed

This research task seeks to provide an understanding and quantification of:

- mechanisms involved in the production of the sand-sized grains that currently make up the sediments mantling the sea floor in the study area;
- primary sources of the grains, that is, autochthonous or allochthonous;
- routes by which these grains become available for deposition on the sea floor;
- secondary routes by which some of these grains are transported shorewards;
- accumulation of permanent sand deposits on the sea floor; and
- the temporal framework operating at each stage.

The list below shows issues, as presented and numbered in the Stakeholders Requirements Report, that will be addressed either directly (marked *) or through linkage with another research task (marked †).

3.2.2 Pollutants (transport and fate of heavy metals, pesticides, ammonia)

3.2.2.6 What is the bioavailability of heavy metals? Are metals locked up in the Gulf St Vincent sediments?†

3.2.5 Seagrass dynamics/ecology†

*3.2.5.13 Does the time of year when discharges occur make an important difference to their effects on the marine environment(s)?—for example, is it sustainable to discharge in winter but not during summer algal growth periods?**

3.2.7 Water quality—objectives / standards, assimilative capacity and maximum contaminant loads

3.2.7.2. What are the principal agents of concern in stormwater? Are pesticides, suspended solids, nutrients, heavy metals or unknown inputs/interactions creating the most significant environmental degradation?†

3.2.7.7 How significant are the effects of turbid water discharge plumes on coastal biota (seagrass, macroalgae)?†

3.2.7.11 Are coastal and catchment wetlands (for holding and retention) the most effective method to treat urban stormwater before release to coastal waters?†

3.2.9 Indicators of disturbance (health)

3.2.9.2. Will the study attempt to quantify marine species biomass along the coastal waters as an indicator of disturbance?†

3.2.10 Coastal processes and sediments

3.2.10.1 What is the effect of large-scale sand dredging in terms of re-mobilisation and denitrification processes?*

The research task will also contribute, with related tasks, to dealing with the following areas and issues.

3.2.1 Nutrients (in sediments and water column)

3.2.4.1 What is the impact of low salinity levels on seagrass communities (and different species within communities)?†

3.2.5.4 Is the relatively recent trend to discharge freshwater directly to the Adelaide coastline causing significant disturbances to inshore seagrass?†

3.2.5.10 Is it possible to get the seagrasses back, and what effect will this have on coastal processes and sand dynamics?†

3.2.5.11 Is re-colonisation of seagrass dependent on the existence of a residual seagrass root mat?†

3.2.7 Water quality—objectives/standards, assimilative capacity and maximum contaminant loads†

3.2.11 Marine habitats—status of reefs, estuary, inlets, wetlands, mangroves†

Rationale

The Scoping Study reiterates the Initial Findings Report's conclusion that there are many complex, interacting processes (physical, chemical and biological) that are insufficiently well understood to permit confident management decisions. It also reveals that the time aspect (in terms of both when things happen and at what rate) has been totally overlooked. Previous studies elsewhere (for example, Port Phillip Bay) have shown that these interacting processes sometimes exhibit unexpected behaviour, with major management implications. The Adelaide coastal waters differ sufficiently from other studied systems that there is major uncertainty and knowledge gaps about these processes. Therefore, there is a need for studies of the entire ecosystem, supplying the current omissions and enhancing the understanding of those issues that have been addressed previously to varying levels. This research task will determine:

- the volumetric contribution of sediment grains from all primary sources, including those already identified and those not yet substantiated
 - (if not implemented, we do not have a foundation on which to base the entire study—for example, how many sediment grains are produced by calcareous plants and animals that are epiphytic on sea-grasses?)
 - (provides primary data for the use of most other studies—for example, some of the consequences of the loss of sea-grasses);
- the approximate timeframe involved in primary sediment grains arriving at their point of entry on to the sea floor, and the linkage of this with finite vs. infinite primary-sourced sediment grains

- (if not implemented, we will not be able to predict how long sediment supply and transport will continue, if all else remains constant)
 - (provides data for forward modelling);
- the fate of the different packages of sediment grains following their deposition, and the timeframe involved
 - (if not implemented, relative importance of the different sediment packages will not be known, and coastal management plans formulated will not have a predictability component);
- the processes involved in stabilising sediment grains on the sea floor in different environments, and the timeframe involved
 - (if not implemented, the seagrass tasks will be missing a vital element in their plans for seagrass re-establishment)
 - (interacts directly with seagrass tasks, and with biota tasks involving infaunal and epifaunal benthic fauna and flora);
- the processes involved in any secondary transport of sediment grains to a final accumulation site, and the timeframe involved
 - (if not implemented, will be a missing cog in the oceanographic tasks)
 - (interacts directly with all oceanographic tasks);
- the quantification of volumes of sediment grains, by type, which are shifted from their primary deposition site; the importance of temporary deposition sites; and the nature and stability of final accumulation sites, and the timeframe involved
 - (if not implemented, no information will be available about where, when and how much sand will build up in accumulation sites, and it will therefore be impossible to plan non-damaging removal for beaches that are severely degraded)
 - (interacts directly with oceanographic tasks, as it provides a timeframe);
- the consequences of removing or restricting primary sources of sediment grains in both the terrestrial and marine environments
 - (if not implemented, there is the very real likelihood of a major primary source becoming 'sterilised'—for example, being built upon, or being blocked from access to seawards transporting medium by the erection of a man-made barrier)
 - (interacts indirectly with tasks involving control of stormwater, especially from roads); and

- the consequences of removing sediment grains from final sediment accumulation sites or the removal/restriction of final sediment grain accumulation sites in both the terrestrial and marine environment, and the timeframe involved
 - (if not implemented, no information will be available about where, when and how much sand will build up in accumulation sites and the potential damage from alterations to these sites—for example, a coastal bikeway across the North Haven site)
 - (interacts with tasks involving other coastal locations, for example, sand build-up in mangrove areas).

Additionally, the research outcomes generated from this task will provide the necessary baseline data on the substrate (sea floor) upon which many of the other tasks will be based, complete with a timeframe for each of the processes involved.

Linkages and dependencies

The data obtained will inform PPM 2 modellers of the sediment dynamics of the region, and allow forward modelling of the Adelaide coastal waters and its beach environments, from Sellicks Beach to Port Gawler, at a level of confidence previously unavailable. It will underpin all other tasks because it concerns the base on which all the other tasks sit. Monitoring of the rates of the identified critical processes is mandatory; monitoring requirements will be communicated to those developing the long-term environmental monitoring program for the study area (for example, EMP 1 task), for incorporation into the monitoring design.

Current status

No research studies of the coastal waters adjacent to a major city of the breadth proposed here have been attempted. Yet, logically, it is obvious that each facet is essential in order to produce a satisfactory outcome for all the involved stakeholders and for scientific completeness and knowledge. However, there are many studies on individual aspects, for example, the effect of sewage outfall on the maintenance of sediment-producing marine invertebrates in the Mediterranean at Marseilles (Harmelin et al., 2001; various studies in the attached literature review), and these will be investigated prior to commencing that particular facet of this study.

A repository of cores obtained by drilling the sea floor and adjacent shoreline areas is held at the PESA Core Library at Glenside. Many of the onshore holes penetrated to the base of the Cenozoic Era strata, and so cover the entire geological history of Gulf St Vincent. Others have only penetrated strata from the last 125,000 years, but these will be the more critical cores for the study. They are available for sub-sampling. Although the geological time aspect of the sea floor sediments is not a priority for this project, it will be studied, in tandem with this study, by Geology and Geophysics, University of Adelaide, and will thus provide a valuable timeframe for all modelling aspects.

Similarly, the task is not involved with the critical factor of nutrient levels, but much is known about nutrient levels throughout the entire 40-million-year history of the St Vincent Basin. For example, the mesotrophic Eocene time (James and Bone, 2000) and the oligotrophic Oligocene–Miocene time are both well revealed in the coastal cliffs from Sellicks Beach to Christies Beach, and in many cores.

Today, the waters in Gulf St Vincent are regarded as oligotrophic, with mesotrophic

conditions in many of the nearshore areas, especially in the vicinity of sewage and stormwater outfalls. Thus, this task will play a minor role in such studies, as it can supply the historical background.

Information gaps

As stated above, no research studies of the coastal waters adjacent to a major city have been attempted of the breadth proposed here.

Currently unknown aspects that are vital to understand the sea floor sediment cycle and budget, to produce a complete scientific understanding of the Adelaide coastal waters, include:

- the primary sources of the sediments, for example: biogenic (marine, terrestrial); coastal erosion of cliffs, beaches and sand dunes; bed-load of rivers; Permian glaciogene sediments (especially from Backstairs Passage); stormwater outlets, human-produced artefacts; terrestrial dust; palimpsest sediments;
- the processes whereby these sediments are transported to the sea floor;
- the percentage of sediment from each primary source at the point(s) of entry;
- the finite vs. infinite primary sediment grain sources;
- the extent to which these ratios change in the different environments;
- the processes and quantification of sea floor stabilisation of the sediments;
- the number of episodic re-locations involved in the movement of any of the sediment grains from one deposition site to another;
- the extent to which this occurs on the sea floor, as opposed to on the beach;
- the volume of sediment that eventually becomes part of a permanent accumulation of sediment, and eventually lithifies, either in the marine or terrestrial environment;
- the extent to which this occurs on the sea floor, as opposed to on the beach;
- the time (date) of all of the above events;
- the rates at which all of the above occur; and
- the effect of atypical events on all of the above, for example, storms, climate change, major seafront alterations and infrastructures.

Data management

Proponents of this task are required to assist the project managers to provide the client with a database in GIS Arcview or ArcInfo format containing all new data collected for the study.

The database shall come complete with metadata down to the Page 0 and Page 1 ANZLIC levels. Data and metadata are to be provided in MS Access format in line

with the ANZLIC Metadata Page 0 and Page 1 levels. Metadata complying with these standards is to be provided to the project managers for each data set developed in the course of Task PPM 1.

Data provided by task proponents shall be in a format that requires minimal editing for compatibility with the EPA's Environmental Data Management System. Guidelines for database formatting will be provided to all proponents by the project managers at the commencement of the study and must be consistently applied.

Task outcomes

The outcomes expected of this task include:

- a complete quantification of the spatial and temporal patterns (in terms of geological time and process rates) of 'sands' (sediment grains), in terms of primary sediment production, transportation to the marine environment, primary deposition, secondary mobilisation, final accumulation and any diagenetic alteration at any stage to these sediments;
- the identification of the components within the sediments at any stage of the above, the quantification of the proportions of each and the actual age of each;
- identification of all the processes associated with this sediment cycle and budget, and the parameters that control their activation, energy levels and cessation; and
- a model of the movement of these sediments into, out of and through the study area, correctly accounting for the transport of pollutants, nutrients, and so on, associated with the movement of sediments.

Task outputs

A report of the research activities will be provided to the stakeholders. Additionally, it is expected that the research will be published in leading peer-reviewed scientific journals and be presented, as both oral papers and posters, at appropriate conferences and at convened meetings of interested parties, for example, local council personnel, industry groups, schools and volunteer groups involved in coastal and nearshore marine endeavours. An interactive CD will be produced, which will also be put on the appropriate website.

Methodology and work plan

An integrated field and laboratory program is to be developed to provide a general overview of the coastal sediment budget for the Adelaide region of Gulf St Vincent and to achieve the task objectives, outcomes and outputs.

The objectives of the field program will be to: sample sediments at all possible points of entry of the sediment grains into the sea floor environment, that is, 'new sand grains'; identify 'old grains' that have been resident for geologically significant times on the sea floor of the coastal area; and identify sources for, and quantify the seasonal and event-specific variation in, the supply of sediment grains to the marine realm, and the episodic movement of the deposited sediment grains from one environment to another.

Concomitant with the collection of the sediment samples, measurements of sea floor and surface temperature and salinity will be taken, the depth recorded and the collection of bottom and surface water samples made, along with any other measurements requested by other groups. All of the data and samples will be made available freely to all other interested parties, as well as being used in the program for this task. The sampling program will be complemented by underwater video footage and 35-mm photography, as needed.

The spatial aspect of the field sampling will be to cover all facies and sub-facies across the study area, from the coast to five kilometres offshore. This limit has been set so as to understand better the nearshore zone that has been impacted by anthropogenic activities; sites from five kilometres offshore to the study boundary, 20 kilometres offshore, are unlikely to add to our understanding of these impacts and responses. Sites will be located after an extensive survey of all pre-existing literature and in consultation with the other groups. Field research and sample collection tasks will be coordinated across all Stage 2 research task programs, as an integral responsibility of sub-task 1 of PPM 2, to maximise task time, effort and budget by doing as much as possible of the fieldwork in a 'piggy-back' mode. This will also allow and encourage the free interchange of ideas between groups.

Sample site location will be determined in consultation with all researchers undertaking coastal waters research in order to co-locate sample sites where appropriate. This will make the resulting data more useful and easier to compare across disciplinary boundaries. The study managers will arrange a meeting to coordinate sample site placement with all relevant study personnel at the completion of initial literature reviews, and within the first three months of Stage 2 tasks commencing.

The temporal aspect of the plan is to collect samples that best portray the likely minimum and maximum variations, that is, mid-summer and mid-winter, along with opportunistic 'catastrophic' events, over a period of two years. Samples should be collected opportunistically in addition to the routine sampling protocol, for example, immediately after a major storm, a spill at sea, information concerning the movement of contaminants on land, and so on. Also, atypical sites shall be sampled as the occasion demands.

The fieldwork is to be complemented by a series of laboratory studies, based on field observations, samples and data collected. This will investigate causal relationships between, on the one hand, shifts in supply and ratios of the grains from the vastly differing sources and, on the other hand, shifts in the ecosystem structure as a result of changes in the various controlling parameters, for example, shifts in the nutrient cycles, loss or gain of seagrass meadows, increased recreational boating activities, increased cliff erosion caused by anthropogenic effects, one-off storms, and so on.

Once the initial samples are obtained, it will be possible to have a number of different laboratory tasks progressing simultaneously. This will enable a continuous flow of data, in order to identify and alert the researchers to any patterns that diverge from either the norm or from anticipated results, given the particular parameters associated with the particular sample.

All laboratory procedures are to be carried out according to well tried and published protocols.

Proposed research activities to understand the sea floor sediment cycle and budget of the Adelaide coastal waters include:

- field study;
- laboratory study—sediment identification (for example, grain size, source, mineralogy, physical parameters);
- laboratory study—geochemical analysis;
- laboratory study—experimental modelling;
- opportunistic field studies, as appropriate;
- photography; and
- facies mapping.

A similar pattern will be repeated during the second year, after review of Year 1 and the making of appropriate revisions. Thus, sites would be allocated to a timetable that spaces out the visits, based on the anticipated data acquisition ranking. It should be noted that these types of studies tend to be expensive, and only limited spatial and temporal coverage is usually possible. Choices will be made after analysis of the Year 1 results and consultation with other researchers investigating associated tasks, in terms of both their results and their needs for shared boat transects, and so on.

Each transect needs samples from the supratidal, intertidal, and shallow subtidal, followed by seaward sampling at five metres, 10 metres, 15 metres, 25 metres, two kilometres and five kilometres, or as appropriate. Advantage should be taken of the opportunity to record physical parameters, particularly temperature, salinity, turbidity, depth and nutrient level. Water samples will also be collected at both the sea floor and sea surface at every site.

Project management and reporting

See above under *Data management*, *Task outcomes* and *Task outputs*. There will be frequent interaction with the overall project manager.

Quality assurance and control

See above under *Data management*, *Task outcomes* and *Task outputs*.

Also, all laboratory and field procedures will be carried out according to well tried and published protocols.

PPM 2—Physical processes and modelling

Physical-ecological studies in the Adelaide coastal waters using high resolution modelling, field observations and satellite techniques

Task description

This task will require field surveys, and the application of hydrodynamic and sediment transport models to the Adelaide coastal waters. It will be necessary to examine water column properties in the study area under a range of forcing conditions (for example, tides, waves, air–sea fluxes, freshwater discharges) that reflect the effects of seasonal variability in the study region. There are three main components of this study:

- development of hydrodynamic models to determine: water movement patterns; pathways of freshwater, nutrients, and suspended particulate matter under historical and current discharge scenarios; and flushing and exchange characteristics of the study region, including nearshore processes;
- measurement of water column properties, including stratification, in the study area—under a range of forcing conditions, such as tides, waves, air–sea fluxes and freshwater discharges that reflect the effects of seasonal variability in the study region—to provide calibration and validation data to the hydrodynamic models; and
- collection of Sea-viewing Wide Field-of-view Sensor (SeaWiFS) satellite data time series, to identify seasonal dynamics of suspended matter in relation to key benthic features in the study area (as a function of oceanographic, meteorological and land-based discharge regimes) and to provide independent verification for model simulations of zones of land-based impact.

There are several sub-tasks required to implement this research task.

Sub-task 1

This sub-task is the collection of field data in different seasons of a year for analyses of the distribution and seasonal variability of water mass properties in the study area and for validation and verification of the numerical model. This includes analyses of seasonal cycles of air–sea fluxes of heat, salt and freshwater; wind-stress patterns; and wave conditions. Coverage and monitoring of extreme events, such as transient stormwater intrusions, are also included.

Sub-task 2

This sub-task is the application of a numerical model to the Adelaide metropolitan coastal strip, to predict dispersion patterns of freshwater, nutrients and suspended particulate matter. The numerical model will use realistic initial and forcing conditions, provided by sub-task 1, to simulate seasonal variations of hydrodynamics and dispersion patterns, including flushing and exchange

characteristics in the study region. This will include analysis of effects arising from historical, present and future discharge scenarios of freshwater, nutrients and sediment inputs.

Sub-task 3

This sub-task is the application of a time series of high spatial and temporal resolution SeaWiFS satellite data, for the period 1997–2003, and Moderate-Resolution Imaging Spectroradiometer (MODIS) data from the *Terra* satellite, post-2003, to delineate seasonal variability of suspended matter in the study region due to the present land-based discharge regime. This will be complemented by numerical modelling and field measurements to identify critical periods when Adelaide coastal waters are subjected to increased levels of productivity (principally chlorophyll a).

Sub-task 4

This sub-task is the determination of the influences of the nearshore region on coastal hydrodynamics, and the implications for the study's modelling and monitoring requirements. This will include application of a wave refraction model, in consultation with the OCM.

Task objectives

The objectives of the task PPM 2 are to:

- define water circulation, flushing and exchange characteristics along Adelaide's coastal strip, their seasonal variability and their impact on the dispersion of nutrients, suspended matter and other pollutants;
- understand sediment movement (from its sources) and re-suspension processes along the coastal strip, and their impact on seagrass distributions;
- understand seasonal variability of suspended matter in relation to key benthic features, as a function of land-based discharge, oceanographic and meteorological factors; and
- examine the effects of historical, present and future patterns of discharges of freshwater and nutrients, and of sediment transport, on changes in seagrass and in suspended matter distribution.

Issues to be addressed

Issues to be addressed by the research task include the following from the Stakeholders Requirements Report.

3.2.1 Nutrients (in sediments and water column)

3.2.1.1 What is the fate of nutrients (nitrogen and phosphorus) and what are their respective impacts on the receiving marine environment and ecosystem functions?

3.2.1.2 What are the relative contributions of all contaminant inputs to the system and how do these compare to the impacts of WWTP sourced nutrients in terms of significance of effects?

3.2.1.3 How does stormwater's contribution to nutrients in the Gulf compare in significance to discharges from the wastewater treatment plants? Is nitrogen the only nutrient input of concern?

3.2.1.4 The EIPs for the coastal WWTPs are designed to result in the target reduction of nitrogen in discharge waters from 30 mg/l to 10 mg/l. What impact will this have on the seagrasses?

3.2.3 Ecotoxicology

3.2.3.2 Is it pollution load or concentration that is important in water quality management?

3.2.4 Salinity—dispersion and interactions/impacts modelling

3.2.4.1 What is the impact of low salinity levels on seagrass communities (and different species within communities)?

3.2.4.2 What is the cumulative impact of the low salinity and high turbidity discharges from the various coastal stormwater outlets on seagrass health?

3.2.4.3 What are the interactions with the larger body of water in the Gulf St Vincent and do these have any effects on the coastal waters?

3.2.5 Seagrass dynamics/ecology

3.2.5.1 Why have we lost, and why do we continue to lose, nearshore seagrass?

3.2.5.2 Is seagrass loss due to freshwater inputs, nutrients, increased turbidity, other pollutants, other effects including coastal processes or a combination of all of the above?

3.2.5.3 Are seagrasses sensitive to salinity changes—what is the tolerance range of Adelaide seagrass species?

3.2.5.4 Is the relatively recent trend to discharge freshwater directly to the Adelaide coastline causing significant disturbances to inshore seagrass?

3.2.5.7 Is seagrass loss progressive or episodic (for example, driven by storm events or high stormwater discharge)?

3.2.5.13 Does the time of year when discharges occur make an important difference to their effects on the marine environment(s)—for example, is it sustainable to discharge in winter but not during summer algal growth periods?

3.2.6 Algal blooms

3.2.6.5 Are there any factors other than or in addition to nutrient enrichment contributing to algal blooms (for example, temperature, salinity and/or turbidity)?

3.2.7 Water quality—objectives/standards, assimilative capacity and maximum contaminant loads

3.2.7.4 What are the relative impacts of the different outfalls along the coast in terms of assimilative capacity? Are discharges in deeper fast flowing water less detrimental than those in shallow slow moving water? Is relocating discharges from Port Adelaide River to Bolivar a good idea?

3.2.7.7 How significant are the effects of turbid water discharge plumes on coastal biota (seagrass, macroalgae)?

3.2.10 Coastal processes and sediments

3.2.10.1 What is the effect of large-scale sand dredging in terms of re-mobilisation and denitrification processes?

3.2.10.2 Are there any suitable areas for the dumping of dredge spoil within the study area?

3.2.11 Marine habitats—status of reefs, estuary, inlets, wetlands, mangroves

3.2.11.2 What will be the likely cumulative impact of the current and proposed power generating plants along the Port Adelaide River? Is there likely to be incremental increase in ambient Port Adelaide River temperatures and, if so, what effects will this have on algal dynamics and survival of other marine organisms (including undesirable introduced marine pests)?

