# Technical Report

Adelaide Coastal Waters Study

***Stage 2** Research Program 2003 - 2005*

Technical Report No. 19 June 2006

## *An Integrated Environmental Monitoring Program for Adelaide's Coastal Waters*

*Final report for the Adelaide Coastal Waters Study Task EMP 1*

Government of South Australia

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# *An Integrated Environmental Monitoring Program for Adelaide's Coastal Waters*

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# Executive Summary

In this report, we present a scientifically credible and cost-effective long-term monitoring program that will assist the Adelaide region's marine and natural resource managers to track changes and assess the impact of management strategies implemented for Adelaide's coastal region. To do this several key steps were required including:

- describing the broad requirements and attributes of an effective integrated environmental monitoring program for the Adelaide Coastal Waters Study region;
- adopting a suitable monitoring framework to guide the development of the EMP as a whole;
- seeking consensus on the objectives that the EMP must seek to address; and
- synthesis of findings from the companion ACWS Stage 2 studies (Input Studies 1, Remote sensing 1, Ecological Processes 1, Physical process modeling 1 and 2), from both ongoing and historical monitoring conducted in the region, and from comparable monitoring studies undertaken further afield to establish a suite of prioritized measures of seagrass, and more generally ecosystem, health.

This latter point was achieved through extensive consultation and discussion with other research task leaders and scientists involved in the ACWS or in other regional waterway monitoring programs, and through solicited feedback on earlier drafts of our recommended program.

In designing this program we have focussed on *what* is to be monitored (indicators) and *how* this monitoring should be undertaken (methods and spatial/temporal considerations) rather than by *whom*. Considerable discussion is likely to be necessary for determining which agencies monitor what and this is best left for the steering committee and study partners to decide on, armed with the recommended EMP, budgets, relevant logistical information and any other pertinent information. In discussing what is to be monitored we prioritised the recommended efforts into essential and desirable, and provided recommended minimum numbers of sites for each zone and each essential seagrass monitoring method.

**Seagrass**

- Initiate a regular annual assessment of seagrass health using fixed quadrat sampling at key sites in each of the zones, but particularly Zones 2, 3 and 3A. Measure indicators such as shoot density and leaf area index (*Posidonia*), number of leaf heads (*Amphibolis*), and species composition. Possibly photograph quadrats to capture a visual record.
- Place permanent markers at the inner and outer extent of seagrass in each zone, but largely in Zones 2 and 3, and measure recession or growth of extent from those markers. Link the location of permanent markers to beach profile / rod lines where possible.
- Conduct (diver / video) transect sampling along fixed 100-200 m transects to assess seagrass density and distribution and species composition. May record as little as presence/absence of seagrass.
- Conduct five-yearly aerial photographic survey of the entire region. Use multiple passes in one year if possible to improve classification accuracy.
- Update / create comprehensive maps of seagrass extent for all five zones so they may be used to provide benchmarks to assess any future change.

- Consider monitoring small number of reference sites outside study region to help identify effect of broader changes in environmental system.

**Sediment stability**

- Maintain beach profile / brass rod monitoring
- Extend some profiles to coincide with recommended key seagrass regions.
- Consider establishing additional profile lines in southern region (Zones 3 and 3A) and in Zone 1.
- Maintain plan for side scan sonar and swath mapping of the metropolitan coast. Establish methods for processing the data.

**Terrestrial inputs**

- **Stormwater**
  - Improve/standardise ‘end of valley’ load estimates – only central creeks are subject to flow-proportional sampling. Others are subject to grab sampling. The Field River in particular is noted as an input source that does not use flow-proportional sampling.
  - Regularly record the dissolved organic carbon (colour) in stormwater outputs from major outlets.
- **Wastewater**
  - Maintain current compliance monitoring of treated effluent from Christies Beach, Glenelg and Bolivar WWTPs.
  - Maintain assessments of water quality in nearby receiving waters of Glenelg and Christies Beach WWTP outfalls
  - Initiate monitoring of receiving waters of Bolivar WWTP outfall.
  - Establish a regular annual nitrogen isotope survey of seagrass to help determine range of influence of the WWTPs and differentiate between sources of nitrogen inputs into Zones 1-3.
- **Port Adelaide River / Barker Inlet**
  - Maintain/improve monthly monitoring of nutrients and toxicants exported from Port Adelaide River / Barker Inlet to GSV. Link to the monitoring that is part of the Port Adelaide River Water Quality Improvement Plan.
- Ensure detailed monitoring of terrestrial inputs in Zones 3 and 3A is undertaken, given the likely population growth in the associated regions.

**Coastal water quality**

- Maintain monthly ambient jetty sampling
- Initiate a regular midshore and offshore monitoring program, either grab sampling or via automatic sampling stations. Focus on both light-related and nutrient indicators as well as chlorophyll-a, temperature and salinity. Concentrate effort in Zones 1-3 given they are subject to greatest anthropogenic influences (which we may be able to control) and less in Zones 4 and 5 which are largely subject to natural physical processes only now. Carry out monthly sampling initially until an understanding of the amount of variation in these indicators is established.
- Undertake artificial seagrass monitoring every two years to measure epiphyte loads and provide an integrated measure of nutrient enrichment in Zones 1-3.

**Physical processes**

- Maintain regular access to wind, wave height, tide height and storm records from the Bureau of Meteorology and National Tidal Centre.

The implementation of the program will require a higher level of detail than has been outlined in this report. This includes aspects such as the precise location and number of sites and the operational procedures for collecting and analysing any monitoring data. The degree of adoption and implementation of the program is likely to also depend on costs associated with undertaking monitoring and these have not been discussed here.

It is recommended that the environmental monitoring program be initiated for 2-3 years in the first instance, with a detailed period of analysis and review after that time. This initial monitoring phase is necessary to confirm the relative merit of the methods proposed and to fully examine the different sources of variability and their relative contributions to the variability in key ecosystem parameters.

# 1. Introduction

## 1.1 The Adelaide Coastal Waters Study

The Adelaide Coastal Waters Study (ACWS) was established early in 2001 by the South Australian Environment Protection Agency (now Environment Protection Authority; SA EPA). This was in response to ongoing community concerns about the decline in coastal water quality, as well as the loss of approximately 5000 hectares of shallow sub tidal seagrass along the metropolitan coast since the 1940s.

The Adelaide Coastal Water Study focuses on the area of Gulf St. Vincent from Port Gawler in the north to Sellicks Beach in the south and extends approximately 20 km offshore (see Figure 1). Although important, the Port Adelaide River and associated estuary and wetlands are not a primary focus for the Adelaide Coastal Waters Study. However, the input of nutrients and other contaminants from these sources to the coastal strip have been considered in developing a recommended environmental monitoring program.

The objective of the ACWS is to develop knowledge and tools to enable sustainable management of Adelaide's coastal waters by identifying causes of ecosystem modifications and the actions required to halt and reverse the degradation. The study will focus on seagrass health, water quality and seafloor stability.

The ACWS Steering Committee has representatives from the South Australian Environment Protection Authority (SA EPA), SA Water, Transport SA, the Torrens, Patawalonga and Onkaparinga Catchment Water Management Boards, Primary Industries and Resources SA (PIRSA), Coast Protection Board, Mobil Australia, TXU Torrens Island, Conservation SA, Local Government Association and South Australian Fishing Industry Council. The Steering Committee has endeavoured to direct the efforts of the ACWS towards activities which will not duplicate the efforts of other bodies.

The ACWS does not have any long-term responsibility for management of Adelaide's coastal waters. However, the ACWS aims to influence organisations which do have such long-term responsibilities by providing knowledge and tools. Further details about this study can be found at http://www.clw.csiro.au/acws/ .

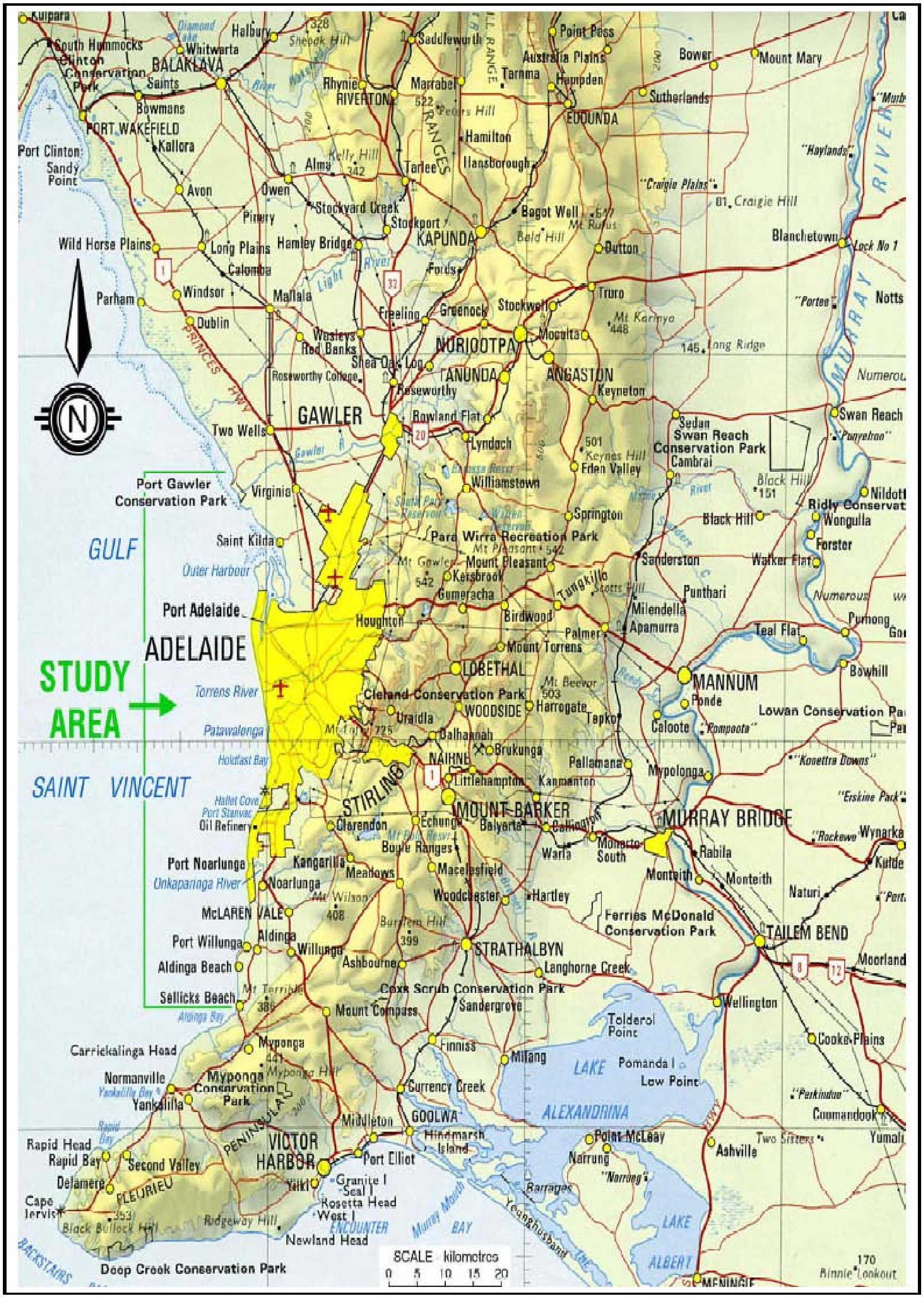


**Figure 1.** Study area for the Adelaide Coastal Waters Study (reproduced with permission from Ellis and Fox, 2003).

## 1.2 EMP 1 scope and objectives

During Stage 1 discussions of the ACWS, stakeholders raised concerns about how the coastal waters and adjoining river systems would be monitored in future. As a result, an Environmental Monitoring Program research task (EMP 1) was established in Stage 2 of the ACWS.

The main objective of this task was to synthesise information gathered during the course of ACWS to design an integrated, cost-effective, long-term monitoring program that will

- monitor key system parameters and values,
- integrate new and existing monitoring activities, and
- assist the region's marine managers to track changes and assess the impact of management strategies implemented for Adelaide's coastal region.

Integration of monitoring activities will need to occur at three levels: across ongoing/new monitoring activities, across study foci and across agencies. The first two are critical to meeting the task objective and are subsequently discussed further in this report. Whilst it would be desirable to suggest relevant agencies to carry out the monitoring detailed in our program to ensure integration across agencies, we believe that this would not be worthwhile nor relevant as ultimately these decisions will probably be directly influenced by costs involved in carrying out the monitoring and agency participation in the EMP subsequent to finalization of the ultimate ACWS report. This aspect of the program is beyond the scope of our objectives. Similarly, providing a cost-benefit analysis is beyond the scope of our objectives. There should however be some consideration prior to implementation, with a more detailed analysis undertaken several years into the program when valuable monitoring data is available.

Finally, the content of this report, particularly the recommendations we make and monitoring protocols we describe, has been based on best available knowledge at the time of writing.

## 1.3 Report aims and outline

In this report, we present a scientifically credible and cost-effective long-term monitoring program that will assist the region's marine managers to track changes and assess the impact of management strategies implemented for Adelaide's coastal region. We have achieved this through extensive consultation and discussion with other research task leaders and scientists involved in the ACWS or in other regional waterway monitoring programs, and through solicited feedback on earlier drafts and aspects of our recommended program.

In undertaking this task, we have tried to consider the big picture for the Adelaide region, that is, the development of a long-term monitoring program and much of the content of this report has kept this in mind. In particular, to help inform the design we review the requirements of an integrated environmental monitoring program (Section 2), the characteristics of an effective monitoring program (Section 3), the specific features that must be considered for Adelaide's coastal waters (Section 4), and the limitations from past and current monitoring in the region (Section 5). We then discuss in detail in Section 6 our recommendations for an integrated environmental monitoring design for monitoring of seagrass, sediment stability, terrestrial inputs, coastal water quality and physical processes. Overarching aspects of an ongoing EMP and recommendations for implementation and long-term monitoring are subsequently presented in Sections 7 and 8 respectively, followed by some overall conclusions in Section 9. The five appendices provide additional information to support our recommendations.

# 2. Integrated environmental monitoring

## 2.1 Environmental monitoring

"*Effective prediction, assessment, policy and management are built on accurate, timely and appropriate observations and monitoring programs*"

(U.S. National Science and Technology Council, 1995)

As captured in this quote, monitoring is critical to risk-informed decision-making and scientific judgment. It is thus important that monitoring recommendations are made after careful consideration of the core environmental issues, our understanding of the scientific processes at work, the needs of the agencies and organisations currently monitoring, and the resources that are required for monitoring. All considerations need to be founded and assessed against the objectives determined for the EMP. This is critical for ensuring the program achieves its objectives. It also collectively enables EMP stakeholders to consider any need to adapt the objectives of the monitoring program as new system understanding and trend assessments are established.

The EMP will play a critical role in assessing the future ecological health of Adelaide's coastal waters. It will enable stakeholders to:

- Provide a baseline for condition so that the impact of future management interventions may be judged;
- Assess trends or change in environmental condition;
- Enable the evaluation of causes and consequences of change. While these are always difficult to establish, it is highly desirable that the EMP, when coupled with ecological understanding and physical modeling, provide some capacity to validate any changes;
- Provide important data and information that may help generate and facilitate future research into the processes at work in Adelaide's coastal waters; and
- Reduce risk in decision-making by providing information that is essential to the decision-making process. This includes measures of uncertainty, predictions into the future, and assessments of possible impacts of future actions.

## 2.2 The need for an integrated approach

The monitoring currently undertaken that is relevant to the Adelaide coastal waters is conducted by a number of different agencies, each with their own specific objectives and motivations. The need for an 'integrated' approach reflects the desire to develop a monitoring program that coordinates the various objectives in the region, builds on the efforts of the different agencies and organisations, and links the outcomes and recommendations of the ACWS. There is thus a need to integrate the environmental and inter-agency objectives under a common EMP. This is important because it

- Reduces duplication
- Reduces costs, e.g. by sharing monitoring sites, resources and system understanding
- Enables measurements of different environmental attributes at the same sites thus facilitating the exploration of attribute interactions, improved system understanding and spatio-temporal trend assessment through formal analyses

- Shares a common vision of ecosystem health
- Ensures compatibility through common sampling and measurement protocols
- Enables coordinated management intervention
- Enables coordinated communication of environmental health through formal reporting to program stakeholders and the general public

An integrated EMP may also look to ‘integrate’ various measures of environmental condition or quality. This often involves bringing together a mix of physical, chemical and biological indicators of health and weighting them in some way so that they may be combined to provide an overall assessment or ‘weight of evidence’ in relation to ecosystem health. An example of this is the EcoH plots that are used in the freshwater Ecological Health Monitoring Program in South East Queensland (EHMP 2006; Harch et al. 2005).

An integrated EMP should also improve the link between monitoring and research. The cost involved in collecting data often prohibits important research being undertaken. Monitoring programs can produce valuable data for scientific research, and where possible, may be tailored so as to facilitate the research that will enhance our understanding of the region and the processes at work. Ultimately this will enable refinement and adaptation of the monitoring efforts.

Ideally an integrated EMP should be embedded in a broader Integrated Coastal Management (ICM) plan, which can be described as a “process that unites government and the community, science and management, sectoral and public interests in preparing and implementing an integrated plan for the protection and development of coastal ecosystems and resources” (GESAMP 1996). Monitoring is then just one part of the ICM plan. Other key components may include legislation, zoning, research, education and public participation (Morecom 2002). Stojanovic et al. (2004) describe some of the important factors for a successful ICM.

A number of other large environmental studies in Australia have also taken integrated approaches. Examples include the Port Phillip Bay Environmental Study, Perth Coastal Waters Study and the Ecosystem Health Monitoring Program in South-East Queensland. These are summarised in Section 2.5.1.