Rationale

The main focus of the Adelaide Coastal Waters Study is the coastal strip between Point Gawler and Sellicks Beach (Figure 8). It is recognised that this narrow coastal strip is under considerable stress due to human activity. Particular concerns include the addition of nutrients, through freshwater inputs from river systems where the catchments have been cleared and currently used for farming, and through wastewater and stormwater discharges. The main aim of the ACWS is to determine the transport and fate of these nutrients and other pollutants and the impact on coastal ecosystems.

Field data and numerical simulations are required to provide essential information on hydrodynamics and sediment movement, so as to understand the hydrodynamic response within the coastal strip to current and historical discharges. Understanding of seasonal variations is deemed essential in the context of this study. A number of tools will be used during this task, in addition to field and numerical studies. These include SeaWiFS satellite data that will provide a regular source of information on chlorophyll a levels, indicative of phytoplankton response to land-based stormwater and effluent discharges, under varying oceanographic and meteorologic conditions.

Detailed understanding of the physical processes within the study region (air–sea exchange, flushing, nutrient dispersion and sediment transport) at a high spatial resolution is required to answer the questions raised by the stakeholders. Without the fundamental tasks such as modelling and field measurements, information on the hydrodynamics, sediment movement and ecosystem response would remain uncertain, and few of the stakeholders' questions could be answered.

It is important to note that the proposed task goes beyond previous modelling studies (for example, DA Lord & Associates et al., 1995), as it considers seasonal forcing and initial conditions. It is deemed essential that model simulations are fully three-dimensional. This is necessary for them to be able to simulate both potential summertime thermal stratification events and the dynamics of the buoyancy-driven flows that appear to dominate circulation patterns during wintertime and that can also occur in summer. Another reason is so that they are able to define vertical structure of the currents in order to enable realistic simulation of sediment dynamics, both as suspended load and bed-load.

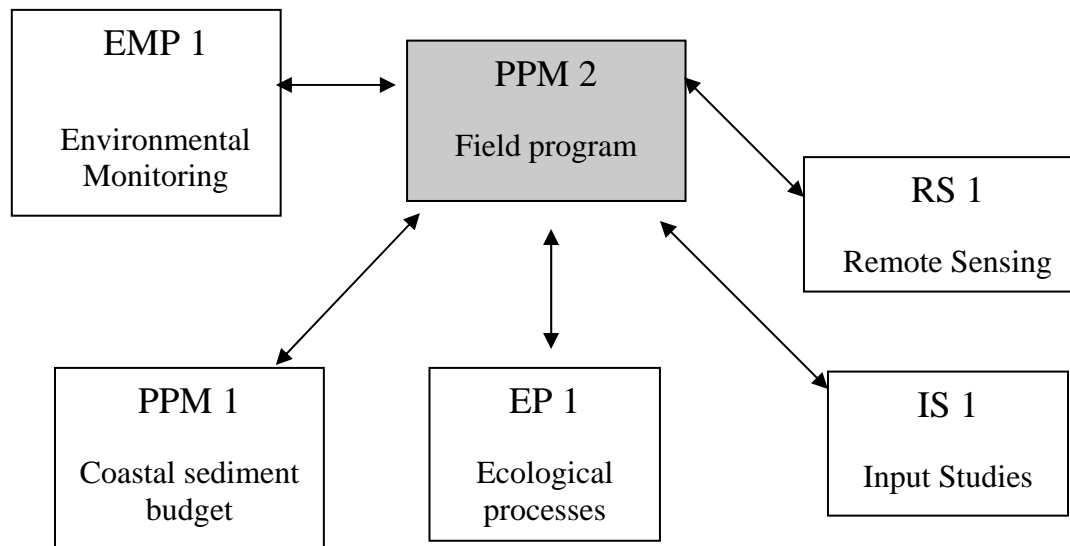
Linkages and dependencies

Task PPM 2 can be considered to be one of the primary tasks of the ACWS. It will require close collaboration with and by almost all participants in the study. The task will depend and rely on the results obtained in the majority of the tasks. Similarly, many of the other tasks will depend on the results of PPM 2.

Some field data exist which could be used in model validation and verification; however, these data are far from being comprehensive. Therefore, it is essential to conduct new field observations along Adelaide's metropolitan coast that cover different seasons of the year and extended spatial limits in order to establish an integrated link between numerical modelling, remote sensing and historic field surveys. Measurement sites will be chosen to satisfy model domain constraints and to aid in interpretation of biological measurements conducted by tasks such as EP 1.

Linkages: field studies

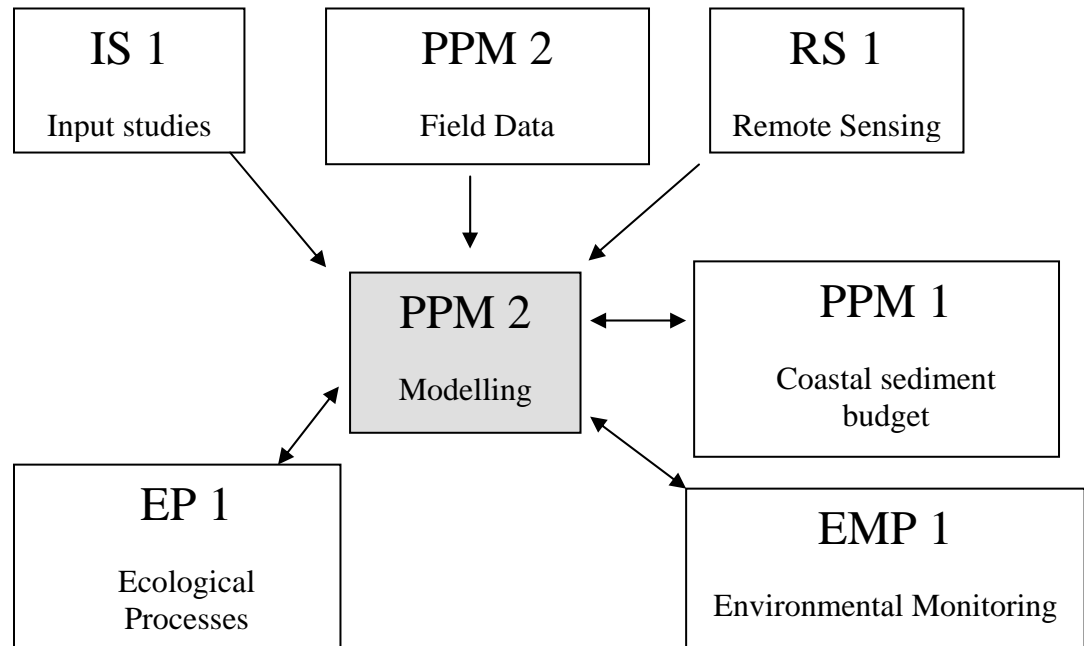
The links between the PPM 2 field program tasks and other field components of the ACWS are summarised below, and show that the field program of PPM 2 is a key link between all field components of the ACWS. This is also reflected in other similar studies such as the Perth Coastal Waters Study and the Port Phillip Bay Study.



- The field program of PPM 2 will collect more than 50 per cent of the sediment data required for PPM 2. To this end, the field program of PPM 2 will concentrate on the nearshore zone (within five kilometres of the shore), but offshore measurements are also deemed important to provide information about far-field influences on local hydrodynamic processes.
- Transects will be coordinated with research sites proposed by EP 1, and two current meter moorings will be deployed in the close vicinity of the key sites of EP 1, to provide a three-dimensional study of oceanographic parameters as well as high resolution time series of currents and turbidity. This data will aid the interpretation of point measurements undertaken by EP 1.
- Transects will be also coordinated with IS 1 by adjusting them to the locations of major rivers (Port Adelaide River, Torrens River, Onkaparinga River) and by undertaking a special field program in the nearshore zone for the estimation of groundwater influence.
- Furthermore, a special field program will explore the details of major freshwater intrusions in the course of strong and persistent rainfall. This field program will also be closely coordinated with IS 1.
- Field data will be provided for RS 1 for verification/calibration of remotely sensed data. This is essential.
- PPM 2 will provide a comprehensive database at high spatial and temporal resolution for consideration by EMP 1.
- Field data will be used to initiate and verify model simulations.

Linkages: numerical modelling

The numerical modelling activities of PPM 2 require significant input from other tasks, such as river inflow rates and sediment characteristics, to be able to make quasi-realistic forecasts. Also, selection of model scenarios needs to be developed closely with other groups, in particular PPM 1 and RS 1, and interpretation of the model results will be undertaken in conjunction with EP 1



- The modelling tasks require input from all of the field programs. Data required for model forcing and validation will be provided through projects IS 1 (for example, historical and current flow rates of freshwater, nutrients and particulate matter), PPM 2 field components (for example, tides, winds, stratification) and RS 1. RS 1 will also provide remote sensing data of plume dispersion and the like, which will be used to validate the hydrodynamic model.
- The model will aid data interpretation within EP 1 in terms of sediment dynamics (validation and verification from PPM 1 are required). In turn, PPM 1 will provide information about sediment characteristics (for example, grain size) essential for the sediment transport modelling, while the output of the model will contribute to the development of a sediment budget for the region.
- The interaction between EP 1 and PPM 2 modelling tasks is crucial. As the project will not develop a coupled hydrodynamic-ecological model, the project will depend on the analysis of the numerical model output and subsequent inferences about ecological responses. Here, findings of EP 1 on ecological function will be used to infer the impacts of freshwater and nutrients. For example, if EP 1 finds that lower salinity has a major impact on the health of seagrasses, the numerical model can be used to predict the regions of lower salinity (due mainly to the influence of freshwater) under historical flow

regimes in order to examine whether there is a correlation between regions of freshwater influence and seagrass loss.

- The numerical modelling results will lead to the development of an environmental management and monitoring program.

Current status

The tidal currents along the Adelaide metropolitan coast generally flow parallel to the shoreline and are dominated by tidal action. The net tidal residual flow is from north to south. However, this net movement can be reversed during periods of high winds. A shear zone appears to develop near the shore (up to approximately one kilometre offshore), immediately prior to the turning of the tide from ebb to flood and from flood to ebb. During the transition from flooding to ebbing tide (at high water), the water near the shore begins to flow southward while, offshore a northward flow continues to prevail. Similarly, during the transition from ebbing to flooding tides (at low water), the currents near the shore flow northward while the offshore current remains southward. A numerical model of the region, at 50-metre resolution, has been applied to the study region to examine the impact of the modifications to the Patawalonga entrance (DA Lord & Associates et al., 1995). The model was applied to investigate the paths, destination and dilution characteristics of flow from point source discharges, under the three different scenarios. The point source discharges that were modelled included the Patawalonga (four different locations), Glenelg WWTP (two different locations), River Torrens, Field River, and stormwater drains and small rivers.

Over the period of urbanisation in the Adelaide region, the added effects of numerous land-based discharges, through rivers, creeks and treated effluent discharges have resulted in a general lowering of the salinity adjacent to the Adelaide metropolitan waters. Bullock (1973) noted a lens of low salinity waters (37.4) adjacent to the Adelaide metropolitan region, although a higher salinity should have resulted from regional dynamics (de Silva Samarasinghe & Lennon, 1986; Bye, 1976). Recent field studies (Kämpf, personal communication) identified a low salinity plume (37.0) and significantly increased turbidity levels (more than one Nephelometric Turbidity Unit) along the coast, as a result of relatively high freshwater runoff from land during the month prior to observations. Outcomes from task IS 1 will be an important input to sub-tasks 2, 3 and 4.

On a shorter timescale, the influence of stormwater has been noted in studies conducted in the southern region of the Adelaide coastal waters. (FIAMS, 1979). Post-storm effects produced low salinity fronts that persisted up to several days. Such events, occurring in water temperatures of about 15°C, were noted to be associated with excessive algal growth.

An increase in the number of algal blooms has been noted in South Australian waters, including the Adelaide metropolitan coastline, Barker Inlet and the Port Adelaide River. Several causes have been suggested for this apparent increase. These include the introduction of harmful algal species through the discharge of ballast water from visiting ships, the impact of urbanisation (particularly treated effluent and stormwater discharges) and, possibly, global scale processes such as the El Niño Southern Oscillation.

A unique tidal regime occurs due to near equivalence of major semi-diurnal (M2, S2) components. When the semi-diurnal components are in opposition, the variation in elevation is due mainly to the diurnal (O1, K1) constituents. The end result of

these features is that, at intervals of 14.8 days, local neap tides can be of an unusually small range. During such periods, and in the absence of strong wind conditions, pronounced stratification may occur with consequent bottom currents evident. These occasions are crucial features that influence the basic three-dimensional circulation of the nearshore zone. Thermal stratification of up to 4°C in the upper two-metre layer has been reported (Petrusevics, 1986).

The combination of anomalous tidal conditions, absence of winds and heat input to the sea in the summer, together with stormwater discharge of sediments and nutrients into the Adelaide coastal waters, presents favourable conditions to promote stratification and subsequent algal growth. Analysis of concurrence of these conditions will be conducted, similar to that reported by Ranasinghe & Pattiaratchi (1999).

Since the recommendations of the ACWS Scoping Report almost four years ago, changes in technology now offer opportunities to examine, on a regular basis, the colour properties of the water column and associated successions in suspended matter and phytoplankton, using satellite data derived from the existing SeaWiFS mission and the MODIS mission in the future.

Oceanographic research in South Australia has benefited from such advances. For example, extensive use has been made of data from the National Oceanic and Atmospheric Administration satellite NOAA-9 relating to the upwelling phenomena adjacent to the Bonney Coast in south-eastern South Australia (Schahinger, 1987; Cai et al., 1990) and for examination of sea surface temperature (SST) frontal structure in the mouth of Spencer Gulf and Gulf St Vincent and gulf-shelf interaction, (Petrusevics, 1984; Petrusevics, 1986c; Petrusevics et al., 1987; Petrusevics, 1993). These studies highlighted the value of Advanced Very High Resolution Radiometer (AVHRR) SST information, in conjunction with field data, as a tool to examine large to medium scale oceanographic processes in SA waters and in providing input to numerical models. Satellite-derived SST and ocean colour maps have recently been employed to examine coastal upwelling dynamics off southern Australia (Kämpf & Fitzpatrick, in preparation; Ward et al., submitted; Matthews et al., submitted).

The advent of the SeaWiFS colour-sensing platform has widened the scope and opportunities for oceanographic-biological coupling in general, including at the Adelaide metropolitan waters scale. The colour properties of Gulf St Vincent and the Adelaide metropolitan waters were examined using SeaWiFS data (Petrusevics & Lennon, 2002). Time series of SeaWiFS suspended matter data were examined at a number of sites in the Adelaide coastal waters and at control sites in the mid-Gulf.

Satellite colour data, including SeaWiFS, together with field surveys, have been successfully applied in many instances to examine broad-scale coastal water quality issues. Recent examples are: Petrusevics & Lennon (2002), in the waters of Gulf St Vincent; Engelsen et al. (2002), in the Barents Sea; Kopelevich et al. (2002), in the Black Sea; Gomes et al. (2000), in the Bay of Bengal; Murphy et al. (2001), in New Zealand; Leonard et al. (2001), in the north Pacific; Lluch-Cota (2002), in the eastern Pacific. These studies have highlighted the value of SeaWiFS data as a means of providing broad-scale patterns of suspended matter in coastal regions.

In a local context, the performance of the SeaWiFS one-kilometre spatial resolution data were examined along the Adelaide metropolitan coastline by Petrusevics & Lennon (2002). Suspended matter levels were measured at a number of sites (within two to three kilometres of the coast) in the Adelaide coastal waters and control sites

in mid-Gulf (about thirty to forty kilometres offshore) using SeaWiFS. All images were subjected to geo-referencing, and all test sites were re-locatable to within the spatial resolution limits of the data (within one pixel). A minimum of 12 months of data were examined for the period 2001–2002. Initial results were as follows.

- Suspended matter levels in the Adelaide metropolitan waters showed a general increase towards the northern portion of the study region. This may indicate the influence of continuous discharge of nutrient-rich waters from the Barker Inlet estuary.
- Sites in the northern portion showed a response to episodic flows from major land based discharges (for example, Torrens River).
- Control sites in Gulf St Vincent showed seasonal variability.

Detailed analysis of SeaWiFS data was also carried out in the upper portion of Gulf St Vincent. Based on SeaWiFS data, the region exhibited periodic increases in suspended matter in middle to late summer (January–February), which persisted until late autumn (April–May). These findings were in agreement with early 1980s reports by the Defence Science Technology Organisation, thus giving support to the recent interpretation of the SeaWiFS observations.

Therefore, application of SeaWiFS data to the ACWS is not an untried technology. It has been examined, and found suitable in application, in the Adelaide metropolitan waters nearshore zone (2–3 km) and at the limits of the ACWS study region (20–30 km offshore). It is a cost-effective tool to identify spatial variability of suspended matter at a scale adequate in relation to key marine benthic features (such as those to be provided by RS 1 CASI surveys). It can identify broad-scale regions of impact due to continuous discharges (such as nutrients from Barker Inlet) and detect broad-scale changes in suspended matter in the nearshore zone due to major episodic stormwater discharges (information to be provided by IS 1). In addition, the SeaWiFS database (1997–2003) provides a tool to identify seasonal characteristics of all these features over a period of at least six sequential annual cycles.

During the course of the sub-task 3 study, the use of satellite data provided by the MODIS mission will be introduced. Although possessing the same spatial attributes, that is, a spatial resolution of 1 km, the MODIS program has been designed with more application to the coastal zone. Algorithms developed for MODIS are designed to yield more accurate measurements of chlorophyll in shallower waters. The use of this method is seen as a cost-effective tool for monitoring of the Adelaide coastal waters in the post-ACWS phase.

Implementation of the MODIS component of sub-task 3 will be carried out in consultation with Dr Arnold Dekker, CSIRO Land and Water, and Prof Merv Lynch, Curtin University, Western Australia.

Resources available

As the result of previous investigations, and continuing data collection by the Bureau of Meteorology and the National Tidal Facility, the majority of the data required for this task are available as listed below.

Data type	Location (s)	Agency/host
Bathymetry	Coastal strip 50m resolution digitised from Admiralty map OCM data to 3km offshore	UWA CWR Office of Coast and Marine
Water Levels	Port Stanvac Outer Harbour Patawalonga Entrance	NTF NTF CWR – 1 month Sep/Oct 1995
Meteorological data	Port Stanvac Adelaide Airport 40 years data from Adelaide Airport Outer Harbour (5 min data)	NTF Bureau of Meteorology OCM Ports Corp
Moored current measurements	Off Glenelg Glenelg WWTP discharge	CWR – 1 month Sep/Oct 1995 Flinders Univ/CWR
Salinity/Temp	Offshore Patawalonga	CWR
Salinity/Temp/ Nutrients/Chlor- a/Turbidity/Currents/Dissolved Oxygen	Transects along coastal strip from Outer Harbour to O'Sullivan Beach	Flinders University
Sediment distribution	Data to 2km offshore Data to 4km offshore (hard copy)	OCM OCM
Wave measurements	Seacliff wave staff	Adelaide University
Nearshore currents	Drogue measurements	OCM
Chlorophyll a	Adelaide metro area	EPA
SeaWiFS chlorophyll a 1997-2002	SA wide	Oceanique Perspectives Oceanique Perspectives
SeaWiFS data processing system		
Seagrass distribution	Coastal region	SARDI

The above data sets, with additional planned field surveys, will provide a sound database which will adequately satisfy the requirements for model calibration and validation.

Information gaps

Oceanography

Apart from tidal sea level variations, there is very little known about the circulation of Adelaide metropolitan waters. In particular, the responses to short-lived stormwater intrusions or synoptic weather events are largely unknown. Some historical data exist, but gaps in time and space mean they are far from being sufficient to undertake sound modelling studies. As far as we are aware modelling studies and/or field experiments that focus on sediment cycling and movement have not been undertaken so far. Hence, field surveys at a high spatial and temporal resolution are clearly required, and those field data will form an essential part of the ACWS.

Flows from the river systems and stormwater drains within the study area are extremely variable, and for long periods during the summer months the flows are negligible. The majority of the land adjoining the study area is heavily urbanised, and most of the flows are directed through artificial drainage channels or along rivers regulated by weirs and/or reservoirs. The important thing to note here is that the majority of the stormwater drains and rivers discharge directly onto the sandy beach and then flow into the ocean. Through this type of discharge, the freshwater (with associated pollutants) is trapped in the narrow, wave-dominated surf zone that is usually separated from the offshore waters by the presence of an offshore bar.

The discharges will be diluted through mixing within the surf zone and transported by the wave-induced longshore current. In periods of high waves, the longshore currents would be able to overcome the effects of the tide. Hence, the wave-induced currents (longshore and cross-shore currents) have a dominating influence on the dispersion of the freshwater discharges into the study region. It is therefore imperative that this process is fully considered in any numerical model developed for the region; the numerical model for the region must have the capability of generating longshore and cross-shore currents. Unfortunately, this is an area where very little work has been undertaken and published in the scientific literature. The prediction of wave-induced currents, in addition to tide- wind- and density-induced currents is a major undertaking, requiring considerable model development and validation.

SeaWiFS data

Adelaide coastal waters are more complex in composition and in optical properties than deep open ocean waters, and are termed Case 2 waters (IOCCG, 1999). Caution is needed in interpretation of the remotely sensed signal associated with Case 2 coastal waters. The presence of various substances can mask and modify the SeaWiFS signal. Spectrophotometer analysis of water components (phytoplankton, dissolved organic and suspended inorganic matter) will be made to determine the contribution of various substances.

Task outcomes

Outcomes expected from this task include:

- a comprehensive understanding of water mass properties, dynamics, sediment transport and implications for seagrass within the coastal strip along Adelaide's metropolitan coast, in different seasons of the year, under historical, current and future discharge scenarios;
- the ability to simulate, through numerical modelling, the outcomes of various management options in the study area;
- scientifically based assessment of questions raised by the stakeholders;
- a cost-effective method for examining the seasonal dynamics of suspended matter within the Adelaide metropolitan waters;
- improved understanding of physical links between development of algal blooms and water column stratification events; and
- understanding of the spatial and temporal distribution of suspended matter in the Adelaide nearshore zone, in relation to regions of key benthic features.

Anticipated outputs

- Model software (ASCII Fortran codes) of all numerical models employed/developed in this study, to be freely available for scientific research in the future.
- Predictive models for waves, and for circulation and transport of dissolved and particulate constituents, for the study region.

- A sediment transport model for the study region that includes sediment re-suspension, deposition and transport.
- High resolution spatial maps showing temperature, salinity (including stratification events), currents and sediment distributions in different seasons of the year.
- Maps showing the dispersion of locally introduced pollution sources (hypothetical or real) at a high spatial resolution.
- Progress and final reports of work undertaken.
- Scientific publications focusing on different aspects of this research task.
- Extensive and detailed analysis of seasonal dynamics (including distribution in relation to key benthic features) of suspended matter along Adelaide coastal waters, as a function of land-based freshwater discharge and local oceanographic and meteorologic regime.
- Application of an established and proven system for acquisition, processing and analysis of remotely sensed data suitable for water quality assessment of the Adelaide coastal waters.

Data management

Proponents of this task are required to assist the task managers to provide the client with a database in GIS Arcview or ArcInfo format containing all new data collected for the study.

The database shall come complete with metadata down to the Page 0 and Page 1 ANZLIC levels. Data and metadata are to be provided in MS Access format in line with the ANZLIC Metadata Page 0 and Page 1 levels. Metadata complying with these standards is to be provided to the task managers for each data set developed in the course of PPM 2.

Data provided by task proponents shall be in a format that requires minimal editing for compatibility with the EPA's Environmental Data Management System. Guidelines for database formatting will be provided to all proponents by the task managers at the commencement of the study and must be consistently applied.

Methodology

Field measurements

In view of the short task duration of two years, the proposed program focuses on the use of established techniques and methods.

The field program (sub-task 1) has been designed in close coordination with the model requirements of sub-tasks 2 and 4. The design of the field program is sub-task-specific; however, the field program is sufficiently flexible to allow for 'opportunistic' field surveys in response to extreme events whose short-term and longer term effects are deemed to play a crucial role in seagrass loss in Adelaide's coastal waters.

While the data from the field program is aimed at meeting the requirements of various sub-tasks of PPM 2, it should be noted that routine acquisition of water samples may be made on behalf of other research groups at selected oceanographic stations.

The proposed field program (see Figure 8) will provide high resolution (in both time and space) data for initialisation and verification of hydrodynamic model simulations. This field program has four major components.

- 1 Spatial surveys using a Flinders University of South Australia research launch (*R/L Hero*), for four seasons during the period 2003–2004, to address the seasonal variability of water properties. Additional field surveys will be undertaken in response to extreme rainfall events. Here, high spatial resolution surveys will be undertaken in the vicinity of major freshwater discharge locations to determine the spatial extent of the plumes. For spatial surveys, the state-of-the-art direct reading vertical profiling instrument RCM-9 (from Aanderaa Instruments, Norway) will be used. This instrument provides high resolution data on current speed and direction, temperature, salinity, pressure, dissolved oxygen and turbidity. A boat-mounted shallow-water Acoustic Doppler Current Profiler (ADCP) will complement these measurements. Data collection will also include water sampling at selected sites, including standard biogeochemical analysis for the determination of chlorophyll a and nutrient (nitrate, nitrite and phosphate) distributions. Field measurements of chlorophyll a distributions will be verified against remotely sensed data (SeaWiFS).
- 2 Longer term moorings within study region for model calibration and validation. Aanderaa RCM-9 instruments will be deployed at locations aligned with field sites of EP 1. The instruments will provide time series of current speed and direction, temperature, salinity and turbidity. Moorings will be deployed over two five-week periods: one in winter and one in summer. Time series of water level measurements at each of the model boundaries will also be undertaken to provide boundary conditions for the numerical model.
3. Nearshore measurements will examine the nearshore wave and current structure as well as sediment re-suspension during summer and winter. Here, a series of surf zone releases of small, compact, low cost GPS drifters are planned, to examine the spatial structure of the surf zone–nearshore flow field, and for determination of diffusion coefficients for the transport of tracers (for example, salinity, temperature, suspended matter). A Nortek vector current meter capable of measuring three-dimensional velocity components at a single point, together with an optical backscatter sensor, will be deployed to measure sediment re-suspension rates. This will provide data for the calibration of the sediment re-suspension module. A Nortek Aquadopp current profiler will also be deployed—this will provide data on the vertical structure of both currents and suspended sediment concentration (through analysis of the backscatter signal). Both of the above instruments are capable of providing directional wave information.

Flinders University will provide all instruments and infrastructure to implement the above task. Additional field equipment, for the nearshore program (see 3 above), will be provided by the University of Western Australia. Field data, once processed, will be immediately made available to other research groups within the ACWS through the internet.

Numerical modelling

The development of a predictive capability for the transport and dispersion of freshwater, nutrients and suspended sediment from discharges to the Adelaide coastal waters, and their impact on key ecological processes, in particular, the health of seagrasses, is the major aim of the present study. In order to achieve this aim, we propose to apply a three-dimensional hydrodynamic model with the following characteristics:

- responsive to forcing from tides (including low frequency fluctuations), wind-stress, air–sea fluxes and point source discharges;
- able to describe pathways of freshwater, nutrients and suspended particulate matter;
- able to consider mixing of freshwater, nutrients and suspended particulate matter across the surf zone;
- able to model sediment transport processes due to the combined action of waves and currents and, in particular, sediment movement from its source and re-suspension processes; and
- fully three-dimensional, to be able to simulate stratification events and buoyancy-driven flows.

The three-dimensional hydrodynamic model, ELCOM, developed by the Centre for Water Research, will be applied to the study region between Port Gawler and Sellicks Beach. The model will have high resolution grid sizes and several vertical layers and will be forced using tides, winds, air–sea fluxes and point source discharges. The model will incorporate the effect of surface gravity waves, to simulate sediment re-suspension and transport through wave–current interaction. The model will be validated using measurements of sea level elevation, currents and conductivity-temperature-depth (CTD) transects (focused on discharge from land-based sources). Comparison of model outputs will be made with field surveys made in sub-task 1.

ELCOM has been used extensively in coastal and estuarine studies both in Australia and overseas and has all of the features required, except for the inclusion of the effects of surface gravity waves, and also incorporates all of the forcing and validation data. The inclusion of surface gravity waves in the model will form a developmental aspect of this project.

ELCOM is a three-dimensional, baroclinic, hydrostatic, hydrodynamic model. The model simulates advection and diffusion of momentum, salinity, temperature and tracers (for example, suspended particulate matter), as well as surface thermodynamics (Hodges, 2000). The hydrodynamic algorithms are based on the Euler-Lagrange method for advection of momentum with a conjugate-gradient solution for the free surface height (Casulli & Cheng, 1992). Passive and active scalars (that is, tracers, salinity and temperature) are advected using a conservative ‘ultimate quickest discretisation’ (Leonard, 1991). ELCOM and its validation are described in detail by Hodges et al. (2000) and hydrodynamic runs on the Swan River under flood conditions are described by Hamilton (2000).

The wave propagation model SWAN (Simulating WAVes Nearshore) will be applied to simulate the generation of local seas and also the propagation of seas and

swell from the Southern Ocean into the Gulf St Vincent and onto the Adelaide coast. The model will take into account wind generation of waves, wave–current interaction (with input from the hydrodynamic model), shoaling, refraction, seabed interaction (dissipation by bottom friction) and depth-induced breaking, and also non-linear interactions (quadruplets and triads).

This model will also be able to predict near-bottom fluid velocities and shear stresses, and hence provide valuable input into the calculation of sediment suspension and transport rates. This information will provide a link to PPM 1, in which the movement of sediment in the study area will be investigated.

Model forcing and validation data

The following data sets will be used for model forcing and validation:

- meteorological data (wind speed and direction, barometric pressure, wet/dry temperature, solar radiation) from coastal stations;
- tidal data from coastal stations;
- time series of Eulerian current measurements (both single point and profile data using ADCPs), for at least five weeks during each of the summer and winter, at several locations within the study region;
- seasonal CTD measurements from the study region;
- high spatial resolution CTD measurements of plume dispersion patterns from opportunistic surveys during high rainfall events;
- time series data of turbidity and light data in the vicinity of seagrass beds close to major discharge locations;
- directional wave data to validate numerical model of waves for sub-task 4 (may be undertaken in conjunction with current measurements);
- CTD (including turbidity), chlorophyll a and nutrient data from the study region at different seasons, as well as during episodic events;
- data from Lagrangian drifters deployed in the nearshore zone;
- process experiments to validate mixing across the surf zone (concurrent measurements of waves, currents, CTD and drifter data) in the nearshore zone;
- process experiments to validate sediment transport and re-suspension (concurrent measurements of waves, currents and sediment re-suspension) in the nearshore zone; and
- remotely sensed data (SeaWiFS, CASI, aerial photographs, and so on).

SeaWiFS satellite data

Broad-scale seasonal variations in suspended matter concentration in the euphotic zone in an alongshore transect between Port Gawler and Sellicks Beach will be analysed to derive seasonal alongshore gradients of suspended matter and to identify regions of elevated suspended matter within the study region. Suspended matter concentrations will be extracted from geometrically co-registered SeaWiFS image files using NASA-supplied software (SeaDAS), custom developed for SeaWiFS data processing and analysis.

1. Time series of suspended matter concentration, at a number of sites in the Adelaide coastal waters, will be produced. Sites will be chosen for proximity to major land-based discharges such as the Barker Inlet, Torrens River, Barcoo Outlet, Onkaparinga Creek and other prominent discharges. Selection will be made on the basis of field survey of land-based discharges along the Adelaide metropolitan coast and in consultation with the team carrying out Task IS 1.
2. Analysis of time series of flow rates of major land-based discharges and the SeaWiFS suspended matter concentrations will be conducted, to identify regions of impact of stormwater discharge. This will also provide validation checks for numerical models designed to show dispersion of land-based discharge (sub-tasks 2 and 4 of PPM 2). Time series of observed flow rates are available from a number of stations in the Torrens River and in the Patawalonga system. The Torrens and Patawalonga CWMB and the Onkaparinga CWMB are the relevant authorities from which the data are available.
3. Control sites in northern and southern regions of Gulf St Vincent will be established to provide seasonal (non-anthropogenic) background levels of suspended matter concentration.
4. Ground-truthing of the SeaWiFS signal will be made with chlorophyll a measurements taken by the field program group of PPM 2 and the EPA metropolitan jetty monthly water quality monitoring program. Chlorophyll a data are available from measurements at the Port Noarlunga, Brighton, Glenelg, Henley Beach, Grange, Semaphore and Largs Bay jetties.
5. Changes in suspended matter and distribution observed by SeaWiFS will be examined, to identify links between stratification and nutrient loading.
6. Field measurements will be conducted using a submersible high spectral resolution absorption spectrophotometer (wavelength range 412–730 nanometres) in the Adelaide coastal waters, in conjunction with the Australian Water Quality Centre, to determine the contribution to the SeaWiFS signal of chlorophyll a, inorganic suspended particulate matter and dissolved organic matter. Measurements will be carried out during both summer and winter. The suspended matter data will be verified by outcomes of the resolution spatial airborne surveys produced by Task RS 1.

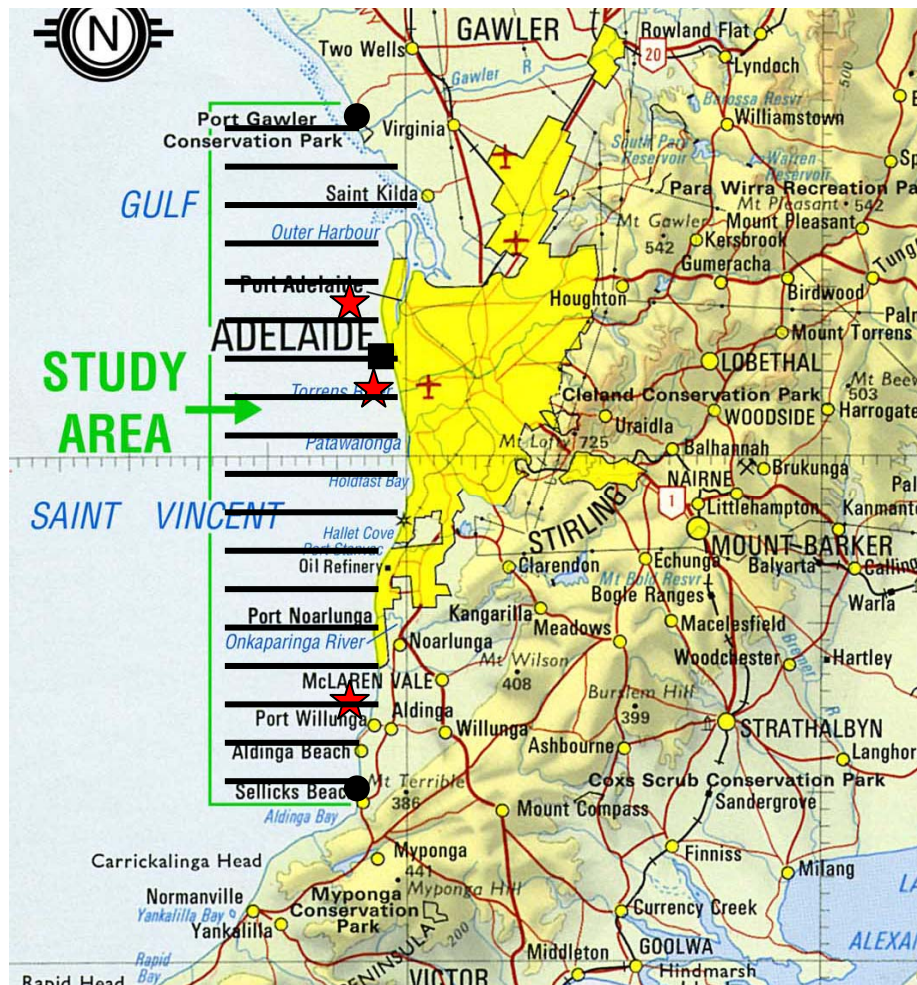


Figure 8. Station map showing transects (solid, black lines) focused on discharge from land based sources of ~10 field stations each, giving a relatively high spatial data resolution of about 7 km alongshore and 2 km normal to the shore. At each station we will take a vertical profile of parameters relevant to the ACWS at a vertical resolution of 1 metre. This data collection (~200 field stations) will be repeated in four subsequent seasons of the year. Red stars indicate locations of bottom moorings. The exact coordinates of moorings will be coordinated with EP 1. Black filled circles indicate tide gage locations and the black square, the location of nearshore measurements.

Field program

Time schedule and milestones of the field program

Timing	Activity
Jan 2003	One-day spatial field survey on <i>R/L Hero</i> , to collect temperature and salinity data for a quick initialisation of the hydrodynamic model. Literature review and acquisition of historical data.
Jan 2003 – Jan 2004	Profiles and water samples taken at selected jetties on a weekly basis. Quantification of surf zone characteristics. ‘Spontaneous’ field surveys (seven days) aboard <i>R/L Hero</i> , in response to strong rainfall events.
March 2003	Summer/Autumn Cruise on <i>R/L Hero</i> (8 days). 1 st deployment of bottom moorings.
April–May 2003	Data analysis. Preparation of database of field data.
Milestones May 2003	Cruise report #1 including preliminary results.
June 2003	Autumn/winter Cruise on <i>R/L Hero</i> (eight days). Retrieval of moorings.
July–Aug 2003	Data analysis. Preparation of data for model verification. Processing of mooring data.

Milestones Aug 2003	Cruise report #2 including preliminary results.
Sept 2003	Winter/spring Cruise on <i>R/L Hero</i> (eight days). Second deployment of moorings.
Oct–Nov 2003	Data analysis. Preparation of field database for model verification.
Milestones Nov 2003	Cruise report #3 including preliminary results.
Dec 2003	Spring/summer Cruise on <i>R/L Hero</i> (eight days). Retrieval of moorings.
Jan–Feb 2004	Data analysis. Processing of mooring data.
Milestones March 2004	Cruise report #4 including preliminary results. Cruise report for ‘spontaneous’ field trips. Final report for jetty-based and surf zone sub-programs.
March–June 2004	Comprehensive analysis and discussion of field data.
July–Dec 2004	Preparation of final report and scientific publications.
Milestones Dec 2004	Final report that summarises findings of the field programs, including interpretations. This report will be combined with that of the modelling program.

Hydrodynamic modelling

Time schedule and milestones for the modelling

Timing	Activity
Jan–June 2003	Model initialisation by means of realistic bottom topography and tidal forcing. Literature review and collection of all data available. Model validation. Preparation of forcing fields (air–sea fluxes, river input, wave data, and so on). Until input comes from IS 1, we will be using historical or hypothetical forcing data.
Milestones July 2003	Progress report including details on the numerical modelling and graphs/tables showing air–sea fluxes and river runoff data.
July 2003 – Dec 2004	Three-dimensional hydrodynamic circulation simulations. Verification of numerical findings against field measurements. Refinement of a wave propagation model in conjunction with the OCM (sub-task 4).
Milestones Jan 2004	Progress report showing 2003 simulation results in comparison with field data. This report will include discussions of dispersion patterns from point sources and findings of numerical case studies.
Jan–June 2004	Sediment transport studies. Continuation of circulation studies. Application of a surf zone – wave propagation model. Development of model scenarios in conjunction with other groups, in particular, EP 1.
Milestones July 2004	Progress report showing simulation results of sediment transport processes in the study region in comparison with field data. This report will also discuss circulation studies for the period spring 2003 – summer 2004. Progress report on surf zone modelling.
July–Dec 2004	Completing of modelling tasks. Further case studies on the effect of stormwater intrusions (optional). Preparation of final report and other publications. Web page design and data visualisation.
Milestones Dec 2004	Final report to be combined with that of the field program.

SeaWiFS analysis

Time schedule and milestones for SeaWiFS analysis

Timing	Activity
Jan–June 2003 * *Dates to be adjusted depending on project commencement.	Summer/autumn field studies to establish components of SeaWiFS signal. Absorption spectra measurements of chlorophyll a, organic and inorganic suspended material in Adelaide metropolitan coastal waters. Production of report. Site selection survey, Adelaide metropolitan waters. Production of time series for selected sites and alongshore transect analysis of archived high resolution SeaWiFS data for period 1997–1998. Identify protocols for acquisition of MODIS data and processing software.
Milestone July 2003	Progress report Jan–June 2003, including independent external audit.
July–Dec 2003	Report on spectrophotometer results summer/autumn 2002–2003. SeaWiFS suspended matter data ground-truth validation using results of summer/autumn 2002–2003 spectrophotometer survey and PPM2 – EPA jetty measurements of suspended matter. Time series analysis of archived high-resolution SeaWiFS data 1999–2000 at selected locations (metropolitan and control), and for alongshore transect. Correlation analysis of SeaWiFS data and land-based flow regime for period 1999–2000. Conduct field spectrophotometer survey in winter 2003. Commence stratification model.
Milestone Jan 2004	Progress report July–Dec 2003, including mid-project independent external report.
Jan–June 2004	Time series analysis of archived high resolution SeaWiFS data 2001–2002 at selected locations (metropolitan and control), and for alongshore transect. Correlation analysis of SeaWiFS data and land-based flow regime for period 2001–2002. Conduct field spectrophotometer survey in winter 2004.
Milestone July 2004	Draft final report, including external audit.
July–Dec 2004	Revise and update report, including recommendations for use of satellite methods for future monitoring of Adelaide coastal waters.
Milestone Dec 2004	Final report, including independent audit.

Work plan

Detailed work plans, including proposed milestones, are outlined above. The linkages between this task and other tasks within the ACWS research program are presented pictorially in the Gantt chart presented as Figure 4 in the Final Research Requirements Report.

Task management and reporting

Findings from the numerical simulations will be reported to the CSIRO task managers in the form of six-monthly progress reports. Findings from field surveys will be reported separately in the form of cruise reports.

In addition, a web page will be created and continuously updated so that, in addition to the CSIRO project managers, all members of ACWS study teams and other interested parties can access the website and examine the up-to-date results of the sub-tasks. Frequent emails will be sent to inform managers and participants when the website is updated. In this manner, the project team hope to keep all of the

participants informed of progress as well as accepting comments and the like that can then be used to modify the modelling. It is suggested that the web page be linked to a main ACWS study website.

A detailed final report (hard copy) will be submitted to the CSIRO task managers within six months of the completion of the task. In addition to this, electronic versions (CD-ROMs) of the final report will be provided. ASCII model codes and selected visualisations of simulations will be provided. A web page summarising outcomes of this task will be developed.

Quality control and assurance

The project team regard the above suggested project management and reporting method suitable to assure that the task milestones are achieved. Furthermore, the proposed close communication between the task managers and the CSIRO project managers on a weekly basis implies that the project managers are aware of the progress of this task at any time during this project. It should also be pointed out that the proposed research will be undertaken on the basis of sound scientific principles. Furthermore, the project team will make available all of the field data and the model code to other scientists within the ACWS, to facilitate constructive criticisms and independent expert advice. This is considered to be a highly transparent way of conducting research and an important method in quality control and assurance.

SeaWiFS component

Emeritus Prof. Geof Lennon AO will conduct independent technical review of the scientific and technical merit of sub-task 3 at conceptual, interim and final stages.

EMP 1 Environmental monitoring program

Task description

Continuing monitoring is essential, as our knowledge of the systems associated with the Adelaide coastal waters will never be complete. The system is unlikely to behave as expected or as modelled, so a well designed monitoring program will be developed during this study, not only to track and correct errors but also to increase managers' understanding of the system.

A continuing monitoring program will be endorsed and documented during Stage 3 of the study, and this will contribute greatly to the adaptive management framework the study will initiate. However, the design of this program will be an integral part of the study and of any research tasks from the start.