## 2.3 Legislation – compliance monitoring

As part of the Environment Protection Act 1993 (the Act), the Water Quality Policy aligns South Australia with the National Water Quality Management Strategy (NWQMS). The Act also requires regular monitoring and reporting to identify trends in environmental quality on a state-wide basis. This is achieved via an ambient water quality monitoring program that covers inland surface waters, underground waters, marine and estuarine waters. The results are published regularly in water monitoring reports.

Hot-spot monitoring is used in South Australia to determine whether there has been a breach of the Act (particularly in relation to general environmental duty). In addition, many licensed activities that discharge regularly into water bodies are required as a condition of their licence to monitor their discharges and report results to the SA EPA.

The report by Dobbie et al. (2005), which can be found in Appendix A, discusses relevant aspects of compliance monitoring in more detail and references figures from the SA State Water Plan (2000) that indicate sites which have been monitored for water quality and may impact on the ACWS region.

## 2.4 Characteristics of an effective EMP

An effective EMP needs to be:

- Robust;
- Fit for purpose;
- Clear in its aims and objectives;
- Scientifically defensible in both the indicators chosen and the spatio-temporal monitoring design devised;
- Complement and enhance existing efforts;
- Able to minimise obvious duplications and redundancies ;
- Adaptive to changing environmental conditions, demographics, government policy and scientific understanding;
- Cost effective;
- Communicable to a range of audiences from the scientific community to policy makers to school children;
- Able to allow reporting at different spatial and temporal scales;
- Directing and facilitating research that improves our understanding, fills in data gaps and improves our ability to interpret the monitoring data collected;
- Underpinned by strong QA/QC procedures, data management practices and rigorous statistical analysis of the data; and
- Involved with the wider community to inform, educate and garner support.

## 2.5 Other integrated coastal monitoring programs

### 2.5.1 **National**

The Australian and New Zealand Water Quality Monitoring and Reporting Guidelines (ANZECC/ARMCANZ 2000a) provide a comprehensive framework for all aspects of a monitoring program that is applicable to freshwater, groundwater, estuarine and marine contexts. The guidelines outline those approaches and attitudes that have been found to be effective in water quality monitoring for Australian and New Zealand conditions. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000b) is broader in scope and provides guidance on a wider range of aspects related to use and protection of our water resources. There is a strong emphasis on guideline values related to various contaminants (e.g. toxicants, sediments, nutrients, heavy metals, pesticides), levels of biological activity, and water quality requirements and guidelines associated with human consumption, recreation and irrigation. Monitoring represents only one aspect. Flaherty & Sampson (2005) describe how to incorporate coastal and marine issues into regional natural resource management plans.

There have been several monitoring studies carried out in coastal areas of Australia that were considered in some detail to help inform an environmental monitoring program for Adelaide's coastal waters. These studies are described briefly now:

**Boags Rocks, Vic**: A study of the receiving environment at Boags Rocks (near Cape Schanck, Victoria) was undertaken to establish the causes and extent of environmental impacts that could be linked to Melbourne Water's discharge from its Eastern Treatment Plant. The results of that comprehensive investigation, together with an assessment of alternative disposal options, were published in the report by Fox et al. (2000). Consequently, a monitoring program was designed that allowed Melbourne Water to assess both compliance with Victorian regulations and benefits arising from upgrades to the Eastern

Treatment Plant. The report by Fox et al. (2000) presents a recommended program for monitoring the receiving waters at the Eastern Treatment Plant.

**Port Phillip Bay, Vic:** The Port Phillip Bay Environmental Study (PPBES) was the largest and most integrated piece of coastal marine research ever carried out in Australia in the early 1990s and was developed to help resolve concerns about the release of effluent into the bay. More specifically, the integration brief was “to determine the environmental status of the bay in relation to nutrients and toxicants and to provide the basis for long term management of point and diffuse loads”. The study focused on groups of organisms that were either of direct concern to management agencies and the community, such as fish, or those that would act as indicators of change within the bay, such as the type of animals living in the surface layers of the seabed. The PPBES demonstrated the key role played by the biodiversity of the bay ecosystem and quantified the threats posed by introduced species. Great emphasis was placed on conservation, protection and restoration of the bay ecosystem in order to maintain water quality. Harris et al. (1996) provides further details.

**Ecosystem Health Monitoring Program, SE Qld**: The Ecosystem Health Monitoring Program (EHMP) delivers a regional assessment of ambient ecosystem health for the waterways of south-east Queensland. It targets fresh and estuarine/marine waterways from Noosa in the north, south to the NSW border and west to Toowoomba. Monitoring of estuarine and marine health commenced in Moreton Bay in 2000, and has expanded north and south since then to include 250 monitoring sites. The EHMP expanded into the freshwater catchments in 2002 with a total of 120 freshwater sites being monitored. It is considered one of the most comprehensive marine, estuarine and freshwater ecosystem health monitoring programs in Australia with partnerships established amongst local councils, state government, research organisations and community groups. Waterway health is measured through an integration of biological, physical and chemical indicators. For further details, see EHMP (2006).

**Cockburn Sound, WA**: An environmental quality management plan was devised for Cockburn Sound in Western Australia and is implemented through the State Environmental (Cockburn Sound) Policy 2005 (SEP). The focus of this policy is to declare, protect and maintain the environmental values of Cockburn Sound, protecting them from the adverse effects of pollutants, waste discharges and deposits. Environmental quality criteria have been specifically developed for Cockburn Sound to tell whether or not the environmental quality meets the objectives that have been set for it in the SEP. Environmental values are broadly classified as the integration of ecosystem health, fishing and aquaculture, recreation and aesthetics, and industrial water supply. See EPA (2005) for more detail.

In addition, we considered some of the research that has been or is being undertaken in the South Australian region that was valuable for designing this EMP. An important and timely article outlining a protocol for monitoring seagrass (health) was the result of a Natural Resources Management Workshop on Kangaroo Island, South Australia in 2005 (Kirkman 2005). The protocols include transects, shoot density (quadrat sampling), and epiphytes on artificial seagrass. Details of these methods are discussed and a list of required equipment is provided.

The SA EPA carried out ambient water quality monitoring of Nepean Bay on Kangaroo Island, prompted by community awareness of seagrass decline in the area. The report by Gaylard (2005) summarises the results of sampling nutrient and microbiological concentrations from five sites in Nepean Bay on a monthly basis between 1999 and 2004. Despite the fact that the study was prompted by seagrass decline, there was no direct monitoring of seagrass health and distribution in this study.

### 2.5.2 **International**

The U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program[1] (EMAP) describes strategies for coastal monitoring in considerable detail. In particular the U.S. EPA's National Coastal Assessment program[2] surveys the condition of the nation's coastal resources using an integrated, comprehensive monitoring program across the coastal states (U.S. EPA 2001a,b). The background motivation for this program and how it relates to the U.S. Clean Water Act is described in detail in U.S. EPA (2000).

More widely, the U.S. National Water Quality Monitoring Council[3] (NWQMC) aims to "provide a national forum for coordination of consistent and scientifically defensible methods and strategies to improve water quality monitoring, assessment and reporting; promote partnerships to foster collaboration, advance the science, and improve management within all elements of the water quality monitoring community". It was recognised that critical differences in monitoring objectives, project design, methods, data analysis, and data management made it difficult for monitoring information to be shared by more potential data users. The NWQMC has developed a monitoring framework to improve collaboration and compatibility. It is a direct attempt to view monitoring and assessment as a sequence of related activities. Figure 2 summarizes the NWQMC framework. A large number of interests are represented, including the U.S. Environmental Protection Agency, U.S. Geological Survey, National Park Service, U.S. Fish and Wildlife Service, U.S. Department of Agriculture, National Oceanic and Atmospheric Administration and various state-level agencies, academic institutions and local organisations.

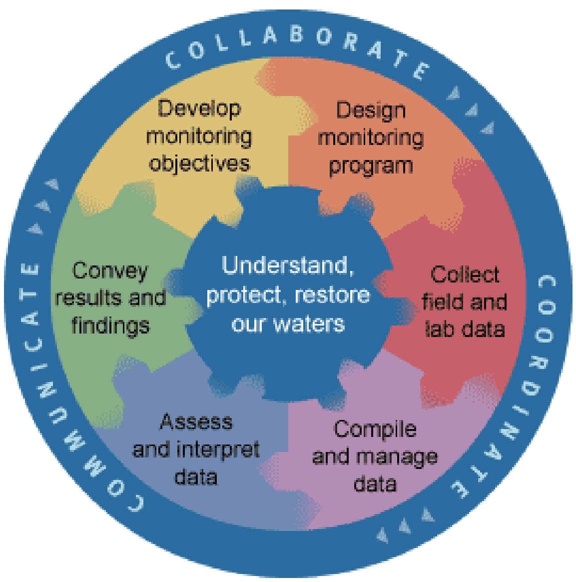


**Figure 2.** U.S. National Water Quality Monitoring Council monitoring framework.

The California Environmental Protection Agency (CEPA) devised a long-term, comprehensive strategy to monitor coastal water quality. The strategy underpins the design of coordinated, scientifically sound surveys in California. The recommended key elements of the California Coastal Monitoring Program (CEPA 1998) are:

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[1] http://www.epa.gov/emap/
[2] http://www.epa.gov/emap/nca/index.html
[3] http://water.usgs.gov/wicp/acwi/monitoring/

1. Long-term commitment
2. Co-operative effort and shared resources
3. Clear monitoring objectives
4. Scientifically sound monitoring design
5. Common methods in sampling and analysis
6. Evaluation and interpretation of results
7. Regular reporting of the results to decision makers
8. Refinement of monitoring program and plan

### 2.5.3 **Lessons learnt**

General details of the monitoring frameworks, and some specific aspects of the programs described in Sections 2.5.1 and 2.5.2, were insightful and informative. However, the primary focus of these programs was determining more generally ecosystem health and as such, numerous physical, biological and chemical indicators, including measures of seagrass health and distribution, were combined to form some measure of ecosystem health. The ACWS is in some sense a unique study in that seagrass health is the primary focus and not just an indicator of ecosystem health.

We now briefly summarise what measures of seagrass health and distribution were considered in each of the programs. In the South-East Queensland EHMP (EHMP 2006) seagrass distribution was measured bay-wide every 3 years and seagrass depth range was measured biannually at 17 sites in the bay. For reporting, each of these indicators was scored from 1 to 5, with higher scores representing better condition. Together with a measure of coral cover (from 5 sites annually), a single Biological Health Rating (BHR) was calculated by averaging the three indicators for each 'zone' in the bay.

The Cockburn Sound study (EPA 2005) was much more informative with regards to specific indicators of seagrass health and distribution and details of their collection. In order to monitor the effects of a range of impacts on seagrass in Perth's coastal waters, seagrass shoot density and seagrass depth range are simultaneously measured *in situ* for the *Posidonia* species. There is detailed information about the procedure for collecting measurements including selection of monitoring sites (reference or otherwise), numbers and size (area/length) of quadrats/transects, and frequency of collection. For reporting, a nutrient-related environmental quality criterion was derived from measurements of chlorophyll a, light attenuation, phytoplankton biomass and seagrass shoot density, to provide an environmental quality benchmark against which environmental quality and the performance of environmental management can be measured. Their environmental quality management framework was particularly of interest to us in considering options for reporting results and assessing monitoring and management objectives (see Section 7).

Fox et al. (2000)'s long-term monitoring program was designed to assess interactions between discharge of treated effluent from the Melbourne Water Eastern Treatment Plant and the receiving environment at the site of the discharge, Boags Rocks, did not specifically address seagrass health and distribution so did not shed light on this aspect of our program. However, details of the framework they adopted and overarching aspects of their recommended ongoing monitoring program, such as data management and implementation, were very useful in helping us think about issues arising within our context.
There were numerous lessons to be learned from the Port Phillip Bay Study (Harris et al. 1996), especially on integration of data by processes. This is particularly beneficial in forming a big picture of the state of an environment, especially when there are various sources of data and a range of complex models describing processes and interactions in that environment.

Hugh Kirkman's article on protocols for monitoring seagrass (Kirkman 2005) provides detailed advice for designing the EMP. The article states that if the main objective of a monitoring program is to monitor marine habitats to determine if deleterious change is occurring, then all seagrass monitoring carried out in South Australia should use the same methods for the sake of comparison and consistency. This will be particularly appreciated if the whole of South Australian coastal seagrass is ever monitored, because it will then be more cost-effective and easier to make comparisons if those sections already being monitored use the same methods. All three methods and the criteria considered for choosing them that were put forward for monitoring seagrass health will be considered further in designing the ACWS EMP.

# 3. A monitoring framework

A monitoring framework is essential to the design and adaptation of an effective monitoring program. It establishes a simple sequential structure that encourages thoroughness, facilitates communication within and between different levels of operation and management, and provides overall direction and focus essential to achieving success in such large-scale and long-term studies.

The framework we adopt in developing the EMP for ACWS is summarised in Figure 3. It has a great deal in common with the procedural framework advocated in Figure 7.1.1 of the Water Quality Guidelines (ANZECC/ARMCANZ 2000b). It is also clearly consistent with the NWQMC framework in Figure 2.

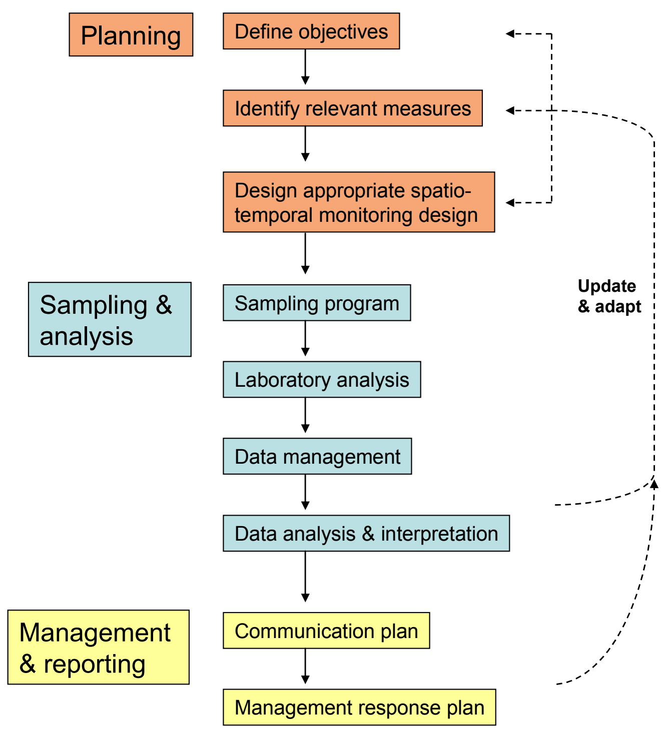


**Figure 3.** Our recommended ACWS monitoring framework.

There are three core phases to the monitoring process, namely planning, sampling and analysis, and management and reporting. Each of these phases is made up of several component steps, which we will now discuss in more detail. For further general information about the components in a comprehensive monitoring framework please refer to the Water Quality Monitoring and Reporting Guidelines (ANZECC/ARMCANZ 2000a).

## 3.1 Define monitoring objectives

Environmental monitoring is motivated by the need to assess, protect, understand and manage important ecological or environmental issues. In order to do this effectively it is critical that these issues are well defined and understood. This knowledge dictates the type of information and data that the monitoring program must provide.

While some monitoring programs may be developed around a single issue, the design of an integrated monitoring program invariably seeks to provide information and knowledge on multiple issues. In the Adelaide Coastal Waters Study context the central driving issue has been the loss of seagrass, however coastal erosion or sediment stability and the quality of water in the region are also flagged as major issues.

It is important that the requirements and interests of all stakeholders, including regulators, government organisations (local, state and federal), industry groups, community groups and the wider public, be canvassed surrounding the specific environmental issues as they may bring different perspectives.

A conceptual model of the operating underlying processes is often an essential developmental step because it is a powerful and simple way to represent the current understanding of how the system is functioning. It identifies relationships between elements of the system and represents those factors that are considered to be causing changes. It also provides something we can readily relate our findings to after the monitoring data are collected and analysed. A conceptual model is often found to be a valuable communication tool.

The monitoring objectives need to be explicit, concise and well-defined. This helps ensure that the EMP is targeted and appropriate, and will inform the motivating issues identified. Well-defined objectives thus provide the focal point for considerations in all subsequent components of the monitoring process.

## 3.2 Determine most relevant measures of ecosystem health

There are a large number of indicators of ecosystem health that can be measured in almost any situation. It is important that those selected are practical and relate as directly as possible to the monitoring objectives and the conceptual understanding of how the system functions. It may be essential to choose a balance of physical, chemical and biological indicators to represent the different objectives and additionally provide a weight-of-evidence in relation to impairment and trend analysis.

It is often useful to structure thinking about indicators according to a framework like the Pressure-State-Response (PSR) framework (OECD 1994) which advocates assessment indicators that fall under the following three broad categories:

- *pressures* on the environment (both anthropogenic and natural),
- the *state* of the ecosystem, and
- *response* by management and society.

The PSR framework is widely used in Australia's State of the Environment reporting. Alternative frameworks are available and may be equally useful in ensuring that the different components and contributors to ecosystem health are adequately represented.

Other factors that are necessary when considering specific indicators include the collection, measurement and analysis costs involved and the inherent natural variability in that indicator as that will influence its ability to reflect change in the system. In some instances, the latter detail is unknown and it is only after commencing the monitoring program (possibly through a more intensive pilot phase), that variability associated with the indicator can be explored and quantified.

The National Resource Management Monitoring and Evaluation Framework (Natural Resource Ministerial Council 2003) suggests that indicators should be selected on the basis of their relevance to the objectives, simplicity (ease of interpretation and monitoring), measurability, accessibility and responsiveness to change. Similar characteristics are suggested in the Australian and New Zealand Monitoring and Reporting Guidelines (ANZECC/ARMCANZ 2000a). The skill of the field and laboratory operator may also be an important consideration. There is, for instance, little point advocating a particularly complicated method if the operator does not have the training or expertise to carry it out.