Task objectives

The objectives of this task are to:

- identify and link with existing environmental monitoring programs and databases;
- assist the project managers, and relevant project personnel, with the integration and synthesis of Task RS 1, and ensure that data to be obtained through the long term environmental monitoring program are amenable to routine analysis by natural resource managers;
- in consultation with stakeholders and ACWS research providers, establish the requirements of a long term environmental monitoring program to monitor key system parameters and values, for implementation throughout and beyond the study;
- identify the parameters to be monitored, the location of monitoring points and the frequency and duration of required monitoring; and
- devise, confirm and document a spatially and temporally explicit environmental monitoring program for the long-term environmental assessment of:
 - 1) The status of the Adelaide Coastal Waters; and
 - 2) Improvement or deterioration in key ecosystem components (that is, trend detection).

Scope of task

The design and documentation of a suitable and workable environmental monitoring program will be treated as an integrated Stage 2 task. From the commencement of Stage 2, the task proponents shall appraise all other monitoring programs under way throughout the study area. These will be identified during literature and data reviews conducted by the ACWS Stage 2 research providers, within the first three months of task activities. The current programs to be appraised are likely to include those undertaken by SA Water, local government councils,

CWMBs, licensed industries, EPA and the OCM. The task proponents shall investigate and report on the relevance of parameters monitored, frequency and duration of sampling and geographical extent of programs.

Details of the current monitoring initiatives will be made available to EMP 1 team members by relevant Stage 2 research providers (for example, those undertaking tasks IS 1, EP 1, RS 1, PPM 1 and PPM 2). From provided information and other sources, an inventory of current monitoring programs, parameters measured and data sets held shall be compiled, made available to all researches undertaking Stage 2 tasks and presented as a study deliverable within the ACWS Environmental Information System.

Appropriate statistical design will be an important consideration in the development of the Environmental Monitoring Program, and attention to this task early in the study will ensure stronger results for the study in the long term.

The task team will consult with all relevant parties (that is, task leaders and stakeholders) on a regular basis, to ensure the development of a comprehensive and cost effective environmental monitoring program. On the basis of priority needs, an integrated EMP shall be designed that integrates current external programs, where these are validated, and those requirements that emerge as a result of scientific investigations during the ACWS.

The recommended and documented environmental monitoring program will encompass the full range of water quality and ecosystem components, parameters and management objectives. The final documented environmental monitoring program must specify what is to be monitored, where such monitoring is to occur, and the frequency and duration of monitoring. The EMP shall also provide indicative methods of data and statistical analysis to a level of sophistication that will allow interpretation by regional natural resource managers.

Data management

Task team members will assist the project managers to provide the Client with a database in GIS Arcview or ArcInfo format containing all new data collected for the study. For this task, this will include but not be limited to the inventory of current monitoring programs, parameters measured, frequency and spatial extent.

The database shall come complete with metadata down to the Page 0 and Page 1 ANZLIC levels. Data and metadata are to be provided in MS Access format in line with the ANZLIC Metadata Page 0 and Page 1 levels. Metadata complying with these standards is to be provided to the project managers for each data set developed in the course of Task EMP 1.

Data provided by the task team will be in a format that requires minimal editing for compatibility with the EPA's Environmental Data Management System.

Guidelines for database formatting will be provided by the project managers at the commencement of the study and will be consistently applied.

Methodology

The ACWS Environmental Monitoring Program to be implemented during Stage 2 will be designed to focus on, and provide information anticipated to be of greatest value to, the tasks, as the specific dynamics, interactions and impacts of the coastal waters and systems are investigated and confirmed. Task leaders undertaking Stage

2 research tasks shall be consulted to determine priority monitoring needs. On the basis of priority needs, an integrated EMP will be designed that integrates current external programs and those activities to be undertaken for the ACWS, on a 'task by task' basis. In this regard, the project team implementing this task have a major coordination role to oversee the immediate monitoring and data collection activities of the various ACWS research tasks.

The various linkages and dependencies of the ACWS are recognised. Good communication between the proponent, the clients and the leaders of other projects in the ACWS will be essential. The project team will therefore hold regular meetings with the above parties and with the CSIRO EPO representative in Adelaide.

The linkages and support for sound experimental designs will enable statistical input at the planning stage of the tasks. The project team will also ensure data quality prior to its incorporation into the study database: this implies statistical input at the analysis stage of those tasks. The benefits of such close collaboration are only to be achieved with significant and continuing effort, which the project team will provide.

The team believes that the development of a monitoring program must be:

- clearly focused on providing management tools;
- collaborative with the other task managers;
- an iterative process.

The project team will not only develop a state-of-the-art monitoring system, but also incorporate cutting edge spatial research. The project team has identified an internally funded research component, the details of which are provided following the methodology section below.

The team will adopt the following approach to the project.

Assessment of needs of other ACWS projects and those of clients

There are numerous parameters that could be usefully measured. It is anticipated that different collaborators will each have their separate emphases. The team is aware that the monitoring must be feasible, especially within the financial constraints, but also fit for purpose. The experience of the team will be an asset in this respect.

The monitoring team has a strong emphasis on 'decision-oriented sampling', so that the expenditure spent on collecting data will provide the greatest benefit to the decision makers.

This phase of the project will identify the monitoring requirements of the clients, and those of current and planned components of the ACWS.

Development of pilot monitoring system

Monitoring will be required to cover any crucial gaps in the existing monitoring system.

The proponent may recommend that any new monitoring be preceded by a pilot system. A pilot monitoring will be required, not only to overcome technical sampling problems, but also to provide crucial initial estimates of the parameters and their variances. Such data are essential inputs for the design of the monitoring program.

Assessment of new data and modification of existing monitoring

New data and new understanding of the Adelaide coastal waters will be generated by the ACWS. The proponent will subject the new data and understanding to quality control. That new knowledge will be used to modify the monitoring system.

The extent of the assessment of the data will be subject to negotiation between the team and the ACWS management.

Refinement of the monitoring system

The refinements of the monitoring system may include identification of redundant measurements (where two components of ACWS are monitoring similar parameters).

The refinement process will also prioritise

- those parameters that should be monitored;
- the location of the monitoring; and
- the frequency of monitoring;

and investigate suitable surrogates that can be monitored (for example, the plastic strip technique developed by Pat Harbison may be a useful predictor of integrated nutrient load).

It is anticipated that the modelling component will give key inputs in to the refining of the EMS. The team will seek to define the expectations and requirements of the South Australian Government and the other organisations, as these needs themselves are refined during Stage 2 of the AWCS. The team will then identify gaps and redundancies, and report these.

In addition to the above, the team will assess whether other forms of improvement are possible. Such forms of improvement could include (but would not be limited to):

- assessment of sampling technique (for example, quadrat size and shape);
- improved choice of parameters measured; and
- incorporation of ancillary information (for example, modelling data, or perhaps a Bayesian approach).

Some measure of redundancy will be required in the monitoring system to enable an assessment of its precision. Initially, the additional data may also be used to locate key monitoring sites. Some of these sites may become redundant during the study. A simple criterion for their requirement is whether those measurements would have

affected the decision-making process or affected the scientific understanding of the ecological system.

The team accepts the need for an integrated monitoring system. The team accepts the need for focused monitoring, especially as this optimises the value of the monitoring for decision making. However, experience has shown that the basic data collected in such a study may be useful in some quite unrelated context.

An adaptive sampling scheme may be required, where initial monitoring, and input from other components of the study (for example, EP 1), lead to the making of adjustments, when and where required. An example would be the location of continuous monitors—these would be placed so that they give the greatest predictive value; the predictive power of a particular location, although it can be modelled, can only be confirmed by spatial monitoring of a range of sites over a broad set of test conditions.

Research component

The need for spatial methods to be used in monitoring design is well known. The team has spatial expertise and experience in Peter Toscas, with his experience in the Moreton Bay study. It also has a recognised world leader in Dr Bill Venables.

CSIRO recently held a series of workshops led by Professor Noel Cressie—a recognised world expert in the field. One of the problems highlighted at the Brisbane workshop is the design of a monitoring system in a river, where the typical assumptions of isotropy are not feasible due to river flow. However, even in a tidal system, there will be isotropy, with generally more flow along the coast than toward the coast. The problem is to adapt the classical theory to the more complex features of the Adelaide coastal waters. The research team will be led by Dr Bill Venables.

Documentation

The team will document its progress in report form, with these reports to be presented to the Adelaide office of the CSIRO EPO. In particular, the reports produced will address the topics indicated in the bullet list below. In addition there will be interim reports that will detail progress on the results.

The recommended and documented environmental monitoring program will encompass:

- the management objectives to be met by the monitoring system;
- the full range of water quality and ecosystem components and parameters that are feasible to measure;
- a subset of those parameters that can be used to achieve the management objectives;
- location and frequency of samples;
- methods of statistical analysis of the data to a level of sophistication that will allow interpretation by regional natural resource managers; and
- indications of how the data can be effectively summarised for communication to diverse stakeholders.

Project management and reporting

Project management

The task leader will establish a steering committee, which will meet regularly with a member of the Adelaide office of the CSIRO project management team.

Project reporting

The project reporting will consist of two components:

- regular meetings with the client and other team leaders; and
- milestone reports.

It is envisaged that there will be written reports delivered to the Adelaide Office of the EPO of CSIRO. The initial report will be within six months of the commencement of this project.

In addition to the regular reports that will ensue from this project, it is anticipated that the monitoring effort, as well as other aspects related to this task, will be recorded in reports from other tasks (for example, from EP 1, the effects of contaminants on seagrasses).

It is standard practice for the environmental statisticians in the team to confirm all advice in emails or other electronic form, so that all appropriate personnel are informed, and so that there is a record of such advice.

Quality assurance and control

Emphasis will be placed on the design of trials and the monitoring system to ensure that the results obtained from those components will answer the appropriate questions. By using appropriate designs, this can be achieved with a minimum number of samples.

Collaboration through the linkages between tasks described above will give one form of quality control for the project. Task team members will check all designs and analyses, and an experienced quality assurance consultant will ensure quality of the project.

A senior CSIRO officer (Allan Adolphson), who is also a qualified quality assurance consultant, will be supervising peer review of all reporting.

A basic input will be the patterns of water movement. These are expected to be available from PPM 1 and PPM 2. Dr Neville Robinson will conduct coordination of this component. Robinson has both engineering and mathematical qualifications and so is eminently suited to the task. The research from this component will be used in the design of the monitoring system.

AMF 1 Development of adaptive management framework

Objective

The objective of this Stage 3 task is the development of an adaptive management framework to integrate research, experimentation, monitoring and management actions.

Rationale

The complete understanding and prediction of the behaviour of complex ecosystems, to the degree necessary to support important, irreversible and expensive management decisions, is not achievable using traditional approaches in a short period of time. Management actions will be carried out based on best available understanding and predictions. Thus, an explicit program is required to continually improve understanding and to adjust the management regime.

Anticipated outputs

The anticipated outputs include an adaptive management plan that describes how the elements above will be integrated, and the method for design, implementation, evaluation and use of management experiments. Decision support tools will provide management with scenario-testing capability, make uncertainty explicit and provide risk assessments for management actions.

Comments

To enable the continual improvement of understanding and management, best existing knowledge must be integrated into the design of management actions with an explicitly investigative framework (a combination of monitoring and explicitly experimental management actions, all designed to critically address uncertainties). This will maximise the acquisition of understanding, through 'learning by doing'.

One obvious possibility is that if significant (80 per cent) reductions in nutrient inputs are planned from the WWTPs, the study should make explicit predictions about the response of the system to that reduction, and monitoring design should take advantage of the resultant large-scale experiment to test those predictions.

Work plan

The process of developing an adaptive management program starts at the outset. All tasks will be charged with contributing to the management framework both their findings and explicit statements of their uncertainties. In particular, all tasks will be charged with developing predictions of the effects of an 80 per cent reduction in nutrient inputs, expected to occur during the life of this study. The beach replenishment program may also provide opportunities for large-scale experiments during the study.

This task should run for the duration of the study, but its major effort will occur during Stage 3.

ACWS DST Development of decision-support tools for management

Introduction

Large, integrated studies such as the ACWS proposed here generate large quantities of field and model data that can be difficult to analyse and interpret. Without tools to aid the manager in visualising and interpreting those data, the value of the study can be significantly diminished. A number of enduring management tools will be developed throughout the study. This section brings together descriptions of those tools under the umbrella of decision support tools for management.

The suite of decision support tools described here will assist managers in visualising and assessing the output of other models, in terms of prospective management actions and the risks associated with those actions. The study database and associated spatial information system will provide the framework for long term data storage, retrieval and visualisation.

Development of these tools will require a close collaboration with managers in order to anticipate the types of scenarios and management actions that they will want to assess. This task is closely linked with task AMF 1 and hence to all others.

Conceptually, work on this suite of management decision support tools will be part of the program from the outset, but the major effort will be made during Stage 3.

Anticipated decision support tools include:

- a coarse resolution management model;
- a spatially and temporally referenced database; and
- a spatial information system.

DST MM 1—Development of a coarse resolution management model for the Adelaide coastal waters

Relative priority (optional)

This is considered to be a lower priority task that may be implemented towards the end of study, as it will depend on the results of other tasks. There has been no budget allocation for this task; however, an indicative cost of \$50,000 has been nominated. The management model would persist in the long term as a component of the decision support tools developed during the study for use by the region's managers.

Task description

The objective of this research task is to

- synthesise the hydrodynamic and ecological modelling results to develop a user-friendly modelling tool which may be used by managers to test the consequences of management strategies (that is, reduction in nutrients from the catchment, relocation of discharges, and so on) on the marine environment of the Adelaide coastal waters.

Issues to be addressed

Issues to be addressed by this task include the following presented in the Stakeholders Requirements Report:

3.2.1 Nutrients (in sediments and water column)

3.2.1.1 What is the fate of nutrients (nitrogen and phosphorus) and what are their respective impacts on the receiving marine environment and ecosystem functions?

3.2.1.2 What are the relative contributions of all contaminant inputs to the system and how do these compare to the impacts of WWTP sourced nutrients in terms of significance of effects?

3.2.1.3 How does stormwater's contribution to nutrients in the Gulf compare in significance to discharges from the wastewater treatment plants? Is nitrogen the only nutrient input of concern?

3.2.1.4 The EIPs for the coastal WWTPs are designed to result in the target reduction of nitrogen in discharge waters from 30 mg/l to 10 mg/l. What impact will this have on the seagrasses?

3.2.4 Salinity—dispersion and interactions/impacts modelling

3.2.4.1 What is the impact of low salinity levels on seagrass communities (and different species within communities)?

3.2.4.2 What is the cumulative impact of the low salinity and high turbidity discharges from the various coastal stormwater outlets on seagrass health?

3.2.4.3 What are the interactions with the larger body of water in Gulf St Vincent and do these have any effects on the coastal waters?

Rationale

The main focus of the ACWS is the coastal strip adjacent to the Adelaide metropolitan coastline. It is recognised that this narrow coastal strip is under considerable stress due to human activity, in the form of input of nutrients, through freshwater inputs from river systems where the catchments have been cleared and currently used for farming, and through wastewater and stormwater discharges.

During the ACWS, some very sophisticated numerical modelling will be undertaken. These models will be highly specialised and require some degree of expertise and large computing power (usually operating in an UNIX environment). However, the model results can be synthesised to develop a user-friendly modelling tool that may be used to examine first-order effects on the ecological processes due to altered discharges from outfalls, stormwater and small rivers.

Linkages and dependencies

This task depends on the results of the Adelaide coastal waters model (PPM 2) and the outcomes of a number of related Stage 2 research tasks within the ACWS study program.

Current status

Although similar models are currently being developed for other regions (for example, Swan River estuary, WA) there is an increasing need for this type of model.

Information gaps

There are no information gaps requiring additional attention outside of the ACWS research program, as all of the information required would be provided as results from the other modelling tasks described in the Research Requirements Report.

Work plan

Tasks and activities required to complete this research tasks include:

- synthesis of the hydrodynamic model runs to define exchanges between the system and coastal waters; and
- undertaking a limited number of model simulations to address the stakeholder requirements.

Resources required

A full-time research officer over a period of six months.

Anticipated outcomes

- Simplified modelling tool available for managers.

Anticipated outputs

- A user-friendly modelling tool to investigate the ecological response of the Adelaide coastal waters to changes in discharges. A user manual will accompany the tool.

DST DB 1—Adelaide Coastal Waters Study database and spatial information system

Introduction

The database and spatial information system that will form the enduring management decision support tool will be developed as a fundamental and integral task during Stage 2. The data management and spatial information system will only be summarised here.

Objective

- To provide an environmental information system that will allow the management and sharing of data sets from all study tasks, facilitating integrated, multidisciplinary studies of the data and the development of an adaptive management framework.

Rationale

While this is the first large-scale and integrated study of Adelaide's coastal waters system, there have been numerous small-scale and focused assessments and environmental monitoring programs initiated during the past thirty or so years. As a result, there is an array of data, about the ecology of the biota and the physio-chemical properties of the coastal waters, dispersed in various agencies and in personal records of participating scientists. This dispersion makes access to these data difficult, if not impossible.

The development of a centralised, comprehensive database from this study is considered imperative, in order to ensure that, in the future, management agencies have continuing and complete access to all data, integrated outputs and models developed during the study.

Compilation of historical data (results and literature) is also fundamental to the study, to allow analyses of trends and other time-based comparisons when assessing the status of the coastal waters. A specially designed database or Environmental Information System (EIS) will be used to address these needs. Experience with similar large-scale studies has shown that an EIS/GIS package alone is insufficient without an adequate relational database. This system will need to be functionally linked with the decision support tools developed during Stage 3 of the study. Graphic display of results and other findings may also play a large part in meeting the management and community information needs of the work program, and is expected to benefit from the development and use of a GIS as a display tool.

Requirements and approach

There will be tens or even hundreds of gigabytes of remotely sensed imagery, scanned aerial photos and digital maps, together with ecological, water quality, sedimentological, meteorological and oceanographic data and reports, compiled or identified during the course of the ACWS. This proposed task would require access to, and interpretation of, all of the spatially and temporally referenced data sets produced by the ACWS. It is critical to establish a functional integrated spatial data

system, and this could then form the basis of all spatial data management and dissemination for the study.

A central feature of the relational database will be the quality management program, to ensure the best possible integrity for any data collected and stored. Throughout the study, and as a final task, all of the data collated will need to be stored in such a way that subsequent access for continuing management purposes can be undertaken with the minimum of effort, through a highly interactive but easy to use spatial data system. 'Safari 2000 system' is an example of an operational hyperlinked spatial information system for managing large data sets. The developed database system would preferably be vested in a State agency that can undertake the long-term maintenance of these data on behalf of the State. This can be achieved by the use of appropriate software such as TNTatlas, which can be distributed free to other researchers and management. The existing Australian Coastal Atlas is not designed for easy access by researchers to source digital data sets; however, it is proposed that the study-specific database and spatial information system would be fully compatible with the Coastal Atlas, and allow linkage during and following completion of the study.

Appendix B Additional information to support the research program

Bibliography of publications and reports relevant to Task EP 1

- Adam, P, 1990. *Saltmarsh ecology*. Cambridge University Press, Melbourne.
- Ayliffe, E, 1999. 'Understanding habitat complexity in seagrass meadows for the purpose of artificial habitat replacement.' Honours thesis, University of Adelaide.
- Borowitzka, MA & Lethbridge, RC, 1989. 'Seagrass epiphytes.' In Larkum, AWD, McComb, AJ & Shepherd, SA (eds) *Biology of seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region*. Elsevier, Netherlands.
- Boxall, VA 1994. 'Potential biochemical indicators of the sublethal stress effects of pollutants in Yellowfin whiting (*Sillago schomburgkii*) and Yelloweye mullet (*Aldrichetia forsteri*) in S.A. gulf waters.' Honours thesis, Flinders University of South Australia.
- Brewster, FJ, 1975. 'Aspects of the population dynamics and general ecology of the razor-shell *Pinna dolabrata* in South Australia.' Thesis, University of Adelaide.
- Brown, K, Bone, Y, Cheshire, A & James, NP, 1999. 'Calcium carbonate quantities from epiphytes on *Posidonia* sp. and *Amphibolis* sp. from along the South Australian coastline, preliminary results.' Fourth Australian Marine Geoscience Conference, Exmouth, Western Australia, Sept.
- Bulthuis, DA & Woelkerling, WJ, 1981. 'Effects of *in situ* nitrogen and phosphorus enrichment of the sediments on the seagrass *Heterozostera tasmanica* (Martens ex Aschers.) den Hartog in Western Port, Victoria, Australia.' *Journal of Experimental Marine Biology and Ecology* 53:193–207.
- Bulthuis, DA & Woelkerling, WJ, 1983. 'Biomass accumulation and shading effects of epiphytes on leaves of the seagrass, *Heterozostera tasmanica*, in Victoria, Australia.' *Aquatic Botany*. 16:137–148.
- Burns, A, 1992. 'The effects of Bolivar effluent outfall on the intertidal seagrass, *Zostera muelleri* Irmisch ex Aschers.' Honours thesis. University of Adelaide.
- Cannon, JA, 1987. 'The ecology of the understorey red algal community of the Southern faces of the "Blocks" off Glenelg, between 1 and 5 meters depth.' Honours thesis, University of Adelaide.
- Cattani, M, Cena, K, Edwards, J & Pisaniello, D, 2001. 'Potential dermal and inhalation exposure to chlorpyrifos in Australian pesticide workers.' *Annals of Occupational Hygiene* 45:299–308.
- Chamberlain, D, 2000. 'Habitat associations of decapod crustaceans in seagrass in Barker Inlet.' Honours thesis, Flinders University of South Australia.

- Chapman, VJ, 1960. *Salt marshes and salt deserts of the world*, Interscience Publishers, New York.
- Cheshire, AC, Butler, AJ, Bathgate, RS, Westphalen, G & Miller, DJ, 1996. 'The impact of sand dredging on benthic community structure at Port Stanvac dredge site.' Interim report on the results of surveys 1992 to 1995. Report to the South Australian Coast Protection Board.
- Cheshire, AC & Kildea, T, 1992. 'The impact of sand dredging on benthic community structure at the Port Stanvac trial dredge site.' An interim report to the Coast Protection Branch, South Australian Department of Environment and Planning.
- Cheshire, AC & Kildea, T, 1993. 'The impact of sand dredging on benthic community structure at the Port Stanvac trial dredge site.' Final report on 1992 activities to the Coast Protection Branch, South Australian Department of Environment and Planning.
- Cheshire, AC & Kildea T, 1994. 'The impact of sand dredging on benthic community structure at the Port Stanvac trial dredge site.' Interim report on 1993 activities to the Coast Protection Branch, South Australian Department of Environment and Natural Resources.
- Cheshire, AC, Westphalen, G, Wenden, A, Scriven, LJ & Rowland, BC, 1996. 'Photosynthesis and respiration of phaeophycean-dominated macroalgal communities in summer and winter.' *Aquatic Botany* 55:159–170.
- Clarke SM, 1978. 'A study of *Hormosira banksii* (Phaeophyta): the taxonomy, genealogy growth and phenology of four morphologically distinct forms on South Australian coasts.' Thesis, University of Adelaide.
- Clarke, SM, 1987. 'Seagrass-sediment dynamics in Holdfast Bay: Summary.' *SAFISH* 11:4–10.
- Clarke, SM & Kirkman, H, 1989. 'Seagrass dynamics.' In Larkum AWD, McComb AJ & Shepherd SA (eds) *Biology of seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region*. Elsevier, Netherlands, pp. 304–345.
- Clarke, S & Thomas, R, 1987a. 'Blowout morphology and dynamics in the seagrass beds of Holdfast Bay, SA.' Manuscript.
- Clarke S & Thomas R, 1987b. 'Effects of increased sediment load on the seagrass *Amphibolis antarctica* & *Posidonia sinuosa* in Holdfast Bay, S.A.' Manuscript.
- Close, RL & GK, Jones, 1971. 'The effect of chlorination of marine fouling organisms.' Thesis?, University of Adelaide.
- Coleman, PSJ, 1996. 'Literature review of bitterns effects on *Avicennia marina*.' Internal Penrice Soda Products File Note.
- Coleman, PSJ, 1998. 'Changes in a mangrove/samphire community, North Arm Creek, South Australia.' *Transactions of the Royal Society of South Australia* 122(4):153–157.
- Collings, GJ, 1989. 'The relationship between canopy community structure and wave force in selected South Australian macroalgal dominated benthic communities.' Honours thesis, University of Adelaide.
- Collings. GJ, 1997. 'Spatiotemporal variation of macroalgal communities of Southern Fleurieu Peninsula, South Australia.' PhD thesis, University of Adelaide.

- Collings, G & Cheshire, AC, 1996. 'Composition of macroalgal communities of the lower gulf waters of South Australia.' *Australian Journal of Botany*. [check publication date]
- Connolly, RM, 1994. 'The role of shallow seagrass meadows as habitat for fish.' PhD thesis, University of Adelaide.
- Connolly, RM, 1994a. 'Effects of oil from the "Era" spill on intertidal seagrasses and associated motile invertebrates in Spencer Gulf, South Australia.' Environmental Protection Council. South Australia.
- Connolly, RM, 1994b. 'A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary.' *Australian Journal of Marine and Freshwater Resources* 45:1033–1044.
- Connolly, RM, 1994c. 'The role of seagrass as preferred habitat for juvenile *Sillaginodes punctata* (Cuv. & Val.) (Sillaginidae, Pisces): habitat selection or feeding?' *Journal of Experimental Marine Biology and Ecology* 180: 39–47.
- Connolly, R, Jenkins, G & Loneragan, N, 1999. 'Seagrass dynamics and fisheries sustainability.' In Butler A, Jernakoff P (eds) *Seagrass in Australia: Strategic review and development of an R & D plan*. CSIRO Publishing, Collingwood, Victoria, pp. 25–64.
- Connolly RM & Jones GK, 1996. 'Determining effects of an oil spill on fish communities in a mangroveseagrass ecosystem in southern Australia.' *Australian Journal of Ecotoxicology* 2:3–15.
- Cooper, RE, 1960. 'Recent sedimentation in the Gulf of St. Vincent, South Australia.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- DA Lord & Associates, 1994. 'Evaluation of receiving water reviews and Glenelg assimilative capacity model.' Engineering and Water Supply Dept.
- Davies, AR, 1987. 'Pelagic and early benthic stages as determinants of the distribution and abundance of the Ascidian *Podoclavella moluccensis* Sluiter.' PhD thesis, Department of Zoology, University of Adelaide.
- De Guia, MB, 1982. Investigation of the effects of thermal effluents on mangrove stands at Torrens Island, South Australia. Thesis, University of Adelaide.
- de Lacerda, LD, 1994. 'Biogeochemistry of heavy metals in coastal lagoons.' In Kjerfve, B (ed.) *Coastal Lagoon Processes*, Elsevier Oceanography Series 60, Elsevier, New York.
- Delistraty, DA & Hershner C, 1984. 'Effects of the herbicide atrazine on adenine nucleotide levels in *Zostera marina* L. (eelgrass).' *Aquatic Botany* 18:353–369.
- Den Hartog, C, 1994. 'Suffocation of a littoral *Zostera* bed by *enteromorpha radiata*.' *Aquatic Botany* 47:21–28.
- Dowd, JM, 1981. 'The effects of substrata and grazing on the eulittoral algae at Port Stanvac, South Australia.' Honours thesis, University of Adelaide.
- Dyer SM, Cattani, M, Pisaniello, L, Williams FM & Edwards, JW, forthcoming. 'Peripheral cholinesterase inhibition by occupational chlorpyrifos exposure in Australian termiticide applicators' *Toxicology*.

- Edwards, JW, Edyvane, KS, Boxall, VA, Hamann, M & Soole, KL, 2001. 'Metal levels in seston and marine fish flesh near industrial and Metropolitan centres in South Australia.' *Marine Pollution Bulletin* 42:389–396.
- Edyvane, K, 1991. 'Pollution the death knell for our mangroves?' *SAFISH* 16:4–7.
- Edyvane, K, 1996. 'Issues in the South Australian marine environment.' In Zann LP & Sutton DC (eds) *State of the marine environment report for Australia. Technical annex: 3 State and territory issues*. Great Barrier Reef Marine Park Authority, Townsville.
- Edyvane, KS, 1999. 'Coastal and marine wetlands in Gulf St Vincent, South Australia: understanding their loss and degradation.' *Journal of Wetlands Ecology and Management* 7(1/2):83–104.
- Edyvane, KS & Boxall, V, 1997. 'An investigation of heavy metal contamination of edible marine seafood in the Port Pirie – Telowie Beach region of South Australia.' Report to South Australian Health Commission?, SARDI Aquatic Sciences, Adelaide.
- Emmerson, LM, 1992. 'Recruitment dynamics of a fucoid dominated macroalgal community.' Honours? thesis, University of Adelaide.
- Environment Protection Agency South Australia, 1998. 'Changes in seagrass coverage and links to water quality of the Adelaide metropolitan coastline.' Environment Protection Agency, Adelaide.
- Fairhead, VA, 1995. 'The relationship between the Bolivar sewage effluent outfall and the decline of the Mangrove *Avicennia marina* (Forssk.) Vierh.' Honours thesis, University of Adelaide.
- Farrell, MJ & Ashton, DH, 1973. 'Environmental Factors Affecting the Growth and Establishment of Mangroves in Westernport Bay.' [Book/report ??]
- Fonseca, MS, 1996. 'The role of seagrasses in nearshore sedimentary processes: a review.' In Nordstrom, KF & Roman, CT (eds) *Estuarine shores, evolution, environments and human alterations*. John Wiley & Sons, Chichester.
- Fowler-Walker, M, 2001. 'Patterns of understory algae across southern Australia.' Honours thesis, University of Adelaide.
- Gabric, AJ & Bell, PRF, 1993. 'Review of the effects of non-point nutrient loading on coastal ecosystems.' *Australian Journal of Marine and Freshwater Resources* 44:261–83.
- Goodsall, P, 2000. 'In the thick of the forest: the effects of habitat spatial configuration on biodiversity.' Honours thesis, University of Adelaide.
- Gordon, DM, Collins, P, Baxter, IN & LeProvost, I, 1996. 'Regression of seagrass meadows, changes in seabed profiles and seagrass composition at dredged and undredged sites in the Owen Anchorage region of South-western Australia.' In Kuo, J, Phillips, RC, Walker, DI & Kirkman, H (eds) *Seagrass Biology: Proceedings of an international workshop Rottnest Island, Western Australia, 25–29 January 1996*. Sciences, University of Western Australia.
- Grice, AM, Loneragan, NR & Dennison, WC, 1996. 'Light intensity and the interactions between physiology, morphology and stable isotope ratios in five species of seagrass.' *Journal of Experimental Marine Biology and Ecology* 195:91–110.

- Hails, JR, Salama, MS, Gostin, VA, Sargent, GEG & von der Borch, CC, 1982. 'Nearshore sediment dynamics and sedimentation in the Gulf of St Vincent, South Australia.' A Report to the Coast Protection Board of South Australia, December.
- Hamann, M, 1994. 'Investigation of cytogenetic effects of environmental pollutants on fish in South Australian coastal waters.' Honours thesis, Flinders University of South Australia.
- Hamman, M, Boxall, VA, Edyvane, K, Edwards, JW & Soole, KS, 1999. 'Biochemical and cytogenetic markers of stress in marine fish near industrial and metropolitan centres in South Australia.' *Biomarkers*, 4(4):290–302.
- Harbison, P & Wiltshire, D, 1996. 'Determination of epiphyte growth rates and seagrass health.' Progress report autumn survey, prepared for EPA and Catchment Management Board, Adelaide.
- Harbison, P & Wiltshire, D, 1997. 'Determination of Epiphyte Growth rate and Seagrass health.' Final report and results of October Survey Prepared for EPA and Catchment Management Board.
- Harlin, MM, 1995. 'Changes in major plant groups following nutrient enrichment.' In McComb, AJ (ed.) *Eutrophic shallow estuaries and lagoons*. CRC Press, pp. 173–187.
- Harrison, PG, 1989. 'Detrital processing on seagrass systems: A review of factors affecting decay rates, remineralization and detritivory.' *Aquatic Botany* 23:263–288.
- Hart, BT & Grant, A, 1995. *Interactions between sediments and water*. CSIRO, Australia.
- Harvey, F, 1990. 'A study of the interaction between the distributions of algal and gastropod communities in the intertidal zones of rocky shores of the Fleurieu Peninsula, South Australia.' Honours thesis, University of Adelaide.
- Hillman, K, 1986. 'Nutrient load reduction, water quality and seagrass dieback in Cockburn Sound 1984–1985.' Technical Series 5, Department of Conservation and Environment, Perth.
- Hillman, K, Lukateliich, RJ, Bastyan, G & McComb AJ, 1991. *Water quality and seagrass biomass, productivity and epiphyte load in Princess Royal Harbour, Oyster Harbour and King George Sound*. Technical Series No. 39, Environmental Protection Authority, Perth.
- Hillman, K, Walker, DI, Larkum, AWD & McComb, AJ, 1989. 'Productivity and nutrient limitation.' In Larkum, AWD, McComb, AJ & Shepherd, SA (eds) *Biology of seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region*. Elsevier, Netherlands.
- Hone, PW, 1982. 'Growth stimulation of *Ulva rigida* C. Agardh influenced by water movement and external nutrient concentration.' Honours thesis, University of Adelaide.
- Horwood, JL, 1981. 'Studies on the growth seasonality and recruitment of *Ulva rigida* C. Agardh.' Honours thesis, University of Adelaide.
- Host, WM, 1977. 'Marine biological studies in relation to the operation of the Torrens Island Power Station.' Master of Science thesis, University of Adelaide.
- Howard, RK, Edgar, GJ & Hutchings, PA, 1989. 'Faunal assemblages of seagrass beds.' In Larkum, AWD, McComb, AJ & Shepherd, SA (eds) *Biology of seagrasses. A treatise on*

the biology of seagrasses with special reference to the Australian region. Elsevier, Netherlands.

- Invers, O, Romero, J & Marta, P, 1997. 'Effects of pH on seagrass photosynthesis: a laboratory and field assessment.' *Aquatic Botany* 59:185–194
- Irving, A, 2000. 'The interactive effects of light and sediment on subtidal epibiota.' Honours thesis, University of Adelaide.
- Jackson, G, 1996. 'Nearshore fish assemblages of the Port River–Barker Inlet estuary, South Australia—a longer-term perspective.' Masters thesis, University of Adelaide.
- Jackson, G & Jones, GK, 1999. 'Spatial and temporal variation in nearshore fish and macroinvertebrate assemblages from a temperate Australian estuary over a decade.' *Marine Ecology Progress Series* 182:253–268.
- Jenkins, GP, Watson, GF, Hammond, LS, Black, KP, Wheatley, MJ & Shaw, C, 1996. 'Importance of shallow water, reef-algal habitats as nursery areas for commercial fish from southeastern Australia.' FRDC Project 92/44. Fisheries Research & Development Corporation. Queenscliff.
- Jenkins, GP & Wheatley, MJ, 1998. 'The influence of habitat structure on nearshore fish assemblages in a southern Australian embayment: Comparison of shallow seagrass, reef-algal and unvegetated sand habitats, with emphasis on their importance to recruitment.' *Journal of Experimental Marine Biology and Ecology* 221:147–172.
- Jernakoff, P, Brearley, A & Nielsen J, 1996. 'Factors affecting grazer-epiphyte interactions in temperate seagrass meadows.' *Oceanographic Marine Biology Annual Review* 34:109–162.
- Johnson, JE, 1973. 'A study of the algal epiphytes on the seagrass, *Posidonia australis* Hook. f., in two areas along the southern Australian coast.' Honours thesis, University of Adelaide.
- Johnson, J, 1981. 'General seagrass distribution and faunal studies.' In Steffensen, DA (ed.) *Port Adelaide Sewage Treatment Works sludge outfall effect of discharge on the adjacent marine environment.* Engineering and Water Supply Department, Adelaide.
- Johnson, JE, 1981. 'The seasonality of the algal epiphytes of *Posidonia sinuosa* in upper Spencer Gulf.' Masters thesis, University of Adelaide.
- Jones, GK, Baker, JL, Edyvane, K & Wright, GJ, 1996. 'The nearshore fish community of the Port River–Barker Inlet Estuary, South Australia. 1. Effect of thermal effluent on the fish community structure, and distribution and growth of economically important fish species.' *Australian Journal of Marine and Freshwater Resources* 47:785–799.
- Jones, GK & Close, RL, 1971. 'The effect of chlorine on fouling organisms in the inlet condenser pipes at the Torrens Island Power Station, S.A.' Thesis?, University of Adelaide.
- Jones, TW & Winchell, L, 1984. 'Uptake and photosynthetic inhibition by atrazine and its degradation products on four species of submerged vascular plants.' *Journal of Environmental Quality* 13:2.243–247.
- Kangas, M, 1999. 'Postlarval and juvenile western king prawn *Penaeus latisulcatus* Kishinouye studies in Gulf St. Vincent, South Australia with reference to the commercial fishery.' PhD thesis, University of Adelaide.

- Keough, MJ, 1981. 'Community dynamics of the epifauna of the bivalve *Pinna bicolor* Gmelin.' PhD thesis, University of Adelaide.
- Kinhill, Metcalf & Eddy, 1995. 'E&WS Department Remote Sensing, numerical modelling and field studies of environmental impacts on marine communities of the Bolivar Wastewater Treatment Plant effluent Discharge.' Report to the Engineering and Water Supply Department, South Australia.
- Kinney, EH & Roman, CT, 1998. 'Response of primary producers to nutrient enrichment in a shallow estuary.' *Marine Ecology Progress Series* 163:89–98.
- Kumar, M, Ferguson, G, Xiao, Y, Hooper, G & Venema, S, 2000. 'Studies on reproductive biology and distribution of the Blue Swimmer Crab (*Portunus pelagicus*) in South Australian waters.' *SARDI Research Report Series* No.47, Adelaide.
- Kwik, J, 1996. 'Habitat preference and distribution of the Leafy Seadragon, *Phycodurus eques* (Syngnathidae) in South Australia.' Honours thesis, Flinders University of South Australia.
- Leinfelder, D, 2000. 'The impacts of bitterns on the benthic communities of North Arm Creek.' Honours thesis, Flinders University of South Australia.
- Leonello, B, 2001. 'Shade has greater effects than grazing on the relative covers of marine invertebrates and algae.' Honours thesis, University of Adelaide.
- Leupold, JD, 1984. 'The occurrence, abundance, seasonality, recolonization and growth of marine algae in a shallow subtidal community.' Honours thesis, University of Adelaide.
- Lewis, RK, 1972. 'The marine ecology of the Port Stanvac area, South Australia.' Honours thesis, University of Adelaide.
- Lewis, SA, 1975a. 'Gulf St Vincent water pollution studies June 1972 – April 1975.' Engineering and Water Supply Dept. EWS 3876/70.
- Lewis, SA, 1975b. 'Gulf St Vincent water pollution studies 1972–1975.' EWS 75/14, Engineering and Water Supply Department, Adelaide.
- Long, ER, McDonald, DD, Smith, SL & Calder, FD, 1995. 'Incidence of adverse effects within ranges of chemical concentrations in marine and estuarine sediment.' *Environmental Management* 19(1):81–97
- Long, M, 1996. 'Cadium toxicity in Dolphins.' Honours thesis, University of Adelaide.
- MacFarlane, JJ, 1979. 'Uptake of ammonia and methylamine by *Ulva*.' Honours thesis, University of Adelaide.
- March, WA, 1996. 'Assessing anthropogenic impacts on the Port Stanvac macrobenthic communities.' Masters thesis, Department of Botany, University of Adelaide.
- Masini, RJ, Cary, JL, Simpson, CJ & McComb, AJ, 1990. 'Effects of light and temperature on the photosynthesis of seagrasses, epiphytes and macroalgae and implications for management of the Albany harbours.' Technical Series No. 32. Environmental Protection Authority, Perth.
- Masini, RJ & Manning, CR, 1997. 'The photosynthetic responses to irradiance and temperature of four meadow-forming seagrasses.' *Aquatic Botany* 58:21–36.

- Mason, DR, 1969. 'Light and sub-light microscopic studies of the mangrove *Avicennia marina* var. *resinifera* (Forst.f.) Bakh. V.d. Brink (1921).' Thesis, University of Adelaide.
- McDonald, B, Keuscamp, D & Saunders, T, 1999. 'Seagrass faunal relationships in inverse estuaries: Progress report to the National Heritage Trust and Sponsors, July 1999.' NHT Project No. 974219, South Australian Research and Development Institute, Adelaide.
- McMillan, C, 1974. 'Salt tolerance of mangroves and submerged aquatic plants.' In Reimold, RJ & Queen, WH (eds) *Ecology of Halophytes*, Academic Press, New York.
- McMillan, C, 1971. 'Environmental factors affecting seedling establishment of the Black Mangrove on the Central Texas Coast.' *Ecology* 52(5):927–930.
- Melville, A. 1999. 'Effects of kelp on the abundance of two morphological groups of coralline algae.' Honours thesis, University of Adelaide.
- Messner, K, 1985. 'Respiration in the sand crab *Ovalipes australiensis* (Haswell) and the blue crab *Portunus pelagicus* (Linnaeus).' Honours thesis, University of Adelaide.
- MFP Australia, 1996. 'Estuary and lakes hydraulic flushing model study.' Report prepared by DA Lord & Associates Pty Ltd.
- Miller, CJ, 1996. 'A Comparison of the sampling efficiency of three infaunal sampling devices.' Masters thesis, Departments of Botany and Zoology, University of Adelaide.
- Miller, DJ, 1997. 'Remote video monitoring as a method of surveying marine soft-bottom epibenthic communities.' Masters thesis, University of Adelaide.
- Miller, DJ & Cheshire, AC, 1999. 'Summary of research completed 1992–1998: The impact of sand dredging on benthic community structure at Pt Stanvac dredge site.' Department of Environmental Biology, University of Adelaide.
- Moriarty, DJW & Boon, PI, 1989. 'Interactions of seagrass with sediment and water.' In Larkum, AWD, McComb, AJ & Shepherd, SA (eds) *Biology of seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region*. Elsevier, Netherlands.
- Morris, K, 1992. 'The Ecophysiological impact of drift *ulva* on the grey mangrove *Avicennia marina*.' Honours thesis, Flinders University of South Australia.
- Morris, K, 1998. 'Salinity and nutrients: growth and water use of aquatic macrophytes under controlled and natural conditions.' PhD thesis, University of Adelaide.
- Mower, AGJ, 1985. 'Physiological tolerances of *Ovalipes australiensis* (Haswell) and *Portunus pelagicus* (Linnaeus), with particular reference to the crab fishery in South Australia.' Honours thesis, University of Adelaide.
- Neverauskas, VP, 1977. 'Some biological effects from warm effluent water discharged from the Torrens Island power station.' Honours thesis, University of Adelaide.
- Neverauskas, VP, 1982. 'Tolerance of blue crab, *Portunus pelagicus* (L) to high temperature.' *Transactions of the Royal Society of South Australia*, 106:215–216.
- Neverauskas, VP, 1985. 'Effects of the Port Adelaide Treatment Works Sludge Discharge on the adjacent marine environment.' *Proceedings of the 1985 Australasian Conference of Coastal Ocean Engineering* 1:193–202.