It is important to review existing knowledge and seek expert opinion on selection of potential indicators, the latter especially so if there is little documented knowledge of the subject domain or the region. However, the indicators that are selected need to have a strong scientific basis. Understanding the performance of indicators of ecosystem health, or collections of such indicators, in other monitoring programs is likely to be of great benefit.

Existing monitoring data for the region may also provide valuable insight into the potential utility of an indicator. Thus, a comprehensive review of historical data should be undertaken. This can help us assess the effectiveness of past monitoring and indicators and ensure that past lessons are incorporated. It may also help provide a baseline and assist in the identification of changes to the system. For instance, knowledge of some historical data might help frame the current monitoring so that a comparison of the historical conditions and the current situation may be made successfully. Furthermore, such a review may reveal limitations and gaps in the temporal and spatial coverage of historical and current monitoring data relevant to the study foci. If deemed critical for future monitoring in the region, then such limitations and gaps could be specifically addressed through the recommended EMP.

The Users Guide for Estuarine, Coastal and Marine Indicators for Regional NRM Monitoring[4] provides a comprehensive set of indicators related to estuarine, coastal and marine issues. See also the OzEstuaries initiative[5] as part of the National Land and Water Resources Audit. A list of recommended resource condition indicators for Australian conditions is also available from the Natural Resource Management website[6].

## 3.3 Devise an appropriate spatio-temporal monitoring design

The spatio-temporal design is a fundamental step in the monitoring process. It determines the specific nature of sampling that is required to address the monitoring objectives. Through an appropriate spatio-temporal design, we aim to identify the

- location and number of sampling sites,
- required frequency and timing of sampling,
- level of replication that is required to achieve sampling power,
- need for stratification in the design to take into account known underlying physical or environmental processes and therefore improve inference,
- sample collection and analysis methods, including the level of precision necessary,
- equipment needs,
- methods to be used for data analysis, and
- human resource requirements.

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[4] http://www.coastal.crc.org.au/Publications/indicators.html
[5] http://www.ozestuaries.org/indicators/
[6] http://www.nrm.gov.au/monitoring/indicators/index.html

These decisions will need to carefully balance the inherent natural spatial and temporal variability in the system, the size of the change that needs to be detected (the effect size), physical constraints pertaining to such large-scale monitoring and the potential size of the sampling domain, and the cost involved with sampling. At the end of the day the spatio-temporal design must be effective, achievable and affordable.

Highly variable systems will require more sampling and/or well-timed sampling (i.e. after an event) to distinguish any change from the background variation and to establish peak concentrations of particular indicators. The natural variation may be quantified from past studies in the region, historical records or experience in other studies. If this is not possible, pilot studies are often undertaken to provide insight into the sources of variation and their relative magnitudes. Sufficient statistical replication is particularly important for quantifying variability associated with indicators and for helping ensure sufficient power to detect true change or trend in the population parameters of interest. Often, a recommended minimum number of sites to be sampled is advised to ensure such replication and to inform and result in a meaningful power analysis (see Fairweather 1991).

In devising an appropriate spatio-temporal design, it is essential to consider the data that will result from implementing the design and how these data will be analysed to address the objectives. Most data analysis methods will make assumptions about the data and how it is collected. It is important to understand these and embed them in the design process so the monitoring delivers data that may be analysed appropriately and used to make reliable inferences.

Monitoring designs can be costly and often have a tendency to become unaffordable. It is imperative that the resource constraints are transparent at the outset. It will often be necessary to establish priorities amongst the objectives. This might, for instance, see us sampling more frequently at locations that are expected to respond to changes in stormwater or wastewater input and less frequently at sites that are not impacted by these potential pressures.

Spatio-temporal designs fall under three broad categories: those that examine changes over time (e.g. trend analyses), those that examine changes over space and look to reconcile the patterns observed with knowledge of impacted and unimpacted locations (e.g. spatial gradient analysis), and those that appeal to specific design families like BACI (Before-After Control-Impact) designs to establish any disturbance by directly contrasting control and impacted sites. These three design types are discussed in detail in the Water Quality Monitoring and Reporting Guidelines (ANZECC/ARMCANZ 2000a).

It may be useful to consider the spatial and temporal designs as separate strategies. The spatial design needs to ensure representation across the population of interest (e.g. existing seagrass meadows) and is adapted to resource characteristics. The temporal design specifies the pattern of revisits to sites selected by the spatial design. Panel surveys (e.g. Skalski 1990; Urquhart et al. 1993) enable a temporal sampling strategy to be combined with a spatial sampling strategy and are particularly useful for guiding long-term monitoring of a mixture of purposely- and randomly-chosen sites (through the spatial design). They provide explicit structure for making inferences about condition and trend. As an illustration, Table 1 describes one particular panel design, a serially alternating augmented panel design, which combines a set number of fixed sites (Panel 0) with a rotating panel of random sites (Panels 1-4) to be monitored over time. Note that the term panel derives from generic sample survey literature and in our context, refers to a set of monitoring sites.

**Table 1.** A serially alternating augmented panel design

| | Time period (e.g. years) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Panel** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **…** |
| **0** | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| **1** | X | | | | X | | | | X | | | | X | |
| **2** | | X | | | | X | | | | X | | | | |
| **3** | | | X | | | | X | | | | X | | | |
| **4** | | | | X | | | | X | | | | X | | |

Statistical design principles may be valuable for ensuring sampling resources are allocated optimally. For instance, it may be useful to consider some stratification in the design so that more effort is placed into the more variable aspects of the system. As an example we may choose to sample outputs from stormwater drains in non-urban areas less frequently during the drier periods of the year when it is known that the input into the coastal system is significantly reduced. Other examples may look to consider the coastal region as a series of ecologically homogeneous zones (or strata). These strata may be selected on the basis of factors like geology, hydrodynamics, anthropogenic pressures, management/monitoring objectives or historical monitoring activities.

If guideline values for important physico-chemical or biological indicators are used they need to be set in this phase of the monitoring process. This will rely heavily on past data and existing knowledge. It will be important to consider any spatial and/or temporal stratification in setting the guidelines for ecosystem health assessments.

## 3.4 Sampling

It is essential that the sampling is undertaken according to standard protocols and methods as this helps ensure reliability and consistency. QA/QC protocols need to be documented and followed closely. Guidelines that outline the recognised sampling procedures are available. See for example the Water Quality Guidelines (ANZECC/ARMCANZ 2000b) for protocols for measuring physico-chemical, biological and ecotoxicological parameters.

The methods that are used and the equipment required need to be carefully considered and communicated. Calibration procedures may be necessary in order to prevent any drift in the measurement due to equipment fouling.

It is important that detailed documentation be kept of the sampling. This includes recording the key attributes like the location and timing of the sample, the method and equipment used, an identifier of the personnel involved and whether there were any exceptional circumstances related to the collection. Any information on data quality should be noted where possible. This is particularly important for samples that are taken in the field and analysed later in the laboratory when no recourse is possible.

Procedures need to be established for the appropriate storage of samples prior to analysis.

## 3.5 Laboratory analysis

The processing of samples in laboratories can involve complicated analytical procedures and needs to be performed according to standard protocols to ensure reliability and consistency. Reliable QA/QC procedures are also essential. A list of preferred analytical methods is given by Standards Australia[7]. See also the Australian Water Quality Guidelines (ANZECC/ARMCANZ 2000b). Alternatively, refer to U.S. EPA resources[8]. Detailed documentation of laboratory samples and analyses is important.

## 3.6 Data management

Data should be archived for future data analysis and interpretation. It is essential that a data management system that is reliable, practical, efficient and incorporates GIS capabilities be adopted. Standardized protocols need to be observed and meta data provided. Data management should also be viewed in a broad sense and the system should incorporate more than just quantitative information. For instance, it is important to keep thorough records of all management interventions as part of the data management exercise. Where data is produced and stored across a number of agencies or organisations, a strong data management system can be a valuable tool for driving inter-agency collaboration and ensuring the most is made of the monitoring data collected.

## 3.7 Data analysis and interpretation

Data analysis is a fundamental component of a monitoring program. It is often necessary to conduct some exploratory data analysis early on in a monitoring study to ensure data integrity and reconcile the collected data with expectations. Some data preparation, such as removal of obvious erroneous observations or data transformation, is often necessary prior to analysis. The appropriate statistical and mathematical analyses should be decided in the design phase, and well before the data is collected, because carefully considered data analysis may have implications for the spatio-temporal monitoring design and help ensure that we maximize our opportunity to address the objectives. That said, statistical and mathematical modeling are often an iterative process and the analysis should be adapted to best suit the data and collection characteristics. It is recommended that statistical diagnostics be examined to check assumptions and ensure the most appropriate analysis is used.

The data analysis should then be interpreted in relation to the monitoring objectives. What implications does the data analysis have? Has it altered our conceptual understanding of the system?

## 3.8 Communication

The results and findings from the monitoring program need to be reported to interested stakeholders. As the requirements of individual stakeholders will not all be the same there will be a need to tailor the communication so that it is relevant. For instance, a report for a scientific audience would be pitched differently to one that is delivered to policy makers. In all cases the report should be concise, informative and centre on the defined monitoring objectives and how the study is addressing these.

Visualisation and graphical techniques are valuable for summarising the information content and conveying the main messages succinctly, e.g. the spatial prediction maps that incorporate measures of uncertainty for the model data that are part of the estuarine/marine EHMP in South East Queensland (EHMP 2006)

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[7] http://www.standards.org.au/default.asp

[8] http://www.epa.gov/ebtpages/water.html

It may be sensible to aid the communication of the ecosystem health by using water quality indices or adopting multi-metric indicators that integrate various measures of ecological health and represent them as a single summary measure, such as something like a report grade or the EcoH plots that are part of the freshwater EHMP in South-East Queensland (EHMP 2006). While care needs to be taken with any such data reduction process, a well chosen multi-metric measure of ecosystem health that is simple, easily conveyed and rapidly evaluated is often of considerable value, especially to the community at large.

## 3.9 Management response

The analysis of the monitoring data may trigger a management response. This might happen fairly quickly if some sort of remedial action is required, e.g. closing a beach to swimming in response to reduced water quality following the outflow associated with a large storm event. It could involve an intervention to try and reduce the nutrients entering the waterways, a decision to cease monitoring of an indicator altogether or a decision to commission a separate research study to improve understanding of a specific aspect. All management interventions need to be adequately documented and assessed against changes to ecosystem health.

## 3.10 Review and refinement of program

Objectives and monitoring programs evolve. It is important to incorporate feedback loops into the monitoring program so that it may be manipulated to reflect changing needs. It is recommended that a review process be made a formal component of any program so that it becomes a regular endeavour and the effectiveness and relevance of the program is maintained by adapting and refining where necessary.

The specific details of the required frequency of this review process are dependent on numerous factors. It may be helpful to undertake as part of any annual reporting that occurs. More or less frequent review may also be helpful depending on the frequency of the sampling. For instance, if aerial photographs are commissioned every five years it makes sense to review that component on a similar interval.

The notion of a pilot program or interim long-term monitoring program is not made explicit in Figure 3. In many ways the process or framework is identical to a mature monitoring program, the only difference being that refinement or adjustment that is necessary following a pilot program may be more sweeping. It is quite common for a pilot monitoring program to demand more sampling resources so that decisions on the optimal spatial or temporal resolution may be resolved by sampling at a higher intensity and considering the amount of information that is lost from sampling less intensively.

Any EMP should aim to continuously improve with advent of new technologies, methods and knowledge. This includes reviewing and improving the underlying science and methodologies, and refining the conceptual model.

# 4. Monitoring objectives for the ACWS region

## 4.1 Overview of Adelaide's coastal waters

The ACWS region is described in Fox et al. (2004) as being characterised by relatively high salinities and both continuous and intermittent freshwater inputs to the coast. Physical circulation is predominantly by tides, although winds and density gradients play important roles. There is tendency for erosion in some of the southern parts of the metropolitan coastline and the subsequent accumulation of sediment in the northern part of the region resulting from a dominant northerly drift.

Fox et al. (2004) also note that the coastal waters have low natural levels of nutrients and algal counts. While these are observed offshore, the near to midshore waters tend to show more moderate nutrient levels as terrestrial inputs are often contained within the near to midshore coastal strip. The Port Adelaide River and Barker inlet are influenced by industrial inputs and Bolivar wastewater treatment plant and thus are characterised by higher nutrient levels.

From consideration of historical aerial photographs and localised underwater survey records, it has been observed that seagrass has been lost around major outfalls and in the nearshore metropolitan zones. The southern part of the ACWS region has been less affected (from what records there are) but is likely to come under increasing pressure with likely population growth.

Figure 4 is a simple conceptual summary of the key components of the ACWS region that need to feature in the EMP. The five components are strongly inter-linked as indicated by the arrows in Figure 4. Terrestrial inputs to the coastal waters have a direct effect on the coastal water quality, particularly in the near- to midshore areas. Some of these are relatively constant inputs (e.g. WWTPs), while others are more event-driven such as stormwater. Physical processes affect the sediment stability and water quality through wave energy, sediment transport and resuspension. Seagrass health is influenced by water quality, particularly nutrient and light related, but also plays an important role in maintaining that quality by taking up nutrients.

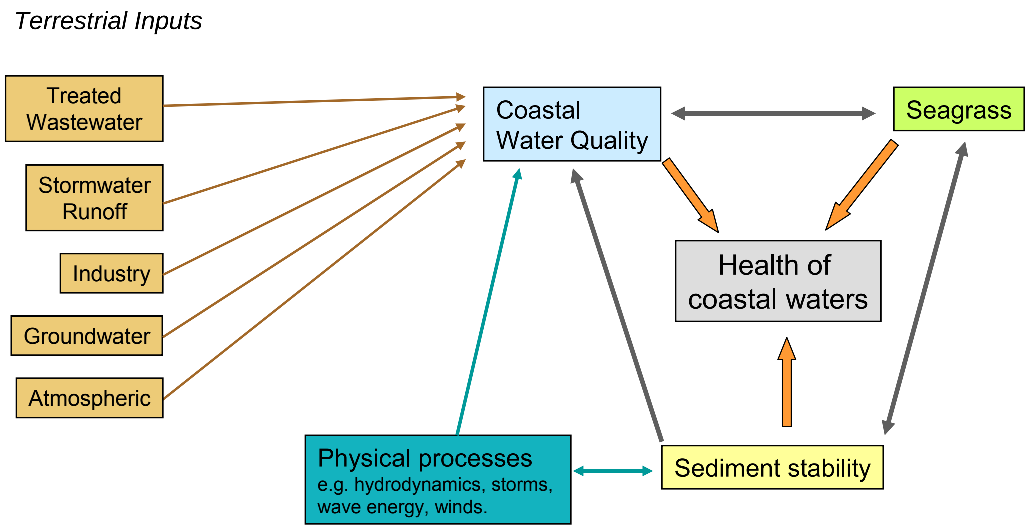


**Figure 4.** Key components of the Adelaide coastal water system that need to feature in the environmental monitoring program. The colours are used to distinguish these 5 key components (seagrass, sediment stability, terrestrial inputs, coastal water quality and physical processes) affecting the health of the coastal waters.

A brief summary of each of these five key components and other contributing factors follows.

### 4.1.1 **Seagrass**

Seagrasses are an important habitat for marine life, stabilise sediment/sand on the seafloor, reduce wave energy and consequent erosion / storm damage, and improve coastal water quality by trapping nutrients. It has been estimated that approximately 5000 ha of seagrasses have been lost from the Adelaide metropolitan coast since the 1940s (Westphalen et al. 2004). The two main genera of seagrass species found in this region are *Posidonia* and *Amphibolis*. There are fundamental structural and physiological differences between these two species (Bryars et al. 2006) and thus, they require different monitoring methods.

### 4.1.2 **Terrestrial inputs**

There some important anthropogenic terrestrial inputs to the ACWS region including:

- Treated wastewater from  the Bolivar, Glenelg and Christies Beach WWTPs;
- Stormwater inputs ranging from the larger outlets like the Torrens, Barcoo and the Onkaparinga to the smaller Southern Creeks and Holdfast drains;
- Heavy industry inputs from the Port Adelaide River, e.g. Penrice Soda Holdings;
- Groundwater inputs; and
- Atmospheric deposition.

Inputs from former sludge outfalls, such as increased levels of nutrients, are thought to have largely contributed to the seagrass losses that have been observed in the vicinity of the outfalls (e.g. Bryars & Neverauskas 2004). The relative amount of $^{15}N$ in the water, expressed as $\delta^{15}N$, can be used to differentiate the sources of nitrogen inputs in marine systems (Bryars et al. 2006). Indeed, Bryars et al. (2006) state that seagrass is an ideal bioindicator and has been used extensively in nitrogen stable isotope studies to source and profile the movement of anthropogenic nitrogen in coastal waters.

### 4.1.3 **Coastal water quality**

The health of the coastal waters is strongly linked to coastal water quality. High turbidity, phytoplankton / epiphyte loads and composition, eutrophication, toxicants and heavy metals concentrations may all negatively affect ecosystem health with flow-on implications for recreation and tourism activities. There may be other elements of the coastal system that may be strongly linked to coastal water quality, such as mangrove health and fish health, but further consideration of these was beyond the scope of the ACWS.

### 4.1.4 **Sediment stability**

The stability of sediment on the seafloor affects the ability of seagrass seedlings to take root and successfully recolonise. It also determines the quantity of material that is available for transport, affects coastal water quality through resuspension of that sediment, affects the need for dredging and sand relocation, and may alter the nature of the hydrodynamic processes.

### 4.1.5 **Physical processes**

The hydrodynamics of the ACWS region plays an important role in the diffusion and distribution of terrestrial inputs to the coastal waters. The predominant northward currents keep contaminant inputs within the near to midshore area, reduces mixing with deep waters and results in the accumulation in the northern parts of the ACWS region. The wave energy, particularly during large storms, may prevent recolonisation in near to midshore areas and cause blow-outs amongst the existing seagrass meadows throughout the region. Rainfall events in the region, especially after extended periods without rain, are likely to produce rapid surface run-off in the urban catchments, leading to peak levels of contaminants and nutrients that had been accumulating on land.

### 4.1.6 **Other contributions to the system**

Aside from the five main components, there are other contributing components in the ACWS system. For instance, coastal development and engineering structures play a role by altering some of the natural processes such as the hydrodynamics of the near-shore areas. The conceptual model in Figure 5 gives a much more complete picture of the ACWS system. However, for the task of our recommended EMP, Figure 4 is the preferred conceptual model because its simpler representation enables us to focus the monitoring more readily.

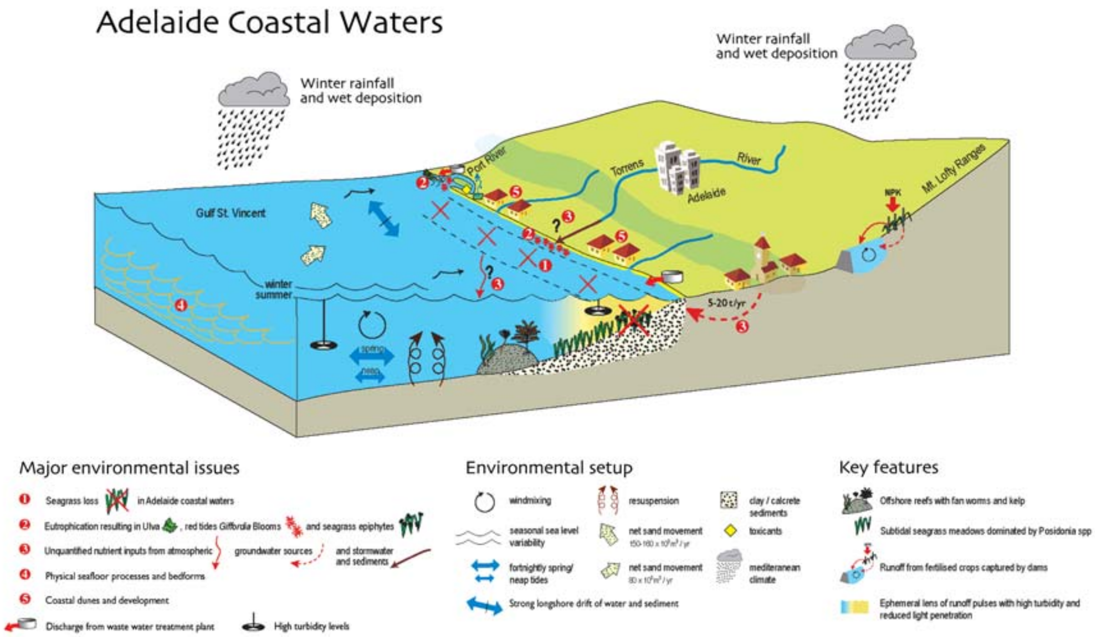


**Figure 5.** Conceptual ecosystem model for Adelaide coastal waters.

## 4.2 Aims of ACWS tasks

The primary objective of the Adelaide Coastal Waters Study is to develop knowledge and tools to enable sustainable management of Adelaide's coastal waters by identifying causes of ecosystem modification and the actions required to halt and reverse the degradation (Fox et al. 2004). The driving issues for the ACWS and the future environmental monitoring program for the region have been identified as

- seagrass health
- seafloor stability, and
- water quality.

There were five core scientific tasks created to refine the understanding of the condition and processes at work in Adelaide's coastal waters. These are each briefly described now.

- **Input studies** (IS 1) has investigated and quantified the diffuse and point source terrestrial, groundwater and atmospheric inputs to the coastal waters
- **Remote sensing** (RS 1) has used remote sensing to study marine and coastal features and interpret changes in relation to natural and anthropogenic processes
- **Ecological processes** (EP 1) has assessed the effects of inputs to the Adelaide coastal waters on seagrass ecosystems and key biota
- **Physical process modeling 1** (PPM 1) has developed a coastal sediment budget
- **Physical process modeling 2** (PPM 2) has conducted physical oceanographic studies in the Adelaide coastal waters using high resolution modeling, in-situ observations and satellite techniques.

The key findings from the five scientific tasks have been summarised and synthesized by Harris (2006), resulting in a refined "state of knowledge in ACWS". Figure 6 graphically represents this refined understanding of processes and factors affecting seagrass area and vitality that have been identified through the ACWS. One of the outcomes of synthesis of information from each of these tasks is that the initial loss of seagrass, and the subsequent losses that have occurred, appear to be a complex product of excess nutrient loading, turbidity, stormwater and river flows "trapped" in the nearshore zone, and nearshore sediment erosion. In other words, research undertaken by these tasks has collectively helped to refine our understanding of and processes occurring in the Adelaide coastal waters system. Full reports for each research task are available as ACWS technical reports (www.clw.csiro.au/acws/).

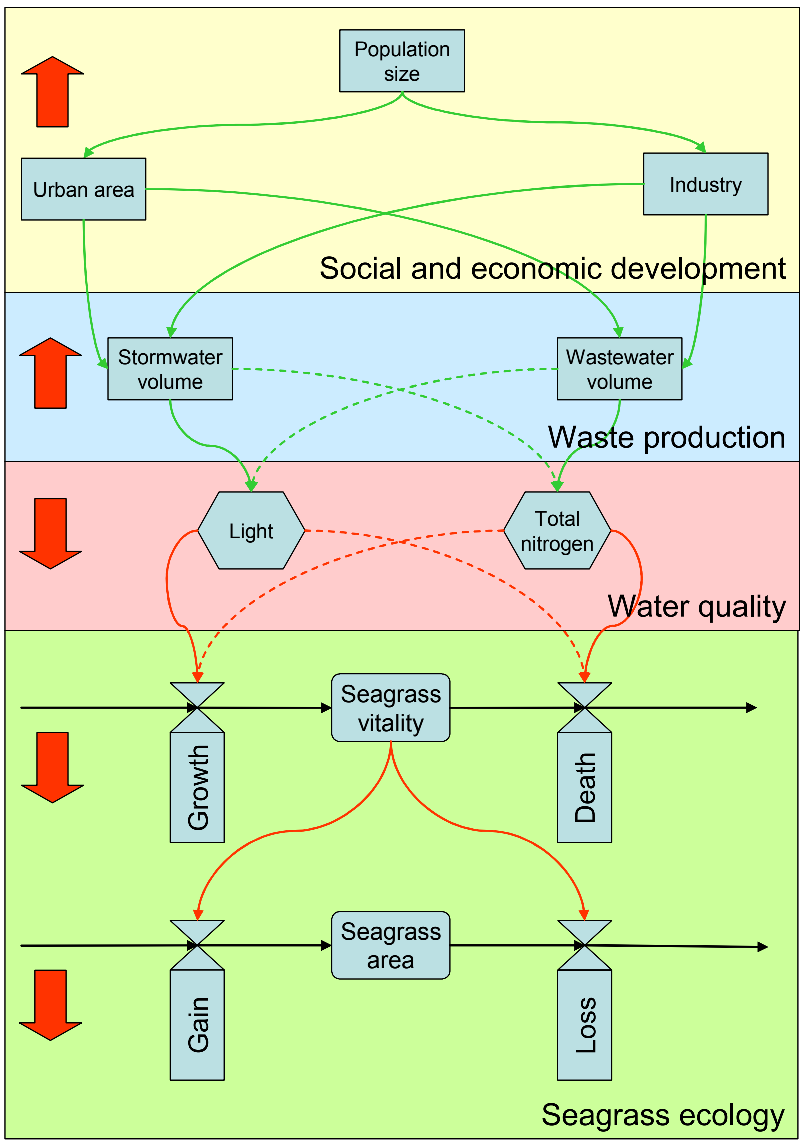


**Figure 6.** Synthesis of refined understanding of processes and factors affecting seagrass health and distribution in Adelaide's coastal waters (developed by A.C. Cheshire).

The **Environmental Monitoring Program** task (EMP 1) was established to perform more of an integrative role to coordinate future monitoring effort in a manner that is reliable, cost-effective, accessible, communicable and is informative for management. The objectives of this task were discussed in more detail in Section 1.2. The design of this EMP is the focus of this report.

## 4.3 Pressure-state-response framework

A *pressure–state–response* framework is used to provide structure to the EMP by explicitly seeking to reflect the ACWS conceptual model and subsequently include relevant indicators or measures that assess the pressures that are placed on the ecosystem, the state of the ecosystem and the response by management and society to manage/control those pressures. More specifically, the EMP will consist of monitoring:

**Pressures**: Indicators that assess the pressures and potential impacts on the ecosystem, e.g. nutrients exported from WWTPs or suspended sediment loads from stormwater inputs to the ACWS region. Current compliance monitoring is focused very much on the pressure indicators as it seeks to ensure contaminants exported into the coastal waters comply with regulatory requirements. Some large storm events may however bypass the normal route and treatment, and exert additional pressures on the ecosystem. Monitoring is also important for its ability to help diagnose the reasons for any observed changes or areas of non-compliance. Without knowing these reasons there is less certainty in any management actions undertaken.

**State**: Indicators that measure the current state or condition of the ecosystem, e.g. the areal extent of a seagrass meadow or a measure of turbidity from a coastal water quality sample. The predominant focus of state indicators is on assessing the values we are trying to protect or improve.

**Response**: Indicators that assess the effectiveness of the management and societal response to pressures. As the response typically seeks to reduce pressures on the ecosystem many of the indicators will be the same, with perhaps a greater focus on changes to the pressures, e.g. reductions in nutrient loads from new filtration technologies. There may however be additional response indicators such as records of compliance with new policy or regulations (e.g. number of environmental breaches), surveys of public opinion, or relevant environmental expenditure (e.g. physical sand movement).

## 4.4 Spatial considerations

The Adelaide coastal water study region is heterogeneous and subject to some important spatial differences. There are clear differences due to the:

- current extent and speciation of seagrass,
- underlying geology and sedimentology,
- the nature of the physical / hydrodynamic processes,
- and, perhaps most critically from a monitoring perspective, differences in the key anthropogenic pressures on seagrass and the general health of the coastal ecosystem.

Stratifying the region into zones attempts to capture these differences. The monitoring program must recognise the different zones through zone-specific objectives where appropriate. The program must also acknowledge that the mechanism for seagrass loss and the capacity for seagrass regrowth may differ throughout the ACWS region.

Figure 7 illustrates the stratification of the ACWS region into five discrete and relatively homogenous zones. These zones were decided upon by the ACWS Scientific Committee. Table 2 describes these zones and the key pressures on seagrass health and extent that exist within each zone.

**Table 2.** Description of spatial zones and key pressures in those zones.

| Zone | Description | Key pressures |
|---|---|---|
| 1 | Gawler to Point Malcolm | Bolivar WWTP & Port Adelaide River including Penrice |
| 2 | Point Malcolm to Marino | Torrens and Patawalonga Rivers, Glenelg WWTP and Holdfast Drains |
| 3 ( and 3A) | Marino to Sellicks Beach<br><br>Break between 3 and 3A is several kilometres south of Onkaparinga Estuary | Zone 3: Christies Beach WWTP, Onkaparinga River<br><br>Zone 3A: Southern Creeks. Limited impact from Onkaparinga River due to northward current during main winter stormwater season. |
| 4 | Offshore from Zone 2 (Marino to Grange) | Physical processes. Largely unaffected by anthropogenic influence. |
| 5 | Former Port Adelaide sludge outfall. Offshore from Zones 1 and 2.<br>(North Haven to Grange) | Physical processes. Largely unaffected by anthropogenic influences since the sludge outfall ceased in 1993. |

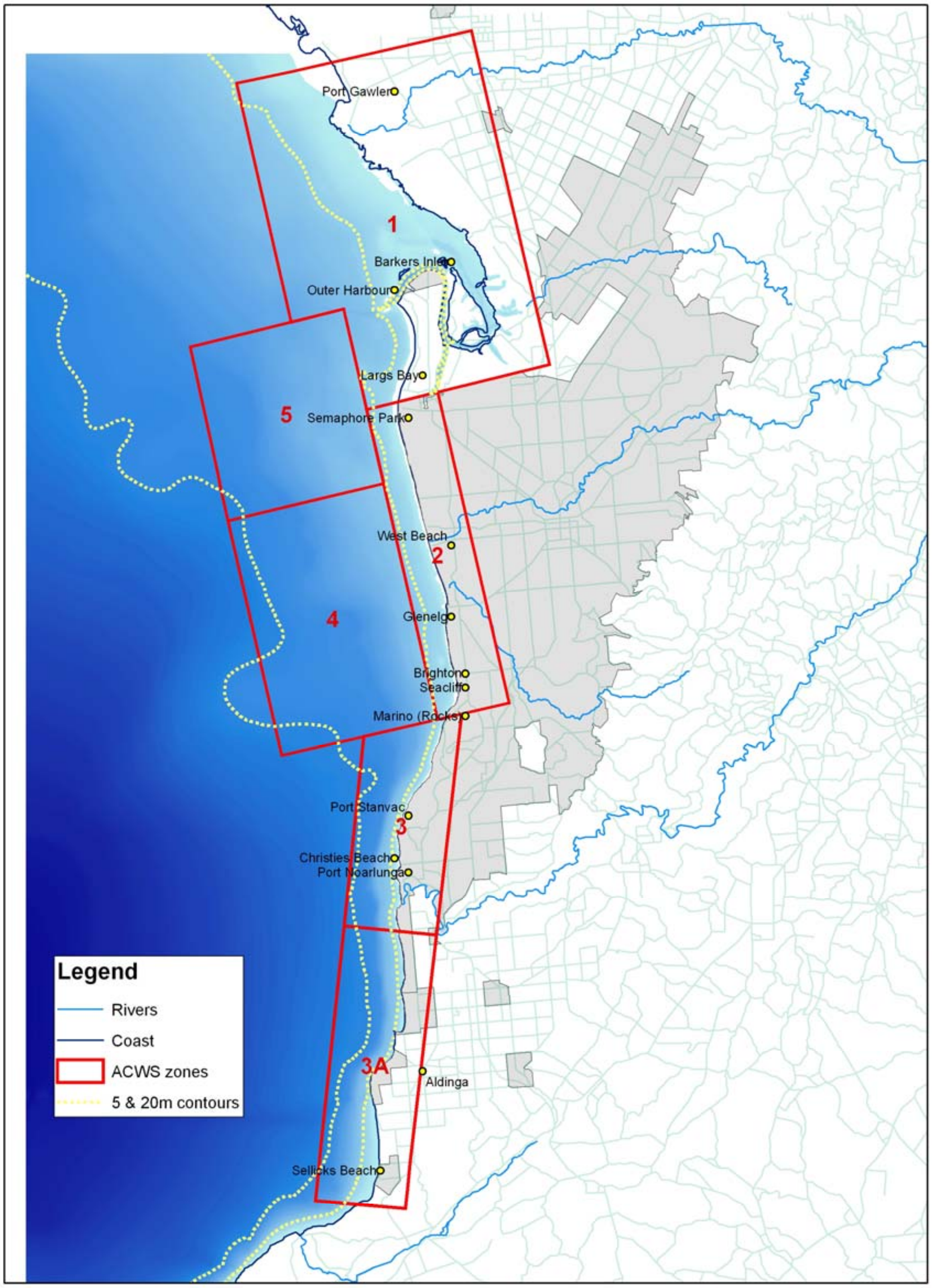


**Figure 7.** Spatial zones defined for the Adelaide Coastal Water Study.

## 4.5 Monitoring and management objectives

In developing an environmental monitoring plan for the Adelaide coastal waters, there are many considerations to take into account and the precise nature of details of the plan is dependent on the key issues and questions of interest. A table of issues to be addressed by the ACWS was drawn up after much consultation with the various stakeholders (Ellis et al. 2001). In subsequent consideration of these issues, each was given a relative priority rating of critical, important, interesting or side, and teams of research tasks were allocated to each priority with the aim of resolving the issue. The EMP 1 research task was not directly involved in resolving any of stakeholder issues as part of developing an integrated environmental monitoring program. However, it is clear that through answering these very specific issues, broader questions emerge and it is these that the recommended EMP has been designed to address.

The broad monitoring program objectives are to:

1. Assess changes to the health of existing seagrass
2. Identify broad changes in spatial extent of seagrass
3. Provide a good baseline against which to assess future change and distribution of seagrass
4. Monitor existing pressures on seagrass and identify changes that occur to those pressures, and
5. Provide a baseline to judge the impact of future management interventions to protect, stabilise or restore seagrass.

The recommended pilot program seeks to incorporate existing monitoring activities in the region, possibly after improvements and refinements in light of the study results so as to optimise the monitoring that is undertaken, to maintain continual records and ensure that they are relevant to the monitoring objectives set by its stakeholders.

In addition, the monitoring program must respond to the objectives of those managing the coastal environment and these management objectives are zone-specific. Table 3 summarises the management and monitoring objectives for each zone.