- Neverauskas, VP, 1987. 'Port Adelaide Sewage Treatment Works sludge outfall effect of discharge on the adjacent marine environment.' EWS 87/28. EWS 87/28. Engineering and Water Supply Department, Adelaide.
- Neverauskas, VP, 1988. 'Response of a *Posidonia* community to prolonged reduction in light.' *Aquatic Botany* 31:361–366.
- Neverauskas, VP, 1988. 'Accumulation of periphyton on artificial substrata near sewage sludge outfalls at Glenelg and Port Adelaide, South Australia.' *Transactions of the Royal Society of South Australia* 112:3–4.175–177.
- Neverauskas, VP, 1989. 'Impact of land based discharges on seagrass beds near Adelaide South Australia.' Proceedings, 9th Australasian Conference of Coastal Ocean Engineering, pp. 24–29.
- Olsen, AM, 1988. *Pesticide levels in some marine and freshwater fish of South Australia*. Fisheries Research Paper. 19. Department of Fisheries, Adelaide.
- Orth, RJ & van Montfrans, J, 1984. 'Epiphyte-seagrass relationships with an emphasis on the role of micrograzing: a review.' *Aquatic Botany* 18: 43–69.
- Owen, WJ, 1971. 'The ecology of the epiflora of the seagrass, *Amphibolis antarctica*.' Honours thesis, University of Adelaide.
- Palmer, M, 1996. 'Osmotic and ionic balance in the blue swimmer crab *Portunus* under different environmental conditions.' Honours thesis, University of Adelaide.
- Parkes, SM, Roder, EMA & Widdows, SJ, 1997. 'Laboratory investigation of the effects of seagrass loss on nearshore processes along the Adelaide metropolitan coastline.' Student Project, University of Adelaide.
- Pedersen, MF, Paling, EI & Walker DI, 1997. 'Nitrogen uptake and allocation in the seagrass *Amphibolis antarctica*.' *Aquatic Botany* 56:105–117.
- Pisaniello, D, Edwards, J, Cattani, M & Tkaczuk, M, 2000. 'Exposures and health effects among pest control operators using the insecticide chlorpyrifos.' Report for the National Occupational Health and Safety Commission, University of Adelaide.
- Pollard, DA & Den Hartog, C, 1984. 'Seagrasses: Consumer ecology and faunal relationships with special emphasis on recent studies in Australia.' *Aquatic Botany* 18:1–2.
- Ralph, PJ, 2000. 'Herbicide toxicity of *Halophila ovalis* assessed by chlorophyll a fluorescence.' *Aquatic Botany* 66:141–152.
- Ralph, PJ & Burchett, MD, 1998. 'Photosynthetic response of *Halophila ovalis* to heavy metal stress.' *Environmental Pollution* 103:91–101.
- Ramachandran, S, Rajendran, N, Nandakumar, R & Venugopalan, VK, 1984. Effect of pesticides on photosynthesis and respiration of marine macrophytes. *Aquatic Botany* 19:395–399.
- Saenger, P, 1982. 'Morphological, anatomical and reproductive adaptations of Australian mangroves.' In Clough, BF (ed.) *Mangrove Ecosystems in Australia: Structure, Function and Management*, Australian National University Press, Canberra.

- Sand-Jensen, K, 1977. 'Effect of epiphytes on eelgrass photosynthesis.' *Aquatic Botany* 3:55–63.
- Santamaria, L & van Vierssen, W, 1997. 'Photosynthetic temperature responses of fresh- and brackish-water macrophytes: a review.' *Aquatic Botany* 58:135–150.
- Saunders, RJ, 1999. 'Experimental analysis of the distribution and abundance of Spirorbid polychaetes on mangroves.' Honours thesis, University of Adelaide.
- Scholander, PF, 1968. 'How Mangroves Desalinate Water' *Physiology of Plants*, 21:251–261.
- Schwarzschild, AC, MacIntyre, WG, Moore, KA & Libelo, EL, 1994. '*Zostera marina* L. growth response to atrazine in root–rhizome and whole plant exposure experiments.' *Journal of Experimental Marine Biology and Ecology* 183:77–89.
- Seddon, S, 2000. 'Causes and ecological consequences of the Spencer Gulf seagrass dieback.' PhD Thesis, University of Adelaide.
- Seddon, S & Cheshire, AC, 2001. 'Photosynthetic response of *Amphibolis antarctica* and *Posidonia australis* to temperature and desiccation using chlorophyll fluorescence.' *Marine Ecology Progress Series* 220:119–130.
- Seddon, S, Connolly, R & Edyvane, KS, 2000. 'Large-scale seagrass dieback in northern Spencer Gulf, South Australia.' *Aquatic Botany* 66:297–310.
- Sergeev, VN, Clarke, SM & Shepherd, SA, 1988. 'Motile macroepifauna of the seagrasses, *Amphibolis* and *Posidonia*, and unvegetated sandy substrata in Holdfast Bay, South Australia.' *Transactions of the Royal Society of South Australia* 112:97–108.
- Shepherd, SA, McComb, AJ, Bulthuis, DA, Neverauskas, V, Steffensen, DA & West, R, 1989. 'Decline of seagrasses.' In Larkum, AWD, McComb, AJ. & Shepherd, SA (eds) *Biology of seagrasses. A treatise of the biology of seagrasses with special reference to the Australian region*. Elsevier, Netherlands. pp. 346–393.
- Shepherd, SA & Robertson, EL, 1989. 'Regional studies—seagrasses of South Australia, western Victoria and Bass Strait.' In Larkum, AWD, McComb, AJ & Shepherd, SA (eds) *Biology of seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region*. Elsevier, Netherlands.
- Shepherd, SA & Sprigg, RC, 1976. 'Substrate, sediments and subtidal ecology of gulf St Vincent and Investigator Strait.' In Twidale, CR, Tyler, MJ, & Webb, BP (eds) *Natural History of the Adelaide region*. Royal Society of South Australia, Adelaide.
- Short, FT, 1983a. 'The seagrass, *Zostera marina* L.: Plant morphology and bed structure in relation to sediment ammonium in Izembak lagoon, Alaska.' *Aquatic Botany* 16:149–161.
- Short, FT, 1983b. 'The response of interstitial ammonium in eelgrass (*Zostera marina*) beds to environmental perturbations.' *Journal of Experimental Marine Biology and Ecology* 68: 195–208.
- Short, FT, 1987. 'Effects of sediment nutrients on seagrasses: literature review and mesocosm experiment.' *Aquatic Botany* 27: 41–57.
- Short, FT, Burdick DM, 1996. 'Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts.' *Estuaries* 19: 3.730–739.

- Short, FT, Burdick, DM, Granger, S & Nixon, SW, 1996. 'Long-term decline in eelgrass, *Zostera marina* L., linked to increased housing development.' In Kuo, J, Phillips, RC, Walker, DI & Kirkman, H (eds) *Seagrass Biology: Proceedings of an international workshop Rottneest Island, Western Australia, 25–29 January*, Sciences, University of Western Australia.
- Short, FT, Wyllie-Echeverria, S, 1996. 'Natural and human-induced disturbance of seagrasses.' *Environmental Conservation* 23: 1.17–27.
- Silberstein, K, Chiffings, AW & McComb, AJ, 1986. 'The loss of seagrass in Cockburn Sound, Western Australia. III. The effect of epiphytes on productivity of *Posidonia australis* Hook. F.' *Aquatic Botany* 24:355–371.
- Sims, MA, 1973. 'The impact of three heavy metals on the marine flora of an inlet at Port Pirie.' Thesis, University of Adelaide.
- Smith, P.A., M.J. Thompson and J.W. Edwards. forthcoming. 'Estimating occupational exposure to the pyrethroid termiticide bifenthrin by measuring metabolites in urine.' *Journal of Chromatography B—Biomedical Sciences and Applications*.
- Smith, SV, Kimmerer, WJ, Laws, EA, Brock, RE & Walsh, TW, 1996. 'Kaneohe Bay sewage diversion experiment: Perspectives on ecosystem responses to nutritional perturbation.' *Pacific Science* 35: 4.279–395.
- Soole, KL, Edwards, JW, Hone, P, Clarke, S & Carragher, J, 1999. 'Feasibility study to evaluate non-lethal measurements of health of farmed tuna using biochemical methods and surrogate species.' Final report to the Fisheries Research & Development Corporation, Project Nos. 95/082 and 97/307.
- Spriggs, RJ, 1992. 'Mangrove die back BHP Long Products Division, Whyalla.' South Australia Department of Fisheries, Adelaide.
- Steckis, RA, Potter, IC & Lenanton, RCJ, 1995. 'The commercial fisheries in three south-western Australian estuaries exposed to different degrees of eutrophication.' In McComb, AJ (ed.) *Utrophic shallow estuaries and lagoons*. CRC Press. ?
- Steffensen, DA, 1981. 'Biological studies.' In Steffensen, DA (ed.) *Port Adelaide Sewage Treatment Works sludge outfall effect of discharge on the adjacent marine environment*. Engineering and Water Supply Department, Adelaide.
- Steffensen, DA, 1985. 'Gulf St Vincent water pollution studies phase II 1976–1983. Part I. Southern and central metropolitan zones.' EWS 84/12. Engineering and Water Supply Department. Adelaide.
- Stevens, R, 1994. 'The Impact of environmental stresses on the reproductive strategy of the South Australian marine prosobranch *bedeva paivae*.' Honours thesis, Flinders University of South Australia.
- Strzelecki, J-M, 1993. 'Spatial patterns of infauna in soft marine sediment.' Honours thesis, University of Adelaide.
- Taylor, DI, Nixon, SW, Granger, SL, Buckley, BA, McMahon, JP & Lin, H-J, 1995. 'Responses of coastal lagoon plant communities to different forms of nutrient enrichment—a mesocosm experiment.' *Aquatic Botany* 52:19–34.

- Thomas, DP, 1974. 'Diatom epiphytes of *Zostera muelleri* Irmisch in the Onkaparinga Estuary.' Honours thesis, University of Adelaide.
- Thomas, DP, 1978. 'The ecology of diatom epiphytes of *Zostera* sp. in the Onkaparinga Estuary S.A. (1974–1977).' Thesis, University of Adelaide.
- Thomas, IM, Ainslie, RC, Johnson, DA, Offler, EW & Zed, PA, 1986. The effects of cooling water discharge on the intertidal fauna in the Port River estuary, South Australia. *Transactions of the Royal Society of South Australia* 109, 159–172.
- Thomas, RM & Clarke, SM, 1986. 'Sedimentology and morphology of classic seagrass beds in Holdfast Bay, South Australia: A locality of high wave energy for species of the *Posidonia australis* complex.' Kinhill Engineers. (to be published in the Proceedings of Seagrass Restoration Workshop, Adelaide 15–16 May.)
- Thornton, JA, McComb, AJ & Ryding S-O, 1995. 'The role of the sediments.' In McComb, AJ (ed.) *Eutrophic shallow estuaries and lagoons*. CRC Press. pp. 205–223.
- Tiller, KG, Merry, RH, Zarcinas, BA & Ward, TJ, 1989. 'Regional geochemistry of metal-contaminated surficial sediments and seagrasses in upper Spencer Gulf, South Australia.' *Estuarine, Coastal Shelf Science* 28:473–493.
- Turnbull, A, 1988. 'The optical properties of aquatic habitats and phytoplankton.' Thesis, University of Adelaide.
- Turner, DJ, 1995. 'A comparative study of destructive and non-destructive survey techniques for use in macroalgal systems.' Honours thesis, University of Adelaide.
- Van Dam, R, 1990. 'The effects of low energy surfaces on marine fouling.' Honours thesis, University of Adelaide.
- Ward, TJ, 1984. 'Role of acute metal toxicity in structuring seagrass fauna near a lead smelter.' *Marine Ecology Progress Series* 17:117–124.
- Ward, TJ, 1987. 'Temporal variation of metals in the seagrass *Posidonia australis* and its potential as a sentinel accumulator near a lead smelter.' *Marine Biology* 95:315–321.
- Ward, TJ, 1989. 'The accumulation and effects of metals in seagrass habitats.' In Larkum, AWD, McComb, AJ & Shepherd, SA (eds) *Biology of seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region*. Elsevier, Netherlands.
- Ward, TJ & Young, PC, 1981. 'Trace metal contamination of shallow marine sediments near a lead smelter, Spencer Gulf, South Australia.' *Australian Journal of Marine and Freshwater Resources* 32:45–56.
- Ward, TJ & Young, PC, 1983. 'The depauperation of epifauna on *Pinna bicolor* near a lead smelter, Spencer Gulf, South Australia.' *Environmental Pollution Series A* 30:293–308.
- Ward, TJ & Young, PC, 1984. 'Effects of metals and sediment particle size on the species composition of the epifauna of *Pina bicolor* near a lead smelter, Spencer Gulf, South Australia.' *Estuarine, Coastal Shelf Science* 18:79–95.
- Ward, TJ, Correll, RL & Anderson, RB, 1986. 'Distribution of cadmium, lead and zinc, amongst the marine sediments, seagrasses and fauna, and the selection of sentinel

accumulators, near a lead smelter in South Australia.' *Australian Journal of Marine and Freshwater Resources* 37:567–585.

- Wardrop, JA, Wagstaff, B, Connolly R & Leeder, J, 1993. 'The distribution and persistence of petroleum hydrocarbons in mangrove swamps impacted by the "Era" oil spill (September, 1992).' 5182. Woodward-Clyde. South Australia.
- Watts, CG, 1968. 'Studies on *Avicennia marina*.' Thesis, University of Adelaide.
- West, KR, 1965. 'Some aspects of the ultrastructure and physiology of a species of *Ulva*.' Thesis, University of Adelaide.
- West, RJ & Larkum, AWD, 1982. 'Seagrass primary production—a review.' *Proceedings of the Linnean Society of N.S.W.* 106:3.213–223.
- Westlake, M & Jones K, 1999. 'Environmental performance indicators for the South Australian Marine Scalefish Fishery.' Research Services Agreement Report to PIRSA. SARDI Internal Report No. 100. Adelaide.
- Wickes, WA, 1973. 'Studies on the crustose coralline algae epiphytic on the seagrasses *Amphibolis antarctica* and *Posidonia australis*.' Honours thesis, University of Adelaide.
- Williams, S, 1997. 'An assessment of human activities and impacts on selected rocky intertidal reefs in the metropolitan Adelaide region. SA.' Thesis, University of Adelaide.
- Wu, J, 1998. 'The distribution of benthic infauna in the nearshore zone of Adelaide's northern metropolitan coast.' Masters thesis, University of Adelaide.
- Wynne, A, 1984. 'Adelaide Coast Protection Strategy Review.' Prepared for The Coast Protection Board, South Australia. Coastal Management Branch, Conservation programmes Division, Department of Environment and Planning, Adelaide.
- Zed, P, 1972. 'The effect of warm water from the Torrens Island Power Station on the marine fauna of the Angas Inlet.' Honours theses, University of Adelaide.

Bibliography of publications, reports and projects relevant to proposed remote sensing task RS 1 in the ACWS

The following references relate to specific studies of the Adelaide coastal region, the application of remote sensing and spatial information systems to environmental studies in general, and methodologies developed for processing and interpreting a range of remotely sensed data sets. They demonstrate the substantial experience and knowledge base that exists in the field of marine and coastal environmental remote sensing.

- Alberotanza, L, Brando, VE, Ravagnan, G & Zandonella, A, 1999. 'Hyperspectral aerial images. A valuable tool for submerged vegetation recognition in the Orbetello Lagoons, Italy.' *International Journal of Remote Sensing*, 20(3):523–533.
- Anstee, JM et al., 2000. 'Use of hyperspectral imaging for benthic species mapping in South Australian coastal waters.' 10th Australian Remote Sensing and Photogrammetry Conference, The Remote Sensing & Photogrammetry Association of Australia, Adelaide, Australia, pp. 1051–1061.
- Armstrong, RA, 1993. 'Remote sensing of submerged vegetation canopies for biomass estimation.' *International Journal of Remote Sensing*, 14(3):621–627.
- Bajjouk, T, Guillaumont, B & Populus, J, 1996. 'Application of airborne imaging spectrometry system data to intertidal seaweed classification and mapping.' *Hydrobiologia*, 327:463–471.
- Bajjouk, T, Populus, J & Guillaumont, B, 1998. 'Quantification of subpixel cover fractions using principal component analysis and a linear programming method: application to the coastal zone of Roscoff (France).' *Remote Sensing of Environment*, 64(2): 153–165.
- BHPE–Kinhill Joint Venture, 1990–1995. 'Environmental Information System for Indian Steel plants.' Steel Authority of India.
- Bierwirth, PN, Lee, TJ & Burne, RV, 1993. 'Shallow sea-floor reflectance and water depth derived by unmixing multispectral imagery.' *ISPRS Journal of Photogrammetry and Remote Sensing*, 59(3):331–338.
- Blackburn, DT, 1994a. *Environmental information systems and GIS applications in impacts management*. In Proceedings, Mining Information Technology Conference. Sydney.
- Blackburn, DT, 1994b. *Environmental modelling and monitoring systems for receiving waters*. In Proceedings, AWWA Seminar—The Environment Protection Authority and SA Water, Adelaide.
- Blackburn, DT, 1999. 'Mapping changes in coastal and marine ecosystems using remote sensing.' Gulf St Vincent 2000 Conference, Adelaide.
- Blackburn, DT, 2001a. 'Distribution of the Mediterranean Fanworm *Sabella spallanzanii* in Gulf St Vincent, South Australia.' Proceedings of the AMSA–NZMSS Conference 2001, Townsville.

- Blackburn, DT, 2001b. 'Mapping dispersion of marine discharges of buoyant wastewater plumes using organic tracers and remote sensing.' Proceedings of the AMSA–NZMSS Conference 2001, Townsville.
- Clark, CD, Ripley, HT, Green, EP, Edwards, AJ & Mumby, PJ, 1997. 'Mapping and measurement of tropical coastal environments with hyperspectral and high spatial resolution data.' *International Journal of Remote Sensing*, 18(2):237–242.
- Clark, SM, 1987. 'Seagrass sediment dynamics in Holdfast Bay: Summary.' *SAFISH* 11, pp 4–10.
- Connolly, RM, 1986. 'Relation of near-shore benthic flora of the Barker Inlet and northern beaches region to pollution sources—with emphasis on *Ulva* distribution.' Report for Marine Sciences Section of Pollution Management Division, Department of Environment and Planning, South Australia.
- Dekker, AG et al., 2001, in press. 'Applications of imaging spectrometry in inland, estuarine, coastal and ocean waters.' In van der Meer, F (ed.) *Imaging Spectrometry: basic principles and prospective applications*. Kluwer Academic Publishers, Dordrecht, Boston, London.
- Dekker, AG, Brando, VE, Anstee, JM, Pinnel, N & Held, A, 2001. 'Preliminary assessment of the performance of Hyperion in coastal waters. Cal/Val activities in Moreton Bay, Queensland, Australia.' IEEE2001 International Geoscience and Remote Sensing Symposium. IEEE, Sydney, Australia.
- Dekker, AG, Peters, SWM, Rijkeboer, M & Berghuis, H, 1998. *Analytical processing of multitemporal SPOT and Landsat images*, Balkema, Rotterdam.
- Dekker AG, Vos RJ & Peters SWM, 2001, in press. 'Analytical algorithms for lake water TSM estimation for retrospective analysis of TM and SPOT sensor data.' *International Journal of Remote Sensing*.
- Dekker, AG, Vos RJ & Peters, SWM, 2001. 'Comparison of Remote Sensing Data, Model Results and In-Situ Data for the Southern Frisian Lakes.' *The Science of the Total Environment* 268:197–214.
- Dunk, I & Lewis, MR, 1999. 'Seagrass and shallow water feature discrimination using Hymap Imagery.' 10th Australian Remote Sensing and Photogrammetry Conference. University of Adelaide, Australia, pp. 1092–1108.
- Durand, D, Bijaoui, J & Cauneau, F, 2000. 'Optical remote sensing of shallow-water environmental parameters.' *Remote Sensing of Environment*, 73(2):152–161.
- DuRieu, R, 2000. 'TNTserver—A Low Cost System For Publishing Massive Geodata Sets Via The Internet Or Your Private LAN.' 10th Australasian Remote Sensing and Photogrammetry Conference, Adelaide, August 2000
- Environment Protection Agency, 1998. 'Changes in seagrass coverage and links to water quality off the Adelaide Metropolitan coastline.' Environment Protection Agency, Adelaide.
- Ferguson, RL, Wood, LL & Graham, DB, 1993. 'Monitoring spatial change in seagrass habitat with aerial-photography.' *Photogrammetric Engineering and Remote Sensing*, 59(6):1033–1038.

- Gobbie, MR & Blackburn, DT, 1993. *Strategies for the future operation of the Glenelg Wastewater Treatment Plant*. Proceedings of the 15th Biannual Australian Water and Wastewater Association Conference, Queensland.
- Green, EP, Mumby, PJ, Edwards, PJ & Clark, CD, 1996. 'A review of remote sensing for the assessment and management of tropical coastal resources.' *Coastal Management*, 24:1–40.
- Hart, DGD, 1996. 'Near-shore seagrass changes between 1949 and 1995—Mapped using digital aerial orthophotography—Metropolitan Adelaide area: Northern Adelaide area: Largs Bay–Glenelg.' Image Data Services, Resource Information Group. Department of Environment and Natural Resources report.
- Hart, DGD, 1997a. 'Near-shore seagrass changes between 1949 and 1996—Mapped using digital aerial orthophotography—Metropolitan Adelaide area: Largs Bay–Aldinga.' Image Data Services, Resource Information Group. Department of Environment and Natural Resources report.
- Hart, DGD, 1997b. 'Near-shore seagrass changes between 1949 and 1996—Mapped using digital aerial orthophotography—Metropolitan Adelaide area: Southern Adelaide area: Glenelg–Marino.' Image Data Services, Resource Information Group. Department of Environment and Natural Resources report.
- Hick, P, 1997. 'Determination of water column characteristics in coastal environments using remote sensing.' PhD thesis, Curtin University of Technology, Perth.
- Hoogenboom, HJ, Dekker, AG & Althuis, IJA, 1998. 'Simulation of AVIRIS sensitivity for detecting chlorophyll over coastal and inland waters.' *Remote Sensing of Environment* 65:333–340.
- Hoogenboom, HJ, Dekker, AG & De Haan, JF, 1998. 'Retrieval of chlorophyll and suspended matter in inland waters from CASI data by matrix inversion.' *Canadian Journal of Remote Sensing* 24(2):144–152.
- Hoogenboom, HJ, Peters, SWM, Hakvoort, JHM & Dekker, AG, 1999. 'The Use of SeaWiFS for Operational Monitoring of Water Quality in the North Sea.' 2nd International Conference on EuroGOOS.
- Jakubauskas, M, Kindscher, K, Fraser, A, Debinski, D & Price, KP, 2000. 'Close-range remote sensing of aquatic macrophyte vegetation cover.' *International Journal of Remote Sensing*, 21(18):3533–3538.
- Jensen, JR et al., 1986. 'Remote sensing inland wetlands: a multispectral approach.' *Photogrammetric Engineering and Remote Sensing*, 52:87–100.
- Jernakoff, P & Hick, P, 1994. 'Spectral measurement of marine habitat: simultaneous field measurements and CASI data.' 7th Australasian Remote Sensing Conference, Melbourne, Australia, pp. 706–713.
- Jupp, DLB et al., 1996. *Port Philip Bay Benthic Habitat mapping project Task G2.2*. CSIRO Land & Water, Melbourne.
- Karpouzli, E et al., 2001, in press. 'Underwater light characterisation for correction of remotely sensed images.' *International Journal of Remote Sensing*.