**Table 3.** Zone-specific management and monitoring objectives.

| Zone | Key pressures | Management objectives | Monitoring objective |
|---|---|---|---|
| 1 | Bolivar WWTP and Port Adelaide River including Penrice | Stabilise / restore seagrass | Ensure remaining seagrass meadows are minimally impacted by discharge from Bolivar WWTP and Barker Inlet / Port Adelaide River system.<br><br>Focus on seagrass health. |
| 2 | Torrens and | Stabilise / restore | Focus on seagrass |

| Zone | Key pressures | Management objectives | Monitoring objective |
|---|---|---|---|
| | Patawalonga Rivers, Glenelg WWTP and Holdfast Drains | seagrass<br><br>Ensure compliant water quality in nearshore and bare sand areas. | health. |
| 3 (and 3A) | Zone 3: Christies Beach WWTP, Onkaparinga River<br><br>Zone 3A: Southern Creeks. Limited impact from Onkaparinga River given northward current during main winter stormwater season. | Protect seagrass meadows from future loss, particularly given the likely population growth and thus increased anthropogenic pressures in this zone. | Improve knowledge/mapping of existing seagrass meadow in this region.<br><br>Focus on seagrass health. |
| 4 | Physical processes. Largely unaffected by anthropogenic influence. | Protect remaining seagrass meadows. | Focus on blow-out monitoring. |
| 5 | Physical processes. Largely unaffected by anthropogenic influence since the sludge outfall was switched off in 1993. | Restore seagrass meadows. | Determine rate of passive recolonisation now that a major pressure has been switched off.<br><br>Focus on blow-out monitoring. |

# 5. Review of monitoring in the ACWS region: Past and present

## 5.1 Review historical / existing monitoring

Dobbie et al. (2005) (see Appendix A) identified and appraised current and historical monitoring programs associated with Adelaide's coastal waters, in particular with reference to the study's three main foci of seagrass health, seafloor stability and water quality. Through the audit we aimed to investigate and report on key parameters that are being and have been monitored, including the type of indicators, the method of monitoring and the spatial and temporal extent of monitoring. We were also interested in which agencies had collected the data as this not only indicates their efforts associated with each of the study foci, but will help in making more informed decisions about integration of monitoring activities, data management and coordination of the recommended integrated environmental monitoring program.

As part of the EP 1 research task, Bryars et al. (2006; Appendix C table) tabulated key details of historical seagrass monitoring in the region, which we have condensed to form a succinct and informative picture of historical monitoring in the region (see Figure 8). The main purpose of this map is to give an overall spatial and temporal feeling for where and when seagrass monitoring efforts have been focused in the past. The map also provides limited detail of the surveys which generated the data, such as year of data acquisition and key indicators measured/recorded. Further detail of the specific surveys is provided in Bryars et al. (2006).

From Figure 8, it is clear that most historical seagrass monitoring was conducted using diver surveys (with or without quadrat sampling) and was focused off the Adelaide Metropolitan Coast during the 1970s, 1980s and 1990s. Other monitoring techniques utilised in the past included aerial photography, satellite imagery, remote video surveying and quadrat sampling. There was limited seagrass monitoring carried out in the very southern extent of the region.

Monitoring of specific aspects of coastal water quality has been undertaken in the last ten years using SeaWiFS technology (broad-scale) and via line transect surveys of subtidal reefs (localised monitoring). There have also been various historical collections of the quality of terrestrial inputs to the coastal region such as stormwater, groundwater and wastewater. In comparison, there is limited historical data on seafloor stability, namely acoustic data for the inshore regions of two metropolitan locations, and a beach surface model for a 30 km stretch of metropolitan coastline.

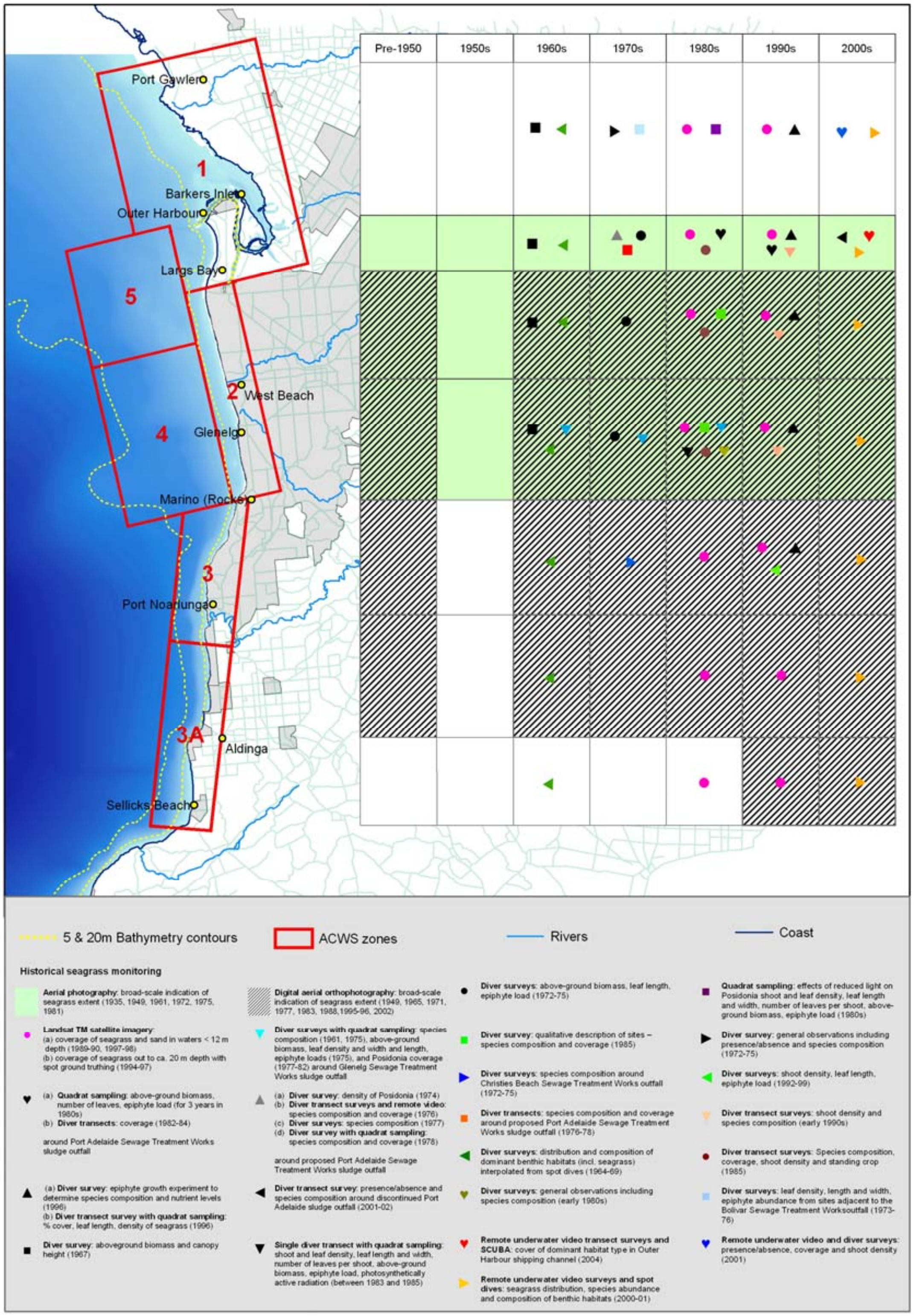


Figure 8. Map of historical seagrass monitoring in the ACWS region indicating spatial and temporal extent as well as method of monitoring.

A map has also been created to indicate the spatial and temporal extent of ongoing seagrass monitoring in the study region (see Figure 9). There are essentially only three ongoing monitoring programs for seagrass in the region and all of these are focussed off of the Adelaide metropolitan coast. Brass rod profile sites have been monitored since the late 1980s, while the other two activities have only been conducted in recent years.

The current monitoring of mostly metropolitan coastal water quality, as carried out by the SA EPA and SA Water, is undertaken to check compliance with national guidelines as is the wastewater monitoring conducted by SA Water. In general, monitoring is carried out on a monthly basis. Groundwater and stormwater are monitored regularly by SA EPA, SA Department of Engineering and Water Supply (now SA Water) and the former Onkaparinga Catchment Water Management Board (now part of the Adelaide and Mt Lofty Ranges NRM Board). Seafloor stability is solely monitored by SA DEH through their beach profiling, beach pole monitoring, and the use of sand level rods. Monitoring is generally carried out on, at most, an annual basis.

## 5.2 Limitations

One of the outcomes of performing such a stocktake of relevant data was to reveal limitations and gaps in the temporal and spatial coverage of historical and current monitoring data relevant to the study foci. These are now briefly summarised.

Whilst the ACWS region extended as far north as Port Gawler, the geographical focus of other research tasks generally seemed to be on the Adelaide metropolitan coast, i.e. only as far north as Outer Harbour and as far south as Marino (Rocks). This is possibly because seagrass loss on this metropolitan section of the coast has been identified as greatest in recent times. It may also be because the majority of the population in the region is located there so the health of seagrass in this region is at most risk of further deterioration. On the whole, there appears to be wide spatial and historical coverage of seagrass distribution and health through aerial photography and diver surveys, especially off of the Adelaide metropolitan coast and since the 1960s. Monitoring of seagrass beds at a more localised level e.g. around outfall point sources, has occurred historically as one-off observations at some sites (generated through specific projects), but at the Port Adelaide WWTP sludge outfall, there have been several surveys undertaken resulting in a more complete historical record for the site. Aerial photography has been carried out over most of the region, although gaps in coverage exist in the extreme south and north of the study region. We note that this technology can be unreliable at times, both due to poor weather conditions at the time photos are taken and due to potential classification and positional error. With the advent of new technology though, the reliability of this method of monitoring is improving. Ground truthing will however remain essential for verification.

There has been limited seagrass monitoring conducted outside of the metropolitan coastal waters, especially south of Port Noarlunga. A reliable and comprehensive map of current seagrass extent in this region (Marino Rocks to Sellicks Beach) should be a high priority. Ideally this would be produced from *in situ* field observations combined with some form of broad-scale monitoring (such as aerial photography). Furthermore, up-to-date, comprehensive maps of seagrass extent for all five zones will be useful in providing benchmarks for future inferences.

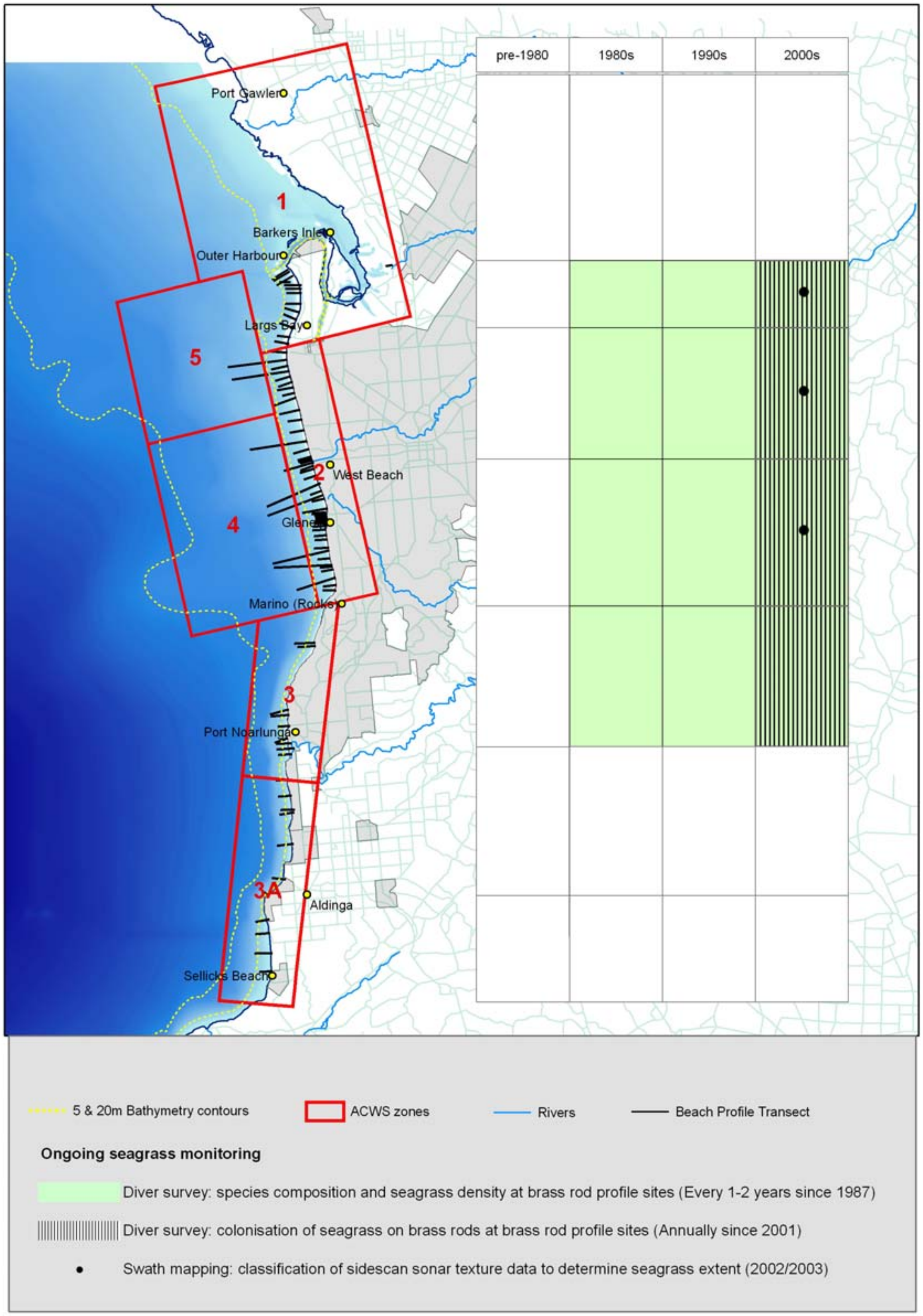


**Figure 9.** Map of ongoing seagrass monitoring for the ACWS region indicating spatial and temporal extent as well as method of monitoring.

There are a couple of known limitations of water quality monitoring in the region. In particular, end-of-valley loads need to be more precisely measured and greater coverage achieved. Also whilst the quality of the receiving waters for Christies Beach and Glenelg WWTPs discharges are monitored regularly, the quality of the receiving waters for the Bolivar WWTP are not and this needs to be addressed.

We found relatively few historical data collections available on seafloor stability covering the whole ACWS region, and this is probably a function of the complexity in the dynamics associated with seabeds, the cost of collecting the data, and the high variability associated with sediment attributes (such as %carbonate). The existence of seafloor texture data via swath mapping is promising as these provide a more accurate and intensive representation of seabed classification than other techniques such as the Compact Airborne Spectrographic Imager (CASI). Swath mapping also provides data at a more localised scale than aerial photography can provide, but the anticipated ten-yearly monitoring time-scale may be too infrequent to use this as a means for establishing losses of seagrass as a result of local events. Also the task of turning the realms of generated data into useful tools such as maps is complex and time-consuming.

## 5.3 Audit of possible monitoring approaches

The choice of monitoring that will feature in the ongoing EMP requires careful consideration of the full range of monitoring possibilities. Appendix B contains a stocktake of seagrass monitoring approaches, while Appendix C lists monitoring methods associated with pressures on the health and distribution of seagrass. The strengths, weaknesses, objectives the monitoring must address and their respective costs must be weighed up and traded off when selecting a suite of suitable methods.

# 6. An Integrated Environmental Monitoring Program design

## 6.1 EMP considerations

This section outlines the proposed monitoring program we have devised for Adelaide's coastal waters. This program attempts to:

- Choose an appropriate spatial sampling intensity to characterise each zone.
- Monitor and report at a range of spatial scales. It recognises that local-scale and broad-scale monitoring may help answer different objectives, and that the spatial zones that have been described are valuable for focussing the monitoring effort on more local conditions and pressures.
- Carefully consider the appropriate temporal frequency and timing for identifying changes in state or pressures.
- Consider the compliance monitoring requirements.
- Recognise that there is a continuing need to refine our understanding of the key processes and the mechanisms for seagrass loss.
- Incorporate and build on existing monitoring efforts if appropriate and wherever possible. Adapt and refine as necessary, though recognising that not all monitoring undertaken in the region will fall under the EMP.
- Help coordinate and integrate sampling efforts of potentially numerous agencies and organisations through recommended close collaboration, co-location of sampling sites and sharing of resources.
- Take into account additional expert knowledge and feedback.
- View the EMP as flexible and adaptive.

## 6.2 Prioritisation of future monitoring effort

There is an enormous amount of monitoring that could be part of a comprehensive and integrated EMP. The proposed monitoring needs to be cost-effective and should build on existing monitoring efforts where possible. Table 4 illustrates how we will present prioritisation of monitoring effort in terms of 'essential' and 'desirable' recommendations associated with each key component. Essential refers to those components we refer to as critical to an integrated EMP. The desirable components cover important aspects that are not critical but should be seriously considered as part of a comprehensive monitoring program. Some of the desirable components require further testing and investigation. If these are found to be valuable these may be assessed a higher priority in the future. We acknowledge that there may be reasons beyond the scope of the ACWS for some of the monitoring recommended as desirable to be prioritised as essential. We also recognise that some monitoring methods may be multi-purpose in that they provide data relevant to more than one key component (e.g. swath mapping provides detailed bathymetry and seagrass distribution through derived texture maps) and this fact may elevate that method's overall priority.

**Table 4.** Prioritisation of the monitoring effort.

| Priority | Key component |
|---|---|
| **Essential** | Seagrass |
| | Inputs |
| | Coastal water quality |
| | Sediment stability |
| | Physical processes |
| **Desirable** | … |

## 6.3 Seagrass monitoring

The focus of seagrass monitoring is to determine the health, the distribution of species and the extent of seagrass meadows. It is important that the protocols for monitoring seagrass are consistent with seagrass monitoring in other parts of South Australia to facilitate meaningful future comparisons.

Table 5 presents the proposed and prioritised seagrass monitoring for the ACWS region.

**Table 5.** Proposed key seagrass monitoring priorities.

| Priority | Proposed monitoring | Monitoring status | |
|---|---|---|---|
| **Essential** | Quadrat sampling | Additional | |
| | Permanent markers | Modified | SA DEH Coast Protection Board |
| | Diver/video transect sampling | Additional | |
| | Aerial photography | Additional | Historically SA DEH but not supported in ongoing manner. |
| **Desirable** | Swath mapping | Existing | SA DEH Coast Protection Board |
| | Dual frequency sonar | Existing | SA DEH Coast Protection Board |
| | Airborne remote sensing | Additional | |

There is limited ongoing seagrass monitoring in the ACWS region (see Figure 9). With the exception of seagrass monitoring around the beach profile / rod lines, most of the seagrass monitoring has been conducted on a project basis, thus was short-term with limited objectives. Aerial photography has a relatively long history with seagrass mapping but is currently not funded in an ongoing manner.

Maps of existing seagrass meadows in the ACWS region have been produced (see EPA 1998; Blackburn et al. 2005) but are focussed on the metropolitan coastal area. There is a need to establish a reliable baseline map of current seagrass against which any changes may be registered. This is particularly true in the southern part of the region (Zone 3A) where near and midshore waters are deeper and it is more difficult to map.

Various criteria and input from experts were used to select and prioritise the monitoring methods in Table 5. There is a need to balance the seagrass monitoring objectives (health, distribution, extent) and the scales at which they need to be assessed. The methods employed need to be reliable, repeatable, sensitive to change, non-destructive, readily communicated and accessible with the skills set available to the relevant South Australian government agencies. The existence and relevance of historical and ongoing monitoring programs associated with the region (summarised in Dobbie et al. 2005, which is provided in Appendix A) also played a key role in deciding prioritisation of monitoring effort.

### 6.3.1 Proposed essential monitoring effort

An effective assessment of seagrass health requires “getting wet”. Regular summer or autumn monitoring of health indicators in fixed **quadrats** at specifically chosen sites is unquestionably the most effective way to assess seagrass health. The most important indicator for dominant *Posidonia* genus is shoot density. Other important indicators to consider for each quadrat are leaf length or the leaf area index. The best indicator for *Amphibolis* is not so clear cut but relates to plant density and could either be the number of leaf heads or the number of leaves per head. It is important these indicators are non-destructive given we need to repeatedly sample each quadrat from year to year. Species composition should always be noted in these quadrats as changes to the composition may be due to a differential response to pressures. Photographs of quadrats would provide a quick and useful record for future comparison.

Sites for quadrat sampling should be predominantly located in Zones 2, 3 and 3A given they are the zones with seagrass beds that need to be stabilised or protected from future seagrass loss and are the most affected from terrestrial inputs. It makes sense to choose sites that are likely to be 'early indicators' of further decline or regrowth (e.g. edge of extent, adjacent to a past blow-out or are directly impacted by a WWTP or stormwater outlet). Effective choice of 'early indicator' sites may be improved by spatial consideration of the risk of seagrass loss given bathymetry, bottom shear stress, likely nutrient exposure and light climate. The 'scope for growth' model being developed as part of the ACWS study (Cheshire 2006) may eventually be used to provide a valuable integrated measure of risk. It will still be important to have a small number of quadrats within the seagrass meadows for comparison and to see if there is any change to composition, health and/or density. Finally, it is sensible to align sites with the beach sediment profile lines wherever possible to share resources and allow any interactions between changes to bathymetry/sediment stability and seagrass to be investigated.

**Permanent markers**, such as brass rods, placed at the inner and outer seagrass extent and the subsequent measurement of the recession or growth from those markers over time is a simple and cost-effective method for assessing any change to the seagrass extent. These measurements should initially be made on an annual basis, though once the markers are established; they could be checked less frequently. The locations for these permanent markers should align with the beach profile / rod lines wherever possible. Indeed, some of the existing rods already aligned with the beach profiles should be useful. Other rod lines may be extended to the inner or outer seagrass edge. These markers should largely be placed in Zones 2 and 3 given these are the zones that are more likely to broadly respond to altered nutrient or light levels and are most affected by hydrodynamic processes in the shallower waters.

**Diver transect surveys** are a valuable component of the seagrass monitoring program because they enable us to assess the distribution and composition of the seagrass community over a wider area than quadrat sampling. This has been the monitoring method most used in past monitoring activity in the region (see Figure 8). Transects of length 100-200 metres are recommended, with the diver recording the presence/absence and the species composition of seagrass at 1 metre intervals along the length of the transects. Making these transects fixed so that they can be revisited on an annual basis improves our ability to detect change, though naturally places greater emphasis on choosing truly representative transects. We recommend diver transect surveys be undertaken in all zones, though focussed more strongly on Zones 4 and 5 where there is a greater risk of seagrass blow-outs. Bryars et al. (2006) found that diver surveys combined with quadrat sampling (50 m transect comprising five equi-spaced sets of five 25 cm x 25 cm quadrats) is not an effective strategy for seagrass health assessment in the southern zones because of the nature of the species habitat coverage observed (i.e. fragmented rather than uniform coverage).

**Underwater video sampling** along transects is an important and fairly local monitoring method that does not involve "getting wet" (which in turn reduces the occupational health and safety risks and the effort involved with the collection of data). It is also attractive because it can potentially give a much broader and comprehensive coverage of seagrass health than feasible via the other recommended core monitoring methods. By coinciding the timing and location of the video and diver transects, costs may be reduced and classification of the video imagery is likely to be improved.

Video sampling has historically been used for seagrass monitoring (see Figure 8), is evidently cost-effective and provides a useful visual record of the nature of seagrass meadows and visual reference for comparison between the sampling periods. Assessment of seagrass health from these records is based on the recognition of broad features such as canopy size or density but can also be based on qualitative estimates of epiphyte loads (Bryars et al. 2006). The main disadvantage of this method is the effort involved in processing of the footage. It is likely to be intensive and there remain issues about the best methods for obtaining an objective assessment. The EP 1 task used SARDI-designed software (written in Visual Basic) to extract relevant data (such as habitat coverage selected from a predetermined number of habitat coverages) from video footage; see Bryars et al. (2006). Gonzalez (2005, Section 2.4) describes methods for extracting relevant data from video footage of seagrass beds recorded by the ACWS EP 1 research team.

As recommended for quadrat sampling and the placement of permanent markers, it is desirable to align diver and video transects with beach profile lines where possible and to focus on locations that are more likely to change, either because they are at greater risk of loss (e.g. higher wave energy and therefore blow-out risk) or greater potential for regrowth. These transects will need to be surveyed every 2-3 years.

**Aerial photography** is still the best way of assessing broad-scale changes to the seagrass extent and distribution. It is also the best link to the past monitoring activity in the region with approximately five-yearly aerial photographs taken since 1949 (although not all are useful). We recommend aerial photographs be taken every five years over the entire ACWS region.

Some challenges with classification and positional accuracy remain, although the advent of new digital and GIS technology are improving these issues. It is recommended that the aerial photographs are used to simply classify the seafloor as bare sand or otherwise in order to reduce some of the inaccuracy surrounding more detailed classification. In addition, if it were feasible to take multiple images during a "season" it would help to improve the classification, e.g. by identifying detrital material in repeat images and eliminating it from the classification.

The placement of permanent control points may help the registration of the aerial photography and ensure that we are comparing like with like over time. Regular ground truthing is an essential way of assessing the classification accuracy and driving improvements in the classification algorithms. Over time, ground truthing will build confidence in the method. Ideally the quadrat, permanent marker and transect sampling components of the monitoring program should all be used as ground truthing.

We note that the digital Vexcel ultracam is a local South Australian product that delivers high resolution photography that is fairly cost-effective, nominally $12 per square kilometre (David Blackburn, pers comm). This may be an alternative method of assessing broad-scale extent and change in seagrass distribution to the traditional aerial photography; however we would recommend a sufficient overlap in technologies to enable calibration.

**Table 6:** Recommended minimum spatial intensities of proposed essential seagrass monitoring.

| Zone | Quadrat samples (No. sites; No. quadrats/ site) | Permanent markers (extent) | Diver transects | Video transects – min. | Aerial photography |
|---|---|---|---|---|---|
| 1 | 4; 10 | 4 (inner) | 3 | 3 | |
| 2 | 4; 10 | 4 (inner) | 3 | 3 | |
| 3 | 4; 10 | 8 (4 inner; 4 outer) | 3 | 3 | Complete coverage |
| 3A | 4; 10 | 8 (4 inner; 4 outer) | 3 | 3 | |
| 4 | 3; 10 | 4 (outer) | 3 | 3 | |
| 5 | 3; 10 | 4 (outer) | 3 | 3 | |

Table 6 summarises the recommended minimum spatial sampling intensities associated with these proposed essential monitoring methods according to zone. Temporally, we recommend carrying out monitoring annually for the quadrat sampling and permanent marker assessment, every 2-3 years for the diver and video transect sampling, and every five years for aerial photography. Within a given year, sampling at approximately the same time each year, nominally in either summer or autumn, is recommended.

A more detailed operational account of all recommended essential methods for seagrass monitoring is given in Appendix D. This includes details such as recommended indicators to measure, frequency of sampling, discussion of location of sites in the region according to zonal stratification, and the recommended minimum number of sites to sample.

### 6.3.2 **Proposed desirable monitoring effort**

The **dual frequency sounder, side scan sonar** and **swath mapping** are currently used by the SA DEH Coast Protection Board to provide detailed bathymetry for the Adelaide metropolitan coast. These technologies may however be used to classify the texture of the seafloor and thus identify seagrass presence. The dual frequency sounder has been used to measure the profile lines annually since 1998. It is an existing and essential priority for sediment stability. As such, a fairly modest additional effort is required to assess the seagrass extent along the profile lines. Side scan sonar monitoring was undertaken in conjunction with swath mapping during 2002/03 but is planned to be repeated every 10 years given it is spatially more comprehensive than the dual frequency sounder. Swath mapping generates a large amount of data with the ensuing processing and classification a non-trivial task. There is a need for a significant investment in ground truthing to establish texture classification algorithms that are accurate and reliable. If this proves to be the case, swath mapping may eventually be elevated from a desirable to an essential activity.

**Airborne remote sensing** such as CASI offers considerable potential but still needs extensive ground truthing and assessment/refinement of the classification routines before it will be considered a credible monitoring alternative. Any future transition from aerial photography to airborne remote sensing will however have to be carefully managed so that value of the historical aerial photography is maintained. There may, for instance, need to be a period where the new technology and the existing aerial photography are both run so as to improve the calibration.

### 6.3.3 **Other relevant issues**

There is value to the monitoring program in placing **reference monitoring sites** in seagrass environments outside ACWS region. Port Hardy and Wallaroo in Spencer Gulf have been used in the past as reference sites (EPA 1998; pers comm. Doug Fotheringham) as they represent environments that are close to that of the Adelaide coast but are not subject to the same anthropogenic pressures. These reference sites would thus provide a valuable contrast and may help identify the effect of broader changes in the environmental system, e.g. climate change.

There is a strong focus in the proposed essential monitoring recommendations on techniques that require "getting wet" and thus use of divers. This unfortunately gives rise to occupational health and safety and resource issues that need careful consideration before implementation. Technologies like remote sensing and swath mapping are promising alternatives but still need development and testing before they become viable and reliable. As an alternative, changes to pressures on seagrass may be easier to identify, though until the relationship between state of seagrass and pressures is quantified, there is no certainty in the consequences that will have for the seagrass meadows.

## 6.4 Sediment stability

The SA DEH Coast Protection Board carries out substantial monitoring of sediment stability in Adelaide's coastal waters as outlined in Section 5.1. The proposed ongoing monitoring for sediment stability is summarised and prioritised in Table 7 and draws directly on the existing monitoring. The only additions / modifications suggested for the EMP is to review the location of the current profile/rod lines with a view to (i) extending some to coincide with key seagrass areas and recommendations made in Section 6.3, and/or (ii) increasing the number of lines in the southern region (Zones 3 and 3A) and in Zone 1.

**Table 7.** Proposed key sediment stability monitoring priorities.

| Priority | Proposed monitoring | Monitoring status | Agency currently monitoring |
| --- | --- | --- | --- |
| **Essential** | • Maintain beach profile / brass rod monitoring | Existing | SA DEH Coast Protection Board |
| | • Extend some profiles to coincide with recommended key seagrass regions. | Modified | SA DEH Coast Protection Board |
| | • Consider establishing additional profiles in southern region (Zones 3 and 3A) and in Zone 1. | Additional | |
| | • Maintain annual dual frequency sounder mapping. | Existing | SA DEH Coast Protection Board |
| **Desirable** | • Maintain plan for current 10-yearly side scan sonar and swath mapping for detailed bathymetry. Establish methods for analysing data collected | Existing | SA DEH Coast Protection Board |

The beach profile/rod lines also play an important role in the ongoing seagrass monitoring with the proposed quadrat sampling, permanent markers and transect samples aligning wherever possible. There are two reasons for this. Firstly, it will be more efficient and cost-effective to share resources and conduct different aspects of the monitoring at the same time. Secondly, co-location (even if approximate) will enable us to consider any interactions that may occur between sediment stability and the seagrass health/extent/distribution.

In addition to the monitoring outlined in Table 7 it is important to keep track of records arising from sand relocation and large-scale sand dredging operations such as those that occur around Outer Harbour, Port Stanvac, West Beach and Glenelg. These may be used to help inform and decide future sediment monitoring efforts associated with the EMP as well as being useful in helping to explain sediment patterns in the region. The impact of large-scale dredging on seagrass communities could be explored through BACI-style designs. These are described in detail in the Australian and New Zealand Quality Monitoring and Reporting Guidelines (ANZECC/ARMCANS 2000a).

## 6.5 Terrestrial inputs

Inputs from land-based sources to the coast predominantly affect Zones 1, 2 and 3, and are generally well represented by existing monitoring of wastewater and stormwater. Table 8 summarizes and prioritises the main recommendations for the ongoing EMP in relation to terrestrial inputs.

It is recommended that water quality sampling of the receiving waters of the Bolivar outfall be monitored to capture any WWTP-related change. Similar sampling is already carried out in the receiving waters for the Glenelg and Christies Beach WWTP outfalls. It is also recommended that improvements to the estimates of 'end of valley' stormwater loads be sought for catchments providing less reliable estimates. This is particularly true of outlets away from the non-metropolitan area. The Field River in particular is noted as a river that does not have end of valley flow-proportional sampling. Another recommended essential additional monitoring priority is to regularly record the dissolved organic carbon (colour) and turbidity of outputs from major stormwater outlets given the potential effect they may have on the light climate. Detailed monitoring of terrestrial inputs in the southern part of the ACWS region is identified as important with the likely population growth in that area and the objective to protect existing seagrass.

Nitrogen is likely to have played a key role in the historic seagrass loss in Adelaide's coastal waters (Harris 2006). Different sources of nitrogen may be identified through stable nitrogen isotope analysis. $\delta^{15}$N is a ratio of two naturally occurring nitrogen isotopes and is high for treated wastewater relative to nitrogen from other sources, such as land use or management practices (e.g. erosion, fertilisers). This offers us the potential to distinguish nitrogen attributable to wastewater treatment plants from other sources of nitrogen. As nitrogen inputs to the coastal waters are readily diluted and absorbed by biological activity such as phytoplankton and plants it is sensible to measure $\delta^{15}$N uptake in plant species like seagrass. Measurements of $\delta^{15}$N can be taken in the root or in the leaves. The advantage of using leaves is that it is convenient, non-destructive and because of leaf turnover the amount of $\delta^{15}$N identified may be used as an integrated measure of exposure to nutrient enrichment in the past 12 months. Bryars et al. (2006) provides considerable background, including the strong level of Australian and international support for $\delta^{15}$N assessments, and details of the nitrogen isotope survey conducted as part of the Adelaide Coastal Waters Study that illustrated degree of $\delta^{15}$N enrichment is inversely related to the distance from major outfalls.

A regular nitrogen isotope survey should thus provide the means to determine the range of influence of output from wastewater treatment plants given the hydrodynamics of the region. It should be carried out annually at the same time of the year in the first few years to establish sound baseline levels for $\delta^{15}N$. In the longer term the survey might be reduced in frequency and ultimately used to demonstrate changes to the source of nitrogen or the range of influence of the WWTPs on coastal water quality and thus seagrass health and distribution. This represents a valuable response indicator as it offers management the potential to illustrate that any improvements to WWTP practices are resulting in less nutrient enrichment in nearby seagrass meadows. Protocols for monitoring $\delta^{15}N$ are described in more detail in Appendix E.

Atmospheric and groundwater inputs to Adelaide's coastal waters are given a lower priority because they contribute a fairly small proportion of the total input. For instance, wet deposition contributes to 1% of the total nitrogen and 3% of the NOx inputs, while groundwater accounts for around 1% of the total water discharged (Wilkinson et al. 2006).

**Table 8.** Proposed key terrestrial input monitoring priorities.

| Priority | Proposed monitoring | Monitoring status | Agency currently monitoring |
|---|---|---|---|
| **Essential** | **Stormwater**<br>• Improve/standardise 'end of valley' load estimates – only central creeks are subject to flow-proportional sampling. Others are subject to grab sampling. The Field River in particular is noted as an input source that does not use flow-proportional sampling. | Modified | Adelaide and Mt Lofty Ranges Natural Resources Management Board, through the former Torrens, Patawalonga and Onkaparinga Catchment Water Management Boards |
| | • Regularly measure dissolved organic carbon (colour) / turbidity of the outputs from the major stormwater outlets. | Additional | |
| | **Wastewater**<br>• Maintain current compliance monitoring of treated effluent from Christies Beach, Glenelg and Bolivar WWTPs. | Existing | SA Water |
| | • Maintain assessments of water quality in nearby receiving waters of Glenelg and Christies Beach WWTP outfalls. | Existing | SA EPA |
| | • Establish regular monitoring of receiving waters of Bolivar WWTP outfall. | Additional | |
| | • Establish a regular nitrogen | Additional | |

| | | | |
|---|---|---|---|
| | isotope ($\delta^{15}$N) survey in seagrass leaves to help differentiate the sources of nitrogen inputs into Zones 1-3. | | |
| | **Port Adelaide River / Barker Inlet**<br>• Maintain / improve monthly monitoring of nutrients and toxicants exported from Port Adelaide River / Barker Inlet to Gulf St Vincent. Link to the monitoring that is part of the Port Adelaide River Water Quality Improvement Plan. | Modified | SA EPA |
| **Desirable** | • Regular monitoring of groundwater inputs to Gulf St Vincent<br><br>• Regular monitoring of atmospheric / wet deposition | Existing<br><br>Additional | Adelaide & Mt Lofty NRM Board (formerly Onkaparinga Catchment Water Management Board); SA EPA |

## 6.6 Coastal water quality

Water quality is a critical component of coastal health and needs to feature prominently in the ongoing EMP. Table 9 summarises and prioritises the monitoring recommendations. The recommended monitoring of receiving waters of WWTPs, Port Adelaide River / Barker Inlet and the $\delta^{15}$N survey as part of the terrestrial inputs in Section 6.5 have obvious implications for coastal water quality and need to be considered simultaneously.