- Kenneth, J, Zhang, H & Chapin, A, 2000. 'Bi-directional reflectance distribution functions (BRDF) of benthic surfaces in the littoral zone.' *Ocean Optics XV*. SPIE, Monaco, France.
- Kinhill Engineers Pty Ltd, 1987–1991. Environmental information management system for a major mixed metal mine in South Australia."
- Kinhill Engineers Pty Ltd, 1989. 'Wasleys to Adelaide pipeline looping project, Barker Inlet monitoring and revegetation study final report. Pipelines Authority of South Australia.
- Kinhill Engineers Pty Ltd, 1995. Mapping historical changes in distributions of mangroves in the vicinity of the Penrice Soda Products bitterns discharges.' Penrice Soda Products Pty Ltd.
- Kinhill Engineers Pty Ltd, 1995. 'MFP Barker Inlet wetland mangrove accession study.' Corporation of the City of Salisbury.
- Kinhill Engineers Pty Ltd, 1995–1997. 'Spatial Information System for Mae Moh coal Mine and Power Stations.' The Electricity Generating Authority of Thailand.
- Kinhill Engineers Pty Ltd, 1996–1997. 'Spatial Information Systems Audit for the East Coast Armaments Complex.' Department of Defence.
- Kinhill Engineers Pty Ltd, 1998. 'Ongoing survey of marine environment impacts of the Bolivar WWTP discharge.' SA Water Corporation.
- Kinhill Engineers Pty Ltd., 1999. 'Options for upgrading the Aldinga Wastewater Treatment Plant.' United Water.
- Kinhill Engineers Pty Ltd, 1999. 'Options for upgrading the Glenelg Wastewater Treatment Plant.' United Water.
- Kinhill Metcalf & Eddy Joint Venture, 1993. 'Strategies for the future operation of the Glenelg wastewater treatment plant.' Engineering and Water Supply Department.
- Kinhill Metcalf & Eddy Joint Venture, 1994. 'Mapping of historical changes in marine communities in the region of the Bolivar WWTP outfall.' Final draft report. Engineering and Water Supply Department.
- Kinhill Pty Ltd, 1998. Northern wastewater treatment plants—marine impact investigation. SA Water Corporation.
- Kinhill Pty Ltd, 1998. 'Pilot study of mapping mound springs vegetation and water features using remote sensing.' WMC (Olympic Dam Operations) Pty Ltd.
- Kinhill Stearns, 1985. 'Wasleys to Adelaide pipeline looping project.' Draft environmental impact statement. Pipeline Authority of South Australia. Supplement also produced.
- Kinhill Stearns, 1985b. 'Wasleys to Adelaide pipeline looping project supplementary environmental studies.' Pipelines Authority of South Australia.
- Kirk, JTO, 1989. 'The upwelling light stream in natural waters.' *Limnology and Oceanography* 34(8):1410–1425.

- KME, 1996. 'Assessment of Marine Environmental effects near the Bolivar Wastewater Treatment Plant reclaimed water discharge.' Engineering and Water Supply Department.
- Lee, Z, Carder, KL, Mobley, CD, Steward, RG & Patch, JF, 1999. 'Hyperspectral remote sensing for shallow waters: 2. deriving bottom depths and water properties by optimization.' *Applied Optics*, 38(18):3831–3843.
- Lennon, P & Luck, P, 1990. 'Seagrass mapping using Landsat TM data: a case study in southern Queensland.' *Asian-Pacific Remote Sensing Journal*, 2(2):6.
- Louchard, EM, Reid, RP & Stephens, CF, 2000. 'Classification of sediment types and estimation of water depth using spectral libraries.' *Ocean Optics XV*, Monaco, p. 13.
- Lyzenga, DR, 1981. 'Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data.' *International Journal of Remote Sensing*, 2:71–82.
- Malthus, TJ et al., 1997. 'Can biophysical properties of submersed macrophytes be determined by remote sensing?' *Fourth International Conference on Remote Sensing for Marine and Coastal Environments: Technology and Applications*. ERIM-Veridian, Michigan, Orlando, Florida., pp. 562–571.
- Malthus, TJ & George, DG, 1997. 'Airborne remote sensing of macrophytes in Cefni Reservoir, Anglesey, UK.' *Aquatic Botany*, 58(3–4):317–332.
- Maritorena, S, 1996. 'Remote sensing of water attenuation in coral reefs: case study in French Polynesia.' *International Journal of Remote Sensing*, 17(1):155–166.
- Maritorena, S & Guillocheau, N, 1996. 'Optical properties of water and spectral light absorption by living and non-living particles and by yellow substances in coral reef waters of French Polynesia.' *Marine Ecology Progress Series*, 131:245–255.
- Maritorena, S, Morel, A & Gentili, B, 1994. 'Diffuse reflectance of oceanic shallow waters: influence of water depth and bottom albedo.' *Limnology and Oceanography*, 39(7):1689–1703.
- Marshall, TR and Lee, PF, 1994. 'Mapping aquatic macrophytes through digital image-analysis of aerial photographs—an assessment.' *Journal of Aquatic Plant Management*, 32:61–66.
- Meulstee, C, Nienhuis, PH & van Stokkom, HTC, 1986. 'Biomass assessment of estuarine macrophytobenthos using aerial photography.' *Marine Biology*, 91:331–335.
- Moussa, HB, Viollier, M & Belsher, T, 1989. 'Remote sensing of macrophytic algae in the Molene Archipelago: ground-radiometry and application to SPOT satellite-data.' *International Journal of Remote Sensing* 10:53–69.
- Mumby, PJ, Clark, CD, Green, EP & Edwards, AJ, 1998a. 'Benefits of water column correction and contextual editing for mapping coral reefs.' *International Journal of Remote Sensing* 19(1):203–210.
- Mumby, PJ, Green, EP, Clark, CD & Edwards, AJ, 1998b. 'Digital analysis of multispectral airborne imagery of coral reefs.' *Coral Reefs* 17(1):59–69.

- Mumby, PJ, Green, EP, Edwards, AJ & Clark, CD, 1997. 'Measurement of seagrass standing crop using satellite and digital airborne remote sensing.' *Marine Ecology Progress Series* 159:51–60.
- Pasqualini, V, Pergent-Martini, C & Fernandez, C, 1997. 'The use of airborne remote sensing for benthic cartography: advantages and reliability.' *International Journal of Remote Sensing* 18(5):1167–1177.
- Penueles, J, Gamon, JA, Griffin, KL & Field, CB, 1993. 'Assessing Community Type, Plant Biomass, Pigment Composition, and Photosynthetic Efficiency of Aquatic Vegetation From Spectral Reflectance.' *Remote Sensing of Environment* 46(2):110–118.
- PPK–Kinhill Joint Venture, 1994–1995. Environmental Information System developed for Municipality of Shanghai, People's Republic of China.
- Pratt, P, Carder, KL & Costello, DK, 1997. 'Remote sensing reflectance algorithms developed to correct underwater coral imagery for the effect of optical thickness to assist in benthic classification.' 4th Remote Sensing Conference for Marine and Coastal Environments. ERIM, Orlando, Florida.
- Russell-Smith, J, Ryan, P & DuRieu, R, 1997. 'A LANDSAT MSS-derived Fire History of Kakadu National Park, Monsoonal Northern Australia, 1980–94: Seasonal Extent, Frequency and Patchiness.' *Journal of Applied Ecology* 34.
- Short, FT & Wyllie-Echeverria, S, 1996. 'Natural and human-induced disturbance of seagrasses.' *Environmental Conservation* 23:17–27.
- Tassan, S, 1996. 'Modified Lyzenga's method for macroalgae detection in water with non-uniform composition.' *International Journal of Remote Sensing* 17(8):1601–1607.
- Wittlinger, S & Zimmermann, R, 2000. 'Hyperspectral remote sensing of subtidal macroalgal assemblages in optically shallow waters.' *Ocean Optics XV*, Monaco, p. 6.
- Zhang, X, 1998. 'On the estimation of biomass of submerged vegetation using satellite thematic mapper (TM) imagery: a case study of the Honghu, PR China.' *International Journal of Remote Sensing* 19(1):11–20.

Bibliography of references relevant to Task PPM 1

List of geological publications

(Note: Adelaide coastal waters are part of the Lacedepe Shelf system)

Refereed journals

- Belperio, AP, Hails JR, Gostin, VA & Polach, HA, 1984. 'The stratigraphy of coastal carbonate banks and Holocene sea levels of northern Spencer Gulf, South Australia.' *Marine Geology* 61(2-4):297-313.
- Belperio, AP, Cann, JH & Gostin, VA, 1986. 'Quaternary stratigraphy and coastal sedimentary environments, northeastern Gulf St. Vincent, South Australia.' In Parker, AJ (comp.) *One day geological excursions of the Adelaide region, including the Barossa Valley, Mount Lofty Ranges and Fleurieu Peninsula*. Parker, pp. 83-98.
- Belperio, AP, Gostin, VA, Cann, JH & Murray-Wallace, CV, 1988. 'Sediment-organism zonation and the evolution of Holocene tidal sequences in southern Australia.' In de-Boer, PL, van-Gelder, A & Nio, SD (eds) *Tide-influenced sedimentary environments and facies*, pp. 475-497.
- Bone, Y, 1984. 'Wardang Island—A refuge for *Marginopora vertebralis*?' *Transactions of Royal Society of South Australia* 108:127-128.
- Bone, Y and Wass, R, 1990. 'Bryozoan-serpulid buildups in the Coorong Lagoon, South Australia.' *Australian Journal of Earth Science* 37:207-214.
- Bone Y, 1991. 'Population explosion of the bryozoan *Membranipora aciculata* in the Coorong Lagoon in late 1989.' *Australian Journal of Earth Sciences* 38:121-123.
- Bone, Y, James, NP and Kyser, TK, 1992. 'Synsedimentary detrital dolomite in Quaternary cool-water carbonate sediments, Lacedepe Shelf, South Australia.' *Geology* 20:109-112.
- Bone, Y and James, NP, 1993: Bryozoa as sediment producers, Lacedepe Shelf, Southern Australia. *Sedimentary Geology* 86:247-271.
- Bone, Y & James, NP, 1997. 'Bryozoan stable isotope survey from the cool-water Lacedepe Shelf, southern Australia.' In James, NP & Clarke, JAD (eds) *Cool Water Carbonates*. SEPM Special Publications Series, No. 56, pp. 94-105.
- Cann, JH, Belperio, AP, Gostin, VA & Murray-Wallace, CV, 1988. 'Sea-level history, 45,000 to 30,000 yr BP, inferred from benthic foraminifera, Gulf St. Vincent, South Australia.' *Quaternary Research* 29(2):153-175.
- Cann, JH, Murray-Wallace, CV, Belperio, AP & Brenchley, AJ, 1999. 'Evolution of Holocene coastal environments near Robe, southeastern South Australia.' *Quaternary International* 56:81-97.
- Conolly, JR & Von der Borch, CC, 1967. 'Sedimentation and physiography of the sea floor of South Australia.' *Sedimentary Geology* 1:181-220.

- Fuller, MK, Bone, Y, Gostin, VA & von der Borch, CC, 1994. 'Holocene cool-water carbonate and terrigenous sediments in Lower Spencer Gulf, South Australia.' *Australian Journal of Earth Sciences* 41:353–363.
- Gostin, VA, 1976. 'Recent coastal carbonate environments, sabkhas and stromatolites in the South Australian gulfs and saline lakes.' *Reservoir* 3(3):1–2.
- Gostin, VA, Hails, JR & Belperio, AP, 1984. 'The sedimentary framework of northern Spencer Gulf, South Australia.' *Marine Geology* 61 (2–4):111–138.
- Gostin, VA, Belperio, AP & Cann, JH, 1988. 'The Holocene non-tropical coastal and shelf carbonate province of southern Australia.' *Sedimentary Geology* 60,(1–4):51–70.
- Hageman, S, Bone, Y, McGowran, B & James, NP, 1995. 'Modern bryozoan assemblages and distribution on the cool-water Lacepede Shelf, southern Australian margin.' *Australian Journal of Earth Sciences* 42:571–580.
- Hageman SJ, Bone, Y, McGowran, B & James, NP, 1996. 'Bryozoan species distribution on the cool-water Lacepede Shelf, southern Australia.' In Gordon, D Smith, A (eds) *Bryozoans in Time and Space*. Proceedings of the 10th International Bryozoology Association, Wellington, NZ, pp. 109–116.
- Hageman, SS, James, NP & Bone, Y, 2000. 'Cool-water carbonate production from epizoic bryozoans on ephemeral substrates.' *Palaios* 15:33–48.
- James, NP, Bone, Y, von der Borch, CC and Gostin, VA, 1992. 'Modern carbonate and terrigenous clastic sediments on a cool-water, high-energy, mid-latitude shelf; Lacepede Shelf, Southern Australia.' *Sedimentology* 39:877–904.
- James, NP, Bone, Y & Kyser, TK, 1997 'Brachiopod ^{18}O values do reflect ambient seawater; Lacepede Shelf, southern Australia.' *Geology*, 25:551–554.
- James NP, Bone, Y, Hageman, SS, Feary, DA & Gostin, VA, 1997. 'Palimpsest temperate carbonate sedimentation and oceanography; Lincoln Shelf, southern Australia.' In James, NP & Clarke, JAD (eds) *Cool Water Carbonates*, SEPM Special Publications Series, No. 56, pp. 73–93.
- Li, Q, McGowran, B, James, NP, Bone, Y & Cann, JH, 1996. 'Mixed foraminiferal biofacies on the mesotrophic, mid-latitude Lacepede Shelf, South Australia.' *Palaios* 11:176–191
- Li, Q, McGowran, B, James, NP & Bone, Y, 1996. 'Foraminiferal biofacies on the mid-latitude Lincoln Shelf, South Australia: oceanographic and sedimentological implications.' *Marine Geology* 129:285–312.
- Li, Q, James NP, McGowran, B, Bone, Y & Cann, JC, 1998. 'Synergetic influence of water masses and Kangaroo Island barrier on foraminiferal distribution, Lincoln and Lacepede shelves, South Australia: A synthesis.' *Alcheringa*:153–176.
- Rahimpour-Bonab, H, Bone, Y & Moussavi-Harami, R, 1997. 'Stable isotope aspects of modern molluscs and inorganic marine cements from cool-water carbonates, Lacepede Shelf, South Australia.' *Geochimica et Cosmochimica Acta* 61:207–218.
- Rahimpour-Bonab, H, Bone, Y, Moussavi-Harami, R & Turnbull, K, 1997. 'Geochemical comparisons of modern cool-water calcareous biota, Lacepede Shelf, South Australia, with

- tropical counterparts.' In James, NP & Clarke, JAD (eds) *Cool Water Carbonates*. SEPM Special Publications Series, No. 56, pp. 77–91.
- Shepherd, SA & Sprigg, RC, 1976. 'Substrate, sediments and sub-tidal ecology of Gulf St. Vincent and Investigator Strait.' In Twidale, CR, Tyler, MJ & Webb, BP (eds) *Natural history of the Adelaide region*, pp. 161–174.
- Short, AD, 1988. 'Wave, beach, foredune, and mobile dune interactions in Southeast Australia.' *Journal of Coastal Research* (3):5–9.
- Sprigg, RC, 1947. 'Submarine canyons of the New Guinea and South Australian coasts.' *Transactions of the Royal Society of South Australia* 71:296–310.
- Sprigg, RC, 1952. 'The geology of the southeast province, South Australia, with special reference to Quaternary coastline migrations and modern beach development.' *Bulletin of the Geological Survey of South Australia* 29.
- Sprigg, RC, 1958. 'Stranded sea beaches and associated sand accumulations of the upper southeast.' *Transactions of the Royal Society of South Australia* 82:183–193.
- Sprigg, RC, 1963. 'New structural discoveries off Australia's southern coast.' *Australian Journal of Oil and Gas* 2:32–42.
- Sprigg, RC, 1979. 'Stranded and submerged sea-beach systems of southeast South Australia and the aeolian desert cycle.' *Sedimentary Geology* 22:53–96.
- Sprigg, M and Bone, Y, 1993: Bryozoa in Coorong-type Lagoons in southern Australia. *Transactions of Royal Society of South Australia* 117:87–95.
- Wallace, MW, Keays, RR & Gostin, VA, 1991. 'Stromatolitic iron oxides; evidence that sea-level changes can cause sedimentary iridium anomalies.' *Geology* 19(6):551–554.
- Wright, LD, Guza, RT & Short, AD, 1982. 'Dynamics of a high-energy dissipative surf zone.' *Marine Geology* 45:41–62.

Theses (Adelaide University)

- Burgess, SN, 1998. 'Neritic biofacies on the Southern Margin: Foraminiferal profiles across the Great Australian Bight and the Bonney Shelf.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Burton, TE, 1984. 'The stratigraphy and mangrove development of the Holocene shoreline north of Adelaide.' Masters thesis, Department of Geology and Geophysics, Adelaide University.
- Cooper, RE, 1960. 'Recent sedimentation in the Gulf of St. Vincent, South Australia.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Depers, AM, 1974. 'Sedimentary facies at Yatala Harbour and the geochemical comparison with Pt. Pirie sediments, Spencer Gulf, South Australia.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Eacott, G, 2000. 'Interactions between the geochemistry of calcareous epibionts and their substrate: potential significance in paleoenvironmental reconstructions.'

- Farrell, BL, 1968. 'A beach study of the Fleurieu Peninsula.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Fuller, M, 1992. 'Holocene cool water carbonate and terrigenous sediments from the lower Spencer Gulf, South Australia.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Hinton, PV, 1981. 'The Quaternary geology of the upper Spencer Gulf.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Joannou, V, 1999. 'Stormwater storage in the Oligo–Miocene Willunga Formation, South Australia: A feasibility study.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Millikan, MI, 1994. 'The Quaternary geology of the Pelican Lagoon area, Kangaroo Island, South Australia.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Murray-Wallace, CV, 1983. 'Quaternary sea levels and coastal evolution, Broughton River "Delta" northern Spencer Gulf, South Australia.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Murray-Wallace, CV, 1988. 'Evolution and application of the amino-acid racemisation reaction in studies of Quaternary coastal and marine sediments on Australia.' PhD Thesis, Department of Geology and Geophysics, Adelaide University.
- Rhamipour-Bonab, H, 1997. 'Comparison of geochemistry of modern temperate and tropical calcareous biota.' PhD thesis, Department of Geology and Geophysics, Adelaide University.
- Ryan, S, 1998. 'Rhodoliths as palaeoecological indicators: Distribution, characteristics and application to the rock record of temperate coralline algae from southern Australian continental shelf and coast.' Honours thesis, Department of Geology and Geophysics, Adelaide University.
- Wirtz, PD, 1994. 'The Quaternary geology of the American River area, Kangaroo Island, South Australia.' Honours thesis, Department of Geology and Geophysics, Adelaide University.

Special publications

- Bone, Y, James, NP, von der Borch, CC & Gostin, VA, 1994. 'Southern Australian Margin: Cool-water carbonates and geological history.' Research Plan: FR 06/94. CSIRO *Franklin* National Facility Oceanographic Research Vessel, Hobart.
- Bone, Y, James, NP & Gostin, VA, 1994. 'Southern Australian Margin: Cool-water carbonates and geological history.' Cruise Summary: FR 06/94. CSIRO *Franklin* National Facility Oceanographic Research Vessel, Hobart.
- Bone, Y, James, NP, Collins, L. & Kyser, TK, 1998. 'Cool-water carbonate sedimentation, Bonney and Lacepede Shelves and eastern Great Australian Bight.' Research Plan: FR 03/98. CSIRO *Franklin* National Facility Oceanographic Research Vessel, Hobart.
- Bone, Y, James, NP, Collins, L & Kyser, TK, 1998. 'Cool-water carbonate sedimentation, Bonney and Lacepede Shelves and eastern Great Australian Bight.' Cruise Summary: FR 03/98. CSIRO *Franklin* National Facility Oceanographic Research Vessel, Hobart.