**Table 9.** Proposed key coastal water quality monitoring priorities.

| Priority | Proposed monitoring | Monitoring status | |
|---|---|---|---|
| **Essential** | • Maintain monthly ambient jetty sampling<br><br>• Establish a regular midshore and offshore monitoring program, either grab sampling or via automatic water samplers. Focus on indicators of *light* (attenuation, turbidity, total suspended solids, Secchi depth, colour) and *nutrients* | Existing<br><br>Additional | SA EPA |

| Priority | Proposed monitoring | Monitoring status | Agency currently monitoring |
|---|---|---|---|
| | (total nitrogen, oxidised nitrogen, ammonia, total phosphorus, phosphates). Other indicators that should be measured are chlorophyll-a, temperature and salinity. Concentrate effort in Zones 1-3 given they are or will be subject to greatest anthropogenic influences (which we may be able to control) and less so in Zones 4 and 5 which are now largely subject to natural physical processes only.<br><br>• Establish regular monitoring of epiphyte loads on artificial seagrass and provide an integrated measure of nutrient enrichment in Zones 1-3. | Additional | |
| **Desirable** | • Use remote sensing (MODIS) to provide broad-scale mapping of chlorophyll-a, colour dissolved organic matter (CDOM) and temperature at a high temporal resolution. Use focus areas for high resolution in receiving waters of WWTPs and major stormwater outlets<br><br>• Undertake event-based sampling during the initial phases of the program so that the range and variability of water quality indicator responses to major events can be quantified. If automatic sampling stations are used this may coincide with the essential priority for a midshore and offshore water quality monitoring program. | Additional<br><br>Additional | |

The existing SA EPA ambient jetty monitoring program is conducted at ten sites along the metropolitan coast (mostly jetties) and has a baseline monthly sampling intensity, which is increased to fortnightly during the summer months. This monitoring is necessary for compliance reasons and importantly informs decisions on the suitability for coastal recreation activities. It also provides a valuable measure of the water quality *after* inputs to the coast are mixed into the existing waters by the prevailing hydrodynamics or fine sediment is resuspended during windy weather. This gives an indication of the water quality that seagrasses in the nearshore zones are likely to face. The parameters measured as part of the jetty sampling include turbidity, heavy metals and bacterial counts. Nutrients are not measured because any nutrients that come in as inputs are so readily absorbed that the observed levels are low.

There is a need to regularly monitor water quality further offshore in the areas of existing seagrass meadows and where seagrass re-colonisation is thought possible because that constitutes a more direct measurement of the water quality which will ultimately determine the seagrass survival.  This monitoring should certainly include light-related measures (attenuation, turbidity, Secchi depth, colour and/or total suspended sediment) and nutrients (total nitrogen, oxidized nitrogen, ammonia, total phosphorus, phosphates). Other important indicators that will be useful are chlorophyll a, temperature and salinity. Ideally this monitoring would be conducted by several well-placed automatic water samplers. However, the maintenance requirements of such technologies is currently considered prohibitively high and that it is more efficient to carry out this offshore monitoring using grab samples from a small boat. This sampling should take place in Zones 1, 2 and 3 as they cover the part of the region that may be affected by terrestrial inputs. We recommend monitoring a minimum of 4 sites per zone, to either be located to coincide with seagrass areas that are subject to greater pressures or co-located with selected seagrass monitoring sites established through Section 6.3 recommendations. This monitoring should be carried out regularly (i.e. monthly) during the first few years of the EMP. If there is modest variation in water quality in a particular zone or during part of the year, then the number of sites monitored in that zone or at that time could be reduced in the longer-term EMP, without losing too much information.

The nutrients that are potentially damaging to seagrass are difficult to assess because they are readily absorbed by phytoplankton, marine biota and indeed the seagrass. The growth of epiphytes on artificial seagrass strips over time is recommended as an integrated measure of nutrient enrichment because epiphyte growth is known to be stimulated by elevated nutrient levels. Artificial seagrass has been used successfully before along the Adelaide metropolitan coast (EPA 1998) and by Bryars et al. (2003) who used artificial seagrasses in the coastal waters of Kangaroo Island.

We recommend monitoring artificial seagrasses for epiphyte loads in Zones 1-3 with a minimum of 4 sample sites per zone. The sites should be selected to contrast areas where elevated nutrients are likely (e.g. close to WWTP or major stormwater outlet) with sites that are not subject to those same nutrient pressures. The numbers of sites may be revised after the first few years if some of the sites are shown to respond to similarly (i.e. if spatial variation is low). The artificial seagrass monitoring should be repeated every two years at the same time of the year, with the short-term epiphyte load measured over a two to three month interval. If there are improvements initiated that will affect the level of nutrients exported from terrestrial sources we recommend recording before and after assessments of epiphyte growth rates on the artificial seagrass.

Protocols for monitoring offshore water quality and artificial epiphyte loads are discussed further in Appendix E.

Remote sensing is useful for providing broad-scale mapping of chlorophyll-a, colour dissolved organic matter (CDOM), suspended sediment and temperature in the water column at a high temporal resolution.  The MODIS satellite passes over Adelaide's coastal waters twice per day and is the recommended mode for assessing changes in offshore water quality, particularly in focus areas around WWTP outfalls and major stormwater outlets. Remote sensing can allow us to monitor with a high temporal frequency, even if retrospectively through satellite data archives. However, there is a need for investing in ground truthing data to build credibility in the method and refine the calibration equations between radiance and each water quality property of interest. Petrusevics (2005) has demonstrated some of the potential of this technology in his ACWS research and activities. In particular, some of the remote sensing monitoring of the water column for total suspended sediments has shown a decrease between 2000 and 2003 at most sites along the coast with the exception of Sellick's Beach which has actually had a general increase. As the relative merits of the remote sensing technology become better understood for this region, and in particular its effectiveness in the shallower seagrass zone versus the broader Gulf of St Vincent, there is a real possibility that remote sensing may be elevated to an essential priority and retrospective assessments of seagrass made by analysing archived imagery.

The existing jetty sampling and the proposed offshore water quality monitoring are ambient monitoring programs. They certainly do not allow us to track the effect of large stormwater events on the coastal waters at their temporal and spatial resolution. While remote sensing can provide a spatially-integrated estimate of the coastal water quality, there is some call to initiate some event-based grab sampling at several key coastal locations to establish the time for conditions to return to normal. There will be variability in this return period corresponding to the size of the event and the time since the last event. The length of this interval may however reflect changes attributable to management intervention in the catchments or the nature of the response of the coastal water system. For reasons of safety and timeliness it would be ideal if any event-based sampling was conducted at a couple of well-placed automatic sampling stations.

Coastal reefs will generally respond to similar pressures to seagrass and their health may be used as an integrated measure of water quality. If the health of the coastal reefs is improving this may indicate improved coastal water quality and thus improved seagrass health. Whilst specific details of monitoring for the health of coastal reefs does not form part of recommendations, we note that in 2005, SARDI commenced regular annual monitoring during summer of reef health off the Adelaide coast, and Reef Watch also coordinates collection of adhoc reef health data. The condition of local mangroves, samphire swamps and fish are similarly a valuable integrated indicator of ecological health. These are however outside the scope of this EMP.

Across all coastal water quality sampling there is a need for it to be done in as short a time as possible to minimize the risk of conditions changing.  That is, say sampling is carried out over 1 to 2 days and not over 1 to 2 weeks if we want to be able to compare different sites/locations reliably. Samples should also be taken at a dedicated preferred time during the day, e.g. high tide to keep conditions as consistent as possible.

## 6.7 Physical processes

Physical processes like the nearshore hydrodynamics and storm events have an important effect on Adelaide's coastal waters. However, these processes are (mostly) beyond our ability to control or influence. Any natural changes to these processes may however have implications for the seagrass, and more broadly the health of the entire coastal ecosystem. It is important to monitor these physical processes so that any naturally occurring changes are realised and may be used to explain other associated ecosystem changes.

Table 10 summarises and prioritises the monitoring recommendations. It is essential to maintain access to wind, wave height, tide height and storm records as these will help inform the processes of interest.

The hydrodynamics of the region affect the transport, mixing and deposition of sediment and contaminants.  The hydrodynamic model (Pattiaratchi et al. 2006) plays a critical role in helping us understand those processes. It has also played an important role in defining the five monitoring and reporting zones of the EMP. It is recommended that the model be updated annually, using the best available data and knowledge at that time, and used to revise risk maps (such as Scope-for-growth; Cheshire 2006). At this point in time this is a non-trivial task and there are resource implications for running these models. Ultimately, it would be useful to have a model that could be run easily (possibly using the internet) for a range of different scenarios.

A regular broader refinement of the entire hydrodynamic model should be considered every 5-10 years in response to the collection of additional data and knowledge, to ensure that the model continues to remain relevant and of use. As part of this process it is sensible to consider where and whether additional wave or tidal gauges would improve the model and insight into the true physical processes further.

**Table 10.** Proposed key physical process monitoring priorities.

| Priority | Proposed monitoring | Monitoring status | |
|---|---|---|---|
| **Essential** | • Maintain regular access to wind, wave height, tide heights and storm information. | Existing | Bureau of Meteorology; National Tidal Centre |
| **Desirable** | • Use a hydrodynamic model to revise risk maps. | Additional | |

# 7. Overarching aspects of the ongoing EMP

A successful environmental monitoring program is more than just a collection of monitoring tasks. It will only be successful in addressing the management objectives in the longer term if it is coordinated. There are four over-arching aspects of the EMP illustrated in Table 11 that are essential to this coordination, and indeed inevitably the effectiveness of the EMP. These are data management, data analysis and evaluation, reporting and adaptive management.

**Table 11.** Over-arching aspects of the ongoing monitoring program.

| Monitoring Priority | Broad measure | Specific measure | Zone | | |
|---|---|---|---|---|---|
| | | | 1 | … | 5 |
| Essential | Seagrass | … | | | |
| | Input | … | | | |
| | Coastal WQ | … | | | |
| | Sediment stability | … | | | |
| | Physical processes | … | | | |
| Desirable | Seagrass | … | | | |
| | Input | … | | | |
| | Coastal WQ | … | | | |
| | Sediment stability | … | | | |
| | Physical processes | … | | | |

| Overarching principles | | | |
|---|---|---|---|
| **Data management** | **Data analysis and evaluation** | **Communication and Reporting** | **Adaptive Management** |
| Use central repository to share data and information between agencies. | Critical to initiate processes that lead to regular and consistent analysis and evaluation to meet management objectives and enable adaptive management | Essential to report on health in a way that reliably and concisely integrates and communicates information at the right level | Management must respond to the derived knowledge by adapting the monitoring program and intervening where necessary |

## 7.1 Data management

An agreed system for data management is essential for managing, storing, analysing, sharing and communicating ecosystem health monitoring data and information. This system must incorporate some geographic information system (GIS) capability given that monitoring data is collected over a range of different spatial scales and needs to be readily synthesised.

The National Water Quality Monitoring and Reporting Guidelines (ANZECC/ARMCANZ 2000a) state that a data management system should incorporate the following:

- Reliable procedures for recording results of analysis and field observations;
- Reliable procedures for systematic screening and validation of data;
- Secure storage of information;
- A simple retrieval system;
- Simple means of analysing data; and
- Flexibility to accommodate additional information.

As there are a number of agencies involved in the monitoring aspects of Adelaide's coastal waters it is recommended that some sort of central repository be created for data management. This will facilitate data and information sharing and will help drive inter-agency collaboration.

This data management system should include:

**Data entry protocols:**
This includes making sure that there are data entry templates, suitable training, adoption of methods that electronically transfer data where possible, standardised validation procedures, and appropriate care taken with censored values and missing data.

**Quality assurance / Quality control procedures:**
This includes having personnel dedicated to managing the data, using write protection priorities to ensure only approved people can alter or add to the data, keeping records of who makes any changes, ensuring detailed meta data is provided, archive data and that the database is backed up routinely.

**Record of non quantitative information**:
A detailed catalogue of qualitative information, e.g. listing management interventions undertaken, reports and publications written, is important so that the collective memory for the region is accessible.

## 7.2 Data analysis and evaluation

There is a fundamental need to turn the data collected into 'information' that can support decision makers. The EMP must initiate processes that will ensure regular and consistent analysis, particularly because much of the focus is on detecting change over time and to do that effectively analyses must be carried out routinely.

The data preparation and scrutiny is essential. This will complement the checks on data integrity that are part of the data management because some anomalies may only be identified during an analysis phase. Specific care is often needed around detecting outliers, determining the basis for missing values and ensuring censored data are appropriately handled.

It is important to base the statistical analysis on methods that are appropriate, may be applied consistently and are well-supported in the literature. It is also important that results may be readily communicated. Often a balance may need to be met between the method that is optimal in terms of its depth of analysis and the method that is mostly readily understood and reported. The statistical methods that are adopted should be decided prior to the collection of the data as they may hold important implications for the sample collection methodologies.

There is a strong focus with the EMP on statistical methods for the detection of change or trends in key ecosystem indicators over both time and space. Methods for assessing trends or changes over time largely fall under the broad heading of regression models, and include non-parametric regression methods like Kendall's tau or generalized additive models (e.g. Jolly et al. 2001) that allow more flexibility in the shape of the trend. If there is a management intervention (e.g. upgrade to the output from a WWTP) there may be a need to formally test for a before and after difference in key water parameters. Two features of the monitoring data that are often important to allow for in any trend analysis are the influence of seasonal variability and the strength of the correlation between observations close together in time or space.

Spatial analyses might be used to produce maps of key ecosystem parameters; these maps are often valuable communication tools. It is however important to recognise that the interpolation process that is required to take data from specific sites to broader-scale map representation is subject to error and that uncertainty needs to be communicated. For example, the maps of key water quality indicators in Moreton Bay that are produced convey an estimate of the spatial mean and the coefficient of variation over the region (EHMP 2006). Spatial analyses also play an important role in characterising the spatial variability, which can then be used to determine the appropriate sampling intensity for detecting changes or trends of a specified magnitude. Methods for spatial analysis are governed by the amount of available data and the form of spatial referencing. When there is data available at a sufficient number of locations the predictions are often obtained using some variant of kriging (see Cressie 1993). This decomposes the observed data into a slowly changing spatial trend (e.g. as represented by a polynomial or spline surface) and a more rapidly changing correlated error process that reflects the tendency for observations that are closer in space to deviate from the spatial trend in a similar manner. More sophisticated statistical analyses may look to combine the spatial and temporal analyses if the data set is comprehensive enough to permit a combined spatio-temporal analysis.

It will often be important to characterise the relative contributions to the uncertainty from different sources to ensure the most effective allocation of monitoring resources. For example, knowing the contribution that zones, sites within zones, quadrats within sites and laboratory analysis make to the total variability will assist any decision about the relative balance in the number of sites to the number of quadrats. Spatial correlations may also need to be considered in such analyses.

Statistical power analyses (Murphy & Myors 2004; Cohen 1988) are often essential to determine the number of sites or samples that must be taken to detect a change of a certain specified magnitude with a known probability (power).

The Australian and New Zealand Water Quality Monitoring and Reporting Guidelines (ANZECC/ARMCANZ 2000a) provide a good description and illustration of statistical methods relevant to a monitoring context. There are a vast number of statistical references available on specific topics. Manly (2001) provides a good general overview of statistics for environmental science and management.

## 7.3 Communication and reporting

It is essential to report on ecosystem health in a way that reliably and concisely integrates and communicates information at the right level for different stakeholders. The reporting procedures that are adopted need to be applied consistently.

The reporting should be simple, visual and easily digested. Reporting mechanisms may need to be tailored for different audiences. A hierarchical approach to reporting is often required, where the reporting may alter in detail in moving between community, political, government agencies and scientific audiences.

Reporting must consider and include reporting levels of uncertainty. A prediction or an estimate of some key ecosystem health parameters, and any decision making that might be based upon it, is significantly enhanced by a representation of uncertainty.

A report card system of communicating monitoring outcomes and management performance is recommended. This has been demonstrated to be effective communication tool elsewhere (e.g. EHMP 2006; EPA 2005). An example report card for Cockburn Sound (EPA 2005) is presented in Figure 10. The management response is coded as ‘monitor’, ‘investigate’ or ‘take action’ according to each indicator relative to set trigger values.