Papers (major conferences)

- Cann, JH & Gostin, VA, 1986. 'Holocene coastal sedimentary facies and foraminiferal biofacies, northeastern Gulf St. Vincent, South Australia.' Geological Society of Australia, 8th AGC, pp. 39–40.
- Belperio, AP & Gostin, VA, 1986. 'Neotectonics and coastal evolution of the Adelaide region.' Geological Society of Australia, 8th AGC, p. 30.
- Belperio, AP, Gostin, VA, Cann, JH & Murray-Wallace, CV, 1986. 'Temperate peritidal carbonates and shoreline evolution, southern Australia.' In *Sediments down-under*, 12th international sedimentological congress, abstracts, Canberra. pp. 26–27.
- Belperio, AP & Gostin, VA, 1988. 'The sedimentary framework and nature of late Pleistocene and Holocene sediments, Gulf St Vincent, South Australia.' in Allen, R (conv.) *Achievements in Australian geoscience*, Geological Society of Australia 21, Sydney, pp. 59–60.
- Belperio, AP & Gostin, VA, 1989. 'Strandline models for cool water carbonate sediments of Southern Australia and neotectonic implications.' *International Geological Congress, Abstracts*, 28(1):120.
- Bone, Y, James, NP, Rice, R, von der Borch, CC, Gostin, VA & Barnett, E, 1989. 'Marine geology of the Lacepede Shelf, S.A.—A failed delta.' Australian Marine Science Association Annual Conference, Wirrina, South Australia, p.13.
- Bone, Y, 1990. 'The Bryozoa *Membranipora aciculata* as an indicator of environmental changes in the Coorong Lagoon during the last 700 years.' Geological Society of Australia, 10th Convention, Hobart.
- Bone, Y, James, NP & Kyser, TK, 1991. 'Multicycle Holocene dolomite in cool-water carbonate sediments, Lacepede Shelf, South Australia.' AAPG (American Association of Petroleum Geologists), Dallas, 75.
- Bone, Y, James, NP, von der Borch, CC & Gostin, VA, 1991. 'Modern cool-water siliciclastic/carbonate shelf sediments, Lacepede Shelf, South Australia.' AAPG, Dallas, 75.
- Bone, Y and James, NP, 1992 'Modern cool-water carbonate/siliciclastic open platform sediments, southern Australia.' Geological Society of Australia, 11th AGC, Ballarat.
- Bone, Y et al., 1994. 'Exploration of the cool-water carbonate margin of southern Australia.' *Department of Geology and Geophysics, University of Adelaide, Seminar for Industry: Program and Abstracts.*
- Bone, Y, 1995. 'Opportunistic encrusting bryozoans in coastal lakes and lagoons, southern Australia.' *10th International Bryozoology Association Conference*, Wellington, NZ., Abstract volume.
- Bone, Y, James, NP, Rahimpour-Bonab, H & Moussavi-Harami, R, 1996. *Stable isotope biogeochemistry of modern cool-water carbonate skeletons in southern Australia, and the implications for the rock record. SEPM/IAS Carbonates and Global Change: An Interdisciplinary Approach.* Wildhaus, Switzerland.
- Brown, KM, Bone, Y & James, NP, 1998. 'Calcareous epiphytes: their significance as carbonate producers.' *Geological Society of Australia Abstracts* 49:55.

- Brown, K, Bone, Y, Cheshire, A & James, NP, 1999. 'Calcium carbonate quantities from epiphytes on *Posidonia* sp. & *Amphibolis* sp. from along the South Australian coastline, preliminary results.' Fourth Australian Marine Geoscience Conference, Exmouth, Western Australia, Sept.
- Brown, K, Cheshire, A, Bone, Y & James, NP 2000. 'Calcareous epiphytes on *Posidonia* sp. and *Amphibolis* sp. along the South Australian coastline: their distribution, abundance and importance.' 15th Australian Geological Conference, Sydney, July.
- Brown, K, Bone, Y, Cheshire, A & James, NP 2000. 'Seasonal variation of calcareous epiphytes on artificial seagrass: Preliminary studies, West Island, South Australia.' 15th Australian Geological Conference, Sydney, July.
- Campbell, EM & Bone, Y, 1997. 'Marine placers—sea-level change and its effect on the occurrence, formation and economic potential of these deposits in South Australia.' Third Australian Marine Geoscience Conference, University of Adelaide, Sept.
- Campbell, EM & Bone, Y, 1998. 'Colour in marine sediments.' *Geological Society of Australia Abstracts* 49.
- Davies, M, Bone, Y & McHenry, B, 1997. 'Ostracod faunas of the Lacepede and Bonney shelves, southern Australia: Preliminary investigations.' Third Australian Marine Geoscience Conference, University of Adelaide, Sept.
- Davies, M, Bone, Y & McHenry, B, 1998. 'Ostracod distribution on the Lacepede and Bonney Shelves: their relation to sedimentary facies and location on the continental shelf and slope.' *Geological Society of Australia Abstracts* 49.
- Gostin, VA, 1976. '*Recent coastal carbonate environments, sabkhas and stromatolites in South Australian gulfs and saline lakes.*' International Geological Congress, Abstracts 25(3):834.
- Gostin, VA, Belperio, AP, Veeh, HH, Cann, JH & Murray-Wallace, CV, 1986. 'Quaternary temperate carbonates of Gulf Saint Vincent, South Australia.' In *Sediments down-under*, 12th international sedimentological congress, abstracts, Canberra, pp. 123–124.
- Hageman, S, Bone, Y, McGowran, B & James, NP, 1994. 'Species and statistical analysis of the bryofacies on the cool-water Lacepede Shelf, southern Australia.' Geological Society of Australia, 12th AGC, Perth.
- Hageman, SJ, Bone, Y, McGowran, B & James, NP, 1995. 'Statistical analysis of bryozoan facies, Lacepede, Shelf, South Australia.' *10th International Bryozoology Association Conference*, Wellington, NZ, Abstract volume.
- Henderson, T & Bone, Y, 1997. 'Mineralogy and stable isotope composition of Recent carbonate sediments and waters from five small lakes, south-eastern South Australia.' Third Australian Marine Geoscience Conference, University of Adelaide, Sept.
- James NP Bone, Y, Hageman, SJ, Gostin, VA & Feary, DA, 1996. 'The Lioness, Bonarparte's tongue and cool-water carbonates on the South Australian continental margin.' AAPG. San Diego, USA.
- Rahimpour-Bonab, H, Bone, Y, Moussavi-Harami, R & Turnbull, K, 1995. 'Comparison of the geochemistry of cool-water corals, coralline algae and bryozoans from the Lacepede Shelf, South Australia, with their warm-water counterparts.' Cool-water Carbonate Workshop, Geological Society of Australia, Geelong, Vic.

Shubber, B, Bone, Y, McGowran, B and James, NP, 1994. 'Cool-water skeletal carbonate facies from the St. Vincent Basin, South Australia.' Geological Society of Australia, 12th AGC, Perth.

von der Borch, CC, Gostin, VA, James, NP, Bone, Y, Rice, R, Barnett, E & Smith, B, 1989. 'Marine geology of the Lacepede Shelf: Results of the 1989 cruise aboard R/V Franklin.' Australian Marine Science Association Annual Conference, Wirrina, South Australia (poster).

Bibliography of references and information relevant to Task PPM 2

- Behrenfeld & Falkowski 1997. 'Photosynthetic rates derived from satellite-based chlorophyll concentration.' *Limnology and Oceanography*, 42(1):1–20.
- Bowers, DG, 1986. 'Catalogue of data collected during CTD surveys in Investigator Strait, South Australia, 1985–1986.' FIAMS Cruise Report No. 11, Flinders University of South Australia.
- Bowers, DG & Lennon, GW, 1990. 'Tidal progression in a near-resonant system—A case study from South Australia.' *Estuarine, Coastal Shelf Science* 30,17–34
- Bye, JAT, 1976. 'Physical oceanography of Gulf St Vincent and Investigator Strait.' In Twidale, CR, Tyler, MJ, Webb, BP (eds) *Natural History of the Adelaide Region: Adelaide*. Royal Society, South Australia, Chapter 11.
- Bye, JAT & Suter, EF, 1974. 'Observations of currents in St Vincent Gulf.' FIAMS Research Report No 11, Flinders University of South Australia.
- Camp Scott Furphy Pty Ltd, 1993a. 'Strategies for the future operation of the Bolivar Wastewater Treatment Plant.' Final Report Vol. 1. Prepared for Engineering and Water Supply Department.
- Camp Scott Furphy Pty Ltd, 1993b. *Strategies for the future operation of the Bolivar Wastewater Treatment Plant*. Final Report volume 2. Prepared for Engineering and Water Supply Department.
- Cheshire, AC, Butler, AJ, Bathgate, RS, Westphalen, G & Miller, DJ, 1996. 'The impact of sand dredging on benthic community structure at Port Stanvac dredge site: interim report on the results of surveys 1992 to 1995.' Report to the Coast Protection Board.
- Cheshire, AC & Kildea, T. 1993. 'The impact of sand dredging on benthic community structure at the Port Stanvac trial dredge site.' SA Dept. of Environment and Land Management.
- DA Lord & Associates, Centre for Water Research & Coastal Information and Engineering Services, 1995. 'Adelaide metropolitan coastal waters study: hydrodynamic modelling.' Housing and Urban Development—MFP Corporation.
- DA Lord & Associates, 1996a. 'Estuary and Lakes Hydraulic Flushing Model Study.' MFP Australia.
- DA Lord & Associates, 1996b. 'Estuary and Lakes Hydraulic Flushing Model Study: Technical appendices: volume one.' MFP Australia
- DA Lord & Associates, 1996c. 'Estuary and Lakes Hydraulic Flushing Model Study: Technical appendices: volume two.' MFP Australia.
- de Silva Samarasinghe, JR. 1987. 'Dynamical and mixing processes in a tidal gulf of evaporation-enhanced salinity: Gulf St Vincent, South Australia.' PhD thesis, Flinders University of South Australia.
- de Silva Samarasinghe, JR, 1998. 'Revisiting Upper Gulf St. Vincent in South Australia: The Salt Balance and its Implications.' *Estuarine, Coastal Shelf Science* 46:51–63.

- de Silva Samarasinghe, JR & Lennon, GW, 1987. 'Hypersalinity, flushing and transient salt wedges in a tidal gulf—an inverse estuary.' *Estuarine, Coastal Shelf Science* 24:483–498.
- Environment Protection Authority. 1997b. Draft Water Monitoring report. September 1995 – December 1996. Ambient water quality monitoring of the Port River estuary. Report No. 1. EPA/DENR.
- Environment Protection Authority, 1997c. Draft Water Monitoring report. December 1995 – November 1996. Sediment quality monitoring of the Port River estuary. Report No. 1. EPA/DENR.
- FIAMS (Flinders Institute for Atmospheric and Marine Sciences), 1979. 'Nearshore current measurements between Hallett Cove and Port Stanvac.' A report to the Coast Protection Board, Department for the Environment, South Australia, November.
- Fotheringham, D, 1994. 'A vegetation survey of Barker Inlet, Gulf St Vincent, South Australia.' Coast Protection.
- Grzechnik, M, & Noye, J, 1996. 'A tidal model of Gulf St Vincent, South Australia, with fine grid submodels of the Outer Harbor and Port Stanvac regions.' Report TM1. Dept of Applied Mathematics, University of Adelaide.
- Gutteridge, Haskins & Davey, 1992. 'Strategies for the future operation of Port Adelaide Sewage Treatment Works.' Engineering and Water Supply Dept.
- Hails, JR, Salama, MS, Gostin, VA, Sargent, GEG & von der Borch, CC, 1982. 'Nearshore Sediment Dynamics and Sedimentation in the Gulf of St Vincent, South Australia.' A Report to the Coast Protection Board of South Australia, December.
- Herzfeld, M, 1988. 'Software for NOAA-9. FIAMS.' Technical Report, December.
- Hine, PT, Steffensen, DA, Fisher, AG & Harvey, MC, 1989. 'Preliminary assessment of stormwater quality to the north arm of the Port River.' Engineering and Water Supply Dept.
- Jayaswal, Z, 1997. 'A study of the dynamics of Franklin Harbour, South Australia.' Honours thesis, Flinders University of South Australia.
- Kämpf, J. (in preparation). 'Process-oriented numerical simulations of the barotropic circulations in Spencer Gulf and Gulf St Vincent, South Australia.'
- Kämpf, J & Fitzpatrick, M, (in preparation). 'Applications of HIREBBL to simulate sediment re-suspension by trawling and the generation of turbidity currents in Spencer Gulf, South Australia.'
- Kämpf, J & Fohrmann, H, 2000. 'Sediment-driven downslope flow in submarine canyons and channels: Three-dimensional numerical experiments.' *Journal of Physical Oceanography* 30(9):2302–2319.
- Kämpf, JD, Griffin, RL, Matthews & Ward, TM, submitted. The upwelling system off southern Australia. *Journal of Marine Systems*.
- King, MO, 1975. 'Water movement in St Vincent Gulf.' Honours thesis, Flinders University of South Australia.

- Kinhill Engineers Pty Ltd, 1989a. 'Wasleys to Adelaide pipeline looping project. Barker inlet monitoring and revegetation study.' Final Report. Prepared for Pipelines Authority of South Australia.
- Kinhill Engineers Pty Ltd, 1989b. 'Wasleys to Adelaide pipeline looping project. Barker inlet monitoring and revegetation study.' Progress report No. 1. Prepared for Pipelines Authority of South Australia.
- Kinhill Engineers Pty Ltd, 1999. 'On going survey of marine environment impacts of the Bolivar WWTP discharge.' Prepared for SA Water Corporation.
- Lawson & Treloar Pty Ltd, 1989. 'Recording and analysis of wave, tide and current data, Port Stanvac, South Australia.' Report 1260, for Petroleum Refineries (Aust.) Pty Ltd, May.
- Lawson & Treloar Pty Ltd, 1996. 'Holdfast shores wave climate studies.' Report J1470/R1669, for Conell Wagner Pty Ltd, August.
- Lennon, GP, Petrusevics, M, Wegner, J, Brandwyk, K, Noakes, D, Bowers, G, Wilkins, D, Clift, G, Mawer & Tickner, A, 1986. 'Development philosophy of the Flinders NOAA–AVHRR receiving facility.' In Proceedings 1st Australian AVHRR Conference, Perth, Western Australia, 22–24 October.
- Lewis, SA, 1975. 'Gulf St Vincent water pollution studies June 1972 – April 1975.' Engineering and Water Supply Dept. EWS 3876/70.
- Luyten, PJ, Jones, JE, Proctor, R, Tabor, A, Tett, P & Wind-Allen, K, 1999. 'COHERENS-A coupled hydrodynamical–ecological model for regional and shelf seas.' User documentation. MUMM Report, Management Unit of the Mathematical Models of the North Sea (There are numerous publications describing applications of COHERENS).
- Lyons, TJ, 1974. 'A climatic survey of the Adelaide region.' FIAMS Research Report, No. 14, Flinders University of South Australia.
- Matthews, RL, Kämpf, J & Ward, TM, submitted. 'Enhanced primary productivity in the eastern Great Australian Bight: field observations and numerical modelling.' *Estuarine, Coastal Shelf Science*.
- Neverauskas, VP, 1985. 'Port Adelaide sewage treatment works sludge outfall. Effects of discharge on adjacent marine environment.' Progress report. July 1982 – May 1984. SA Engineering and water supply Dept. EWS Lib Ref 85/6.
- Ng, S, Bye, JAT & Petrusevics, P, 1993. 'The St Vincent Gulf stream.' *Bulletin of the Australian Meteorological and Oceanography Society* 6:50–55.
- Nunes, RA & Lennon, GW, 1987. 'Episodic stratification and gravity currents in a marine environment of modulated turbulence.' *Journal of Geophysical Resources* 92:5465–5480.
- Oceanique Perspectives, 1996. 'Review of the physical oceanography of the Port Adelaide River and Barker Inlet region, South Australia.' Report prepared for Estuary and Lakes Hydraulic Flushing Model Study. MFP Australia.
- Pattiaratchi, C, 2000. 'Modelling study of Torrens Island Power Station development. Report Prepared for Burns and Roe Worley.' Centre for Water Research, University of Western Australia.

- Pattiaratchi, C & Svenson, T, 1994. 'Assessment of the Port River destratification system.' Final report. Centre for Water Research, University of Western Australia.
- Petrusevics, P, 1986. 'Report on water movement investigations adjacent to the E&WS Port Adelaide sludge outfall.' Pollution Management Branch Technical Report 86/2, Department of Environment and Planning.
- Petrusevics, P, 1989. 'Sea surface temperature fronts and gulf-shelf communication from satellite, oceanographic and meteorologic data.' PhD thesis, Flinders University of South Australia.
- Petrusevics, P, 1993. 'SST fronts in inverse estuaries, South Australia—indicators of reduced gulf-shelf exchange.' *Australian Journal of Marine and Freshwater Resources* 44:305–23.
- Petrusevics, P, 1995. 'Leeuwin environment index—pelagic recruitment strength relationship.' Final report to Fisheries Research Development Committee, Project 93/50.
- Petrusevics, P & Austin, W, 1986. 'A low cost image processing system.' In *Proceedings 1st Australian AVHRR Conference*, Perth, Western Australia, 22–24 October.
- Petrusevics, P & Lennon, G, 2001, in preparation. 'The spatial and temporal distribution of chlorophyll—a in an inverse estuary dominated oceanographic regime.'
- Petrusevics, P, Lennon, G & Bowers, D, 1986. 'Temperature measurements in the upper layer of the sea.' In *Proceedings 1st Australian AVHRR Conference*, Perth, Western Australia, 22–24 October.
- Petrusevics P, Riddle, J & Lennon, G, 1987. 'Fronts and SST in SA Gulfs.' *Proceedings of the 4th Australasian Remote Sensing Conference*, Adelaide, September, Vol. 2
- Petrusevics, P, Tapley, I & Bathols, J, 1984. 'Satellite observations of SST variation in Gulf St Vincent.' Abstracts, 1984 National Conference of the Australian Marine Science Association, Geelong, November 1984.
- Provis, DG, 1985. 'Tidal stream predictions, Port Adelaide sewerage treatment works sludge outfall.' Prepared by Steedman Limited, March.
- Provis, DG & Lennon, GW, 1983. 'Eddy viscosity and tidal cycles in a shallow sea.' *Estuarine, Coastal Shelf Science* 16:351–361.
- Provis, DG & Radok, R, 1979. 'Sea-level Oscillations Along the Australian Coast.' *Australian Journal of Freshwater Resources* 30:295–301.
- Radok, R, 1977. 'Winds, tides and currents.' Report 1—appears as Appendix 2 in Steffensen (1981).
- Ranasinghe, R & Pattiaratchi, C, 1999. Circulation and mixing characteristics of a seasonally open tidal inlet: a field study. *Marine and Freshwater Resources* 50:281–90
- Riedel & Byrne Pty Ltd, 1985. 'Port Stanvac wave climate study.' Report No. R136, for Seatech Consultants Pty Ltd, August.
- Roche, MT, 1976. 'An investigation of the sedimentary processes in the middle beach area, St. Vincent Gulf, South Australia.' Honours thesis, Flinders University of South Australia .

- SA Dept of Environment and Conservation, (1975). 'Report of the Port Adelaide Sewage sludge outfall working group.' SA Water.
- SA Water. (1995). 'Adelaide wastewater treatment plants environment improvement programs.' SA Water.
- Schahinger, RB, 1987. 'Structure of coastal upwelling events observed off the South-East coast of South Australia during February 1983 – April 1984.' *Australian Journal of Marine and Freshwater Resources* 38:439–459.
- Schluter, C, 1992. *The one-dimensional hydrodynamic model, RIS, and its application to the Port River Estuary, Adelaide*. FIAMS Computing Report No. 14, Flinders University of South Australia.
- Shepard, SA & Sprigg, RC, 1976. 'Substrate sediments and subtidal ecology of Gulf St.'
- Steedman, RK, 1985. 'Tidal stream predictions Port Adelaide sewerage treatment works sludge outfall.' Steedman Ltd, March. Cited in Camp Scott Furphy 1993.
- Steedman, RK, 1984. 'Wasleys to Adelaide pipeline looping project E.I.S.—for southern section—Physical oceanography.' Steedman Ltd, December. Cited in Camp Scott Furphy 1993.
- Steffensen, DA, 1981. 'Port Adelaide sewage treatment works sludge outfall—Effects of discharge on the adjacent marine environment.' Engineering and water supply Dept. EWS Lib Ref 81/8.
- Steffensen, DA & Walters, RP, 1980. 'Port River water quality surveys 1973 to 1979.' Engineering and Water Supply Dept. EWS Library Ref. 80/13.
- Symonds, G, 1977. 'Temperature and salinity measurements in St Vincent Gulf, 1976.' FIAMS Cruise Report No 6, Flinders University of South Australia.
- Thomas, IM, Ainslie, RC, Johnson, DA, Offler, EW, & Zed, PA, 1986. 'The effects of cooling water discharge on the intertidal fauna in the Port River estuary, South Australia.' *Transactions of the Royal Society of South Australia* 109:159–172.
- Tronson, K, 1974. The hydraulics of the South Australian gulf system. 1. Circulation. *Australian Journal of Marine and Freshwater Resources* 25:413–423.
- Tronson, K, 1975. The hydraulics of the South Australian gulf system. 2. Resonances. *Australian Journal of Marine and Freshwater Resources* 26:363–374.
- Tucker, R & Thomas, R, 1985. 'Offshore sand investigations in the Adelaide metropolitan area.' South Australia Dept. Environment and Planning, Coastal Management Branch Technical report 84/2.
- Van Senden, DC, 1980. 'Part 1: Tidal characteristics of the Gulf St Vincent, Part 2: Calculating tidal currents from sea level data.' Honours thesis, Flinders University of South Australia.
- Walter, NR, 1975. 'Temperature and salinity measurements in St Vincent Gulf, 1974.' FIAMS Cruise Report No 5, Flinders University of South Australia.
- Walters, RP, 1978. 'West Lakes water quality monitoring 1974–78.' Engineering and Water Supply Dept. EWS 4347/74.

- Ward, TM, McLeay, LJ, Dimmlich, W, Rogers, A, Matthews, RL & Kämpf, J, submitted. Why do juvenile bluefin tuna, *Thunnus maccoyii*, aggregate and grow quickly in the Great Australian Bight during summer–autumn? *Canadian Journal of Fishery and Aquatic Science*.
- Waters, C. (?) ‘Sedimentation in Gulf St Vincent.’ PhD thesis, Flinders University of South Australia.
- Wolanski, E, 1986. ‘An evaporation-driven salinity maximum zone in Australian tropical estuaries.’ *Estuarine, Coastal Shelf Science* 22:415–424.
- Wright, LD, Guza, RT & Short, AD, (1982) ‘Dynamics of high energy dissipation surfzone.’ *Marine Geology* 45:41–62.
- Zimmermann, D. (?) ‘Carbonate sediment studies in the northern region of Gulf St Vincent on sublittoral seagrass zones and in intertidal mud flats.’ Honours thesis, Flinders University of South Australia.