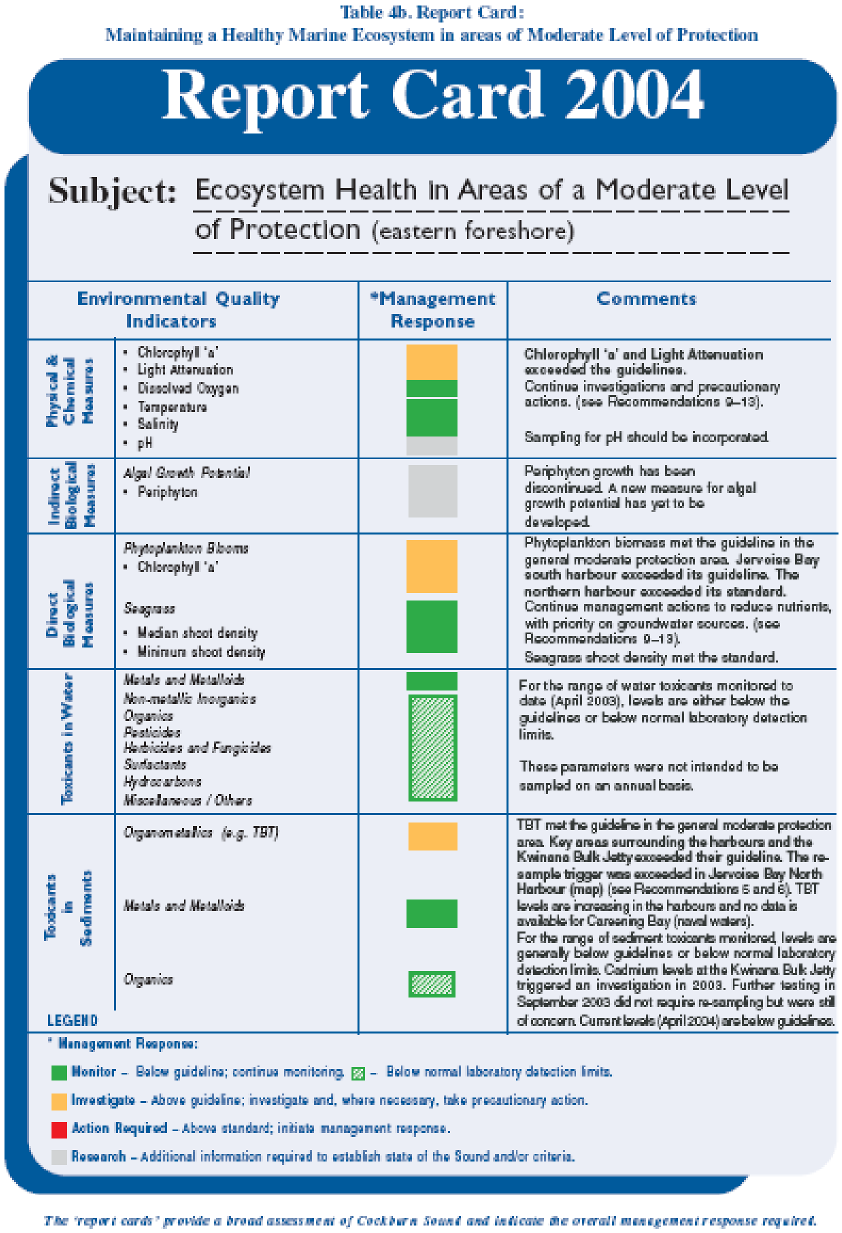
**Table 4b. Report Card:**
**Maintaining a Healthy Marine Ecosystem in areas of Moderate Level of Protection**

# Report Card 2004

**Subject:** Ecosystem Health in Areas of a Moderate Level of Protection (eastern foreshore)

| Environmental Quality Indicators | | *Management Response | Comments |
|---|---|---|---|
| Physical & Chemical Measures | • Chlorophyll 'a'<br>• Light Attenuation<br>• Dissolved Oxygen<br>• Temperature<br>• Salinity<br>• pH | | Chlorophyll 'a' and Light Attenuation exceeded the guidelines.<br>Continue investigations and precautionary actions. (see Recommendations 9–13).<br><br>Sampling for pH should be incorporated. |
| Indirect Biological Measures | *Algal Growth Potential*<br>• Periphyton | | Periphyton growth has been discontinued. A new measure for algal growth potential has yet to be developed. |
| Direct Biological Measures | *Phytoplankton Blooms*<br>• Chlorophyll 'a'<br><br>*Seagrass*<br>• Median shoot density<br>• Minimum shoot density | | Phytoplankton biomass met the guideline in the general moderate protection area. Jervoise Bay south harbour exceeded its guideline. The northern harbour exceeded its standard. Continue management actions to reduce nutrients, with priority on groundwater sources. (see Recommendations 9–13).<br>Seagrass shoot density met the standard. |
| Toxicants in Water | *Metals and Metalloids*<br>*Non-metallic Inorganics*<br>*Organics*<br>*Pesticides*<br>*Herbicides and Fungicides*<br>*Surfactants*<br>*Hydrocarbons*<br>*Miscellaneous / Others* | | For the range of water toxicants monitored to date (April 2003), levels are either below the guidelines or below normal laboratory detection limits.<br><br>These parameters were not intended to be sampled on an annual basis. |
| Toxicants in Sediments | *Organometallics (e.g. TBT)*<br><br>*Metals and Metalloids*<br><br>*Organics* | | TBT met the guideline in the general moderate protection area. Key areas surrounding the harbours and the Kwinana Bulk Jetty exceeded their guideline. The re-sample trigger was exceeded in Jervoise Bay North Harbour (map) (see Recommendations 5 and 6). TBT levels are increasing in the harbours and no data is available for Careening Bay (naval waters).<br>For the range of sediment toxicants monitored, levels are generally below guidelines or below normal laboratory detection limits. Cadmium levels at the Kwinana Bulk Jetty triggered an investigation in 2003. Further testing in September 2003 did not require re-sampling but were still of concern. Current levels (April 2004) are below guidelines. |

LEGEND
* Management Response:
Monitor – Below guideline; continue monitoring. – Below normal laboratory detection limits.
Investigate – Above guideline; investigate and, where necessary, take precautionary action.
Action Required – Above standard; initiate management response.
Research – Additional information required to establish state of the Sound and/or criteria.

*The 'report cards' provide a broad assessment of Cockburn Sound and indicate the overall management response required.*

**Figure 10.** Example of report card from Cockburn Sound, Western Australia (Source: EPA 2005, Table 4a).

Information from the monitoring may be communicated in different ways. For instance, annual written reports may be delivered to relevant state government authorities, newsletters may be used to provide updates on the region on a regular basis, community forums may be held to report on progress and solicit feedback, and web-based reporting systems may be used to widely disseminate monitoring results.

The ACWS region has an important spatial dimension with the five different zones subject to differing pressures and management objectives that should be addressed in any report on the health of the region based on the monitoring program. For instance, consider the additional information in reporting changes to the areal extent of seagrass by zone rather than as a regional total.

When there are multiple lines of evidence on aspects of the environmental monitoring system, for instance seagrass monitoring at quadrat, transect and regional levels, expert opinion could be used to subjectively combine information sources initially. As monitoring data is collected over many years and background levels and variability become better understood, more objective assessment measures will be possible.

Monitoring must be communicated in a way that captures and addresses community concerns if it is likely to persist in the long run. Simple visual summaries such as tracking the near shore seagrass line over time may be a good way of conveying change. As any change to the seagrass health and distribution may occur slowly, particularly with respect to recolonisation, there is a need to focus communication efforts on pressures and changes to them brought about by well-chosen management interventions to maintain momentum and community engagement. For instance, there have been some significant improvements in recent years (e.g. Environmental improvement plans for the WWTPs) and these need to be conveyed to the public. Changes in these pressures are likely to be seen before any impact on seagrass meadows. Maps of 'risk' resulting from different pressures (e.g. bottom shear stress or light-related productivity) may be useful if communicated appropriately.

## 7.4 Adaptive management

Management of Adelaide's coastal water must respond to signals from the monitoring program. This feedback loop is essential if the program is to react and adapt appropriately to major interventions on the system in the region. This occurs best through a formalised process whereby the management response is triggered by observed values on important monitoring indicators. An example of such a process is given in Figure 11 which presents a conceptual model from Cockburn Sound in Western Australia (EPA 2005). The management response in Figure 11 is driven by the risk of the problem, which in turn is assessed by monitoring indicators and some set environmental quality thresholds on those indicators which they term the 'guidelines' and 'standards'. While the environment is seen to be in its natural state, regular monitoring is carried out. If the indicators are found to exceed the environmental guidelines (but not the environmental standards) the management response is to investigate further, possibly through additional targeted monitoring. If however the indicators of ecosystem health are found to exceed the environmental standards there is a high risk of lasting environmental damage and the management response must be to intervene in some way to return the health of the system to a level that no longer exceeds the environmental quality criteria.

There are clearly considerable challenges in setting these trigger values so that they align with the risk of the situation appropriately. In some cases these values may be chosen by appealing to the literature or other similar studies. It is however more likely that these values will need to be based on historical data on that indicator under reference style conditions. Where that is not available there may be a genuine need to collect data during a pilot phase so that these trigger values are supported.

This would be possible for the types of monitoring indicators that are discussed in Section 6. For instance, the areal estimate of the seagrass coverage from aerial photography may be assigned specific percentage reductions that will elicit management responses. Or the seagrass shoot density may characterise a site by its median shoot density across a number of quadrats and have a management response plan that is initiated if the median shoot density falls below a specified % related to the lower levels known to occur in ‘healthy’ seagrass communities.

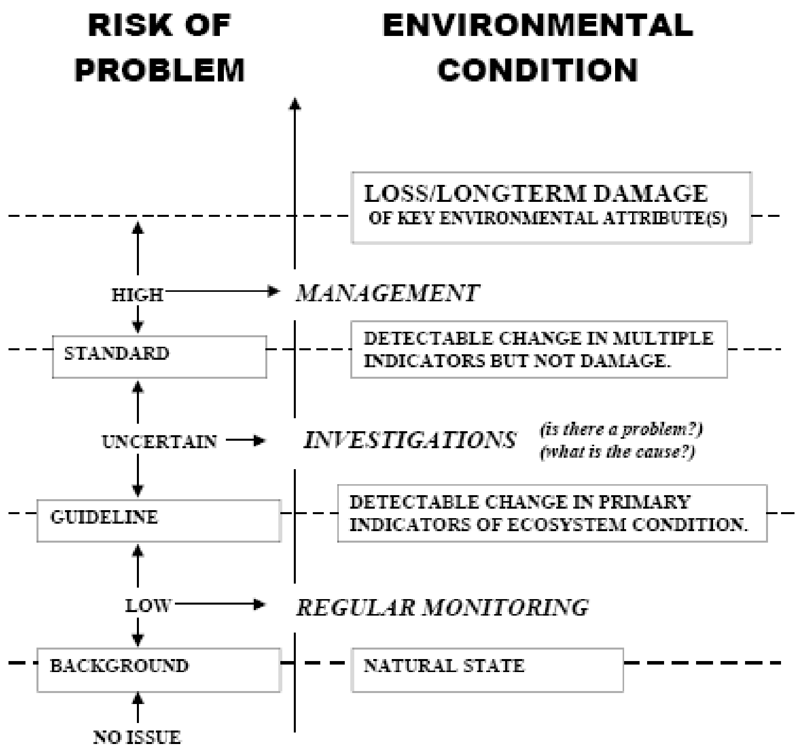


**Figure 11.** Conceptual diagram from the Environmental Quality Criteria for Cockburn Sound (EPA 2005) demonstrating the relationship between the environmental quality criteria, the condition and the management response.

The ANZECC/ARMCANZ Water Quality Guidelines (ANZECC/ARMCANZ 2000b) recommend that these ‘guideline’ and ‘standard’ values be selected based on specific percentiles for that indicator under reference conditions. For an indicator where low values relate to greater impairment, they recommend the use of the 20$^{th}$ percentile from reference data for as the ‘guideline’ when there is a need for a high level of protection. If there is only a need for a moderate level of protection the guidelines recommend the 5$^{th}$ percentile.

Monitoring should also be employed to demonstrate that the management actions of government agencies and authorities, local industry and councils are leading to improvements in the health of the coastal waters and are not creating any unexpected effects. Under the pressure-state-response framework the emphasis is on response indicators. If for example the current dredging related to the Outer Harbour channel widening was considered to have the potential to impact on existing seagrass through increased turbidity then seagrass and turbidity-related water quality monitoring might be increased, either in frequency or spatial intensity, in the region to identify any change in state or risk so that an appropriate response could be made if necessary.

## 8. Implementation and long term monitoring

This report has outlined the essential components of an effective ongoing monitoring program for Adelaide's coastal waters. In designing this program we have focussed on *what* is to be monitored (indicators) and *how* this monitoring should be undertaken (methods and spatial/temporal considerations) rather than by *whom*. Considerable discussion is likely to be necessary for determining which agencies monitor what and this is best left for the steering committee and study partners to decide on, armed with the recommended EMP, budgets, relevant logistical information and any other pertinent information.

The creation of a state-wide data management system is viewed as an essential catalyst for bringing various agencies that collect and produce the monitoring data together and sharing in a more integrated vision of the monitoring.

The implementation will also require a higher level of detail than has been outlined in this report. This includes aspects such as the precise location and number of sites and the operational procedures for collecting and analysing any monitoring data. The degree of adoption and implementation of the program is likely to also depend on costs associated with undertaking monitoring and these have not been discussed here. However, in discussing what is to be monitored we prioritised the recommended efforts for each key component into essential and desirable, and provided recommended minimum numbers of sites for each zone and each essential seagrass monitoring methods.

It is recommended that the environmental monitoring program be initiated for 2-3 years in the first instance, with a detailed period of analysis and review after that time. This initial monitoring phase is necessary to confirm the relative merit of the methods proposed and to fully examine the different sources of variability and their relative contributions to the variability in key ecosystem parameters. It is not uncommon for this initial phase of an environmental monitoring program to demand more monitoring resources than will be used in the longer term. This is because there is a need to have data at higher spatial and temporal intensities in order to optimise the sampling intensity according to efficiency, scientific rigour and meaningful inferences. A detailed cost-benefit analysis might be undertaken at the end of this period to help assess the relative merit of the different monitoring options more objectively. It is highly likely that there will be changes to essential monitoring components, even if it is simply in terms of sampling intensity. For instance, there is potential for some of the components to not form part of the routine monitoring but be triggered if certain conditions are met. As an example, additional diver or video transects may be called for in response to a reduction in seagrass identified through analysis of the aerial photography.

Once the long-term program is up and running it should be formally reviewed every 5 years to ensure that guiding objectives of the program are aligned with management objectives for the region. It must however remain responsive and adaptable over shorter time scales if the need arises.

## 9. Conclusions

In this report we have described the broad requirements and attributes of an effective integrated environmental monitoring program for the Adelaide Coastal Waters Study region. In developing such a program, there was a need to synthesise findings from the companion ACWS Stage 2 studies and also from both ongoing and historical monitoring conducted in the region and from comparable monitoring studies undertaken further afield.

A consensus on the objectives that the EMP must seek to address was reached and the relevant measures of seagrass, and more general ecosystem, health were derived in consultation with other researchers in the study. This was not an easy task, given the large number of possible choices. Unfortunately, the EMP is not comprehensive as far as total ecosystem health is concerned, and therefore some important monitoring tasks necessarily sit outside the integrated EMP.

The recommendations for essential monitoring of the health of Adelaide's coastal waters are as follows:

**Seagrass**

- Initiate a regular annual assessment of seagrass health using fixed quadrat sampling at key sites in each of the zones, but particularly Zones 2, 3 and 3A. Measure indicators such as shoot density and leaf area index (*Posidonia*), number of leaf heads (*Amphibolis*), and species composition. Possibly photograph quadrats to capture a visual record.
- Place permanent markers at the inner and outer extent of seagrass in each zone, but largely in Zones 2 and 3, and measure recession or growth of extent from those markers. Link the location of permanent markers to beach profile / rod lines where possible.
- Conduct (diver / video) transect sampling along fixed 100-200 m transects to assess seagrass density and distribution and species composition. May record as little as presence/absence of seagrass.
- Conduct five-yearly aerial photographic survey of the entire region. Use multiple passes in one year if possible to improve classification accuracy.
- Update / create comprehensive maps of seagrass extent for all five zones so they may be used to provide benchmarks to assess any future change.
- Consider monitoring small number of reference sites outside study region to help identify effect of broader changes in environmental system.

**Sediment stability**

- Maintain beach profile / brass rod monitoring
- Extend some profiles to coincide with recommended key seagrass regions.
- Consider establishing additional profile lines in southern region (Zones 3 and 3A) and in Zone 1.
- Maintain plan for side scan sonar and swath mapping of the metropolitan coast. Establish methods for processing the data.

**Terrestrial inputs**

- **Stormwater**
  - Improve/standardise 'end of valley' load estimates – only central creeks are subject to flow-proportional sampling. Others are subject to grab sampling.

The Field River in particular is noted as an input source that does not use flow-proportional sampling.
    - Regularly record the dissolved organic carbon (colour) in stormwater outputs from major outlets.
- **Wastewater**
    - Maintain current compliance monitoring of treated effluent from Christies Beach, Glenelg and Bolivar WWTPs.
    - Maintain assessments of water quality in nearby receiving waters of Glenelg and Christies Beach WWTP outfalls
    - Initiate monitoring of receiving waters of Bolivar WWTP outfall.
    - Establish a regular annual nitrogen isotope survey of seagrass to help determine range of influence of the WWTPs and differentiate between sources of nitrogen inputs into Zones 1-3.
- **Port Adelaide River / Barker Inlet**
    - Maintain/improve monthly monitoring of nutrients and toxicants exported from Port Adelaide River / Barker Inlet to GSV. Link to the monitoring that is part of the Port Adelaide River Water Quality Improvement Plan.
- Ensure detailed monitoring of terrestrial inputs in Zones 3 and 3A is undertaken, given the likely population growth in the associated regions.

**Coastal water quality**

- Maintain monthly ambient jetty sampling
- Initiate a regular midshore and offshore monitoring program, either grab sampling or via automatic sampling stations. Focus on both light-related and nutrient indicators as well as chlorophyll-a, temperature and salinity. Concentrate effort in Zones 1-3 given they are subject to greatest anthropogenic influences (which we may be able to control) and less in Zones 4 and 5 which are largely subject to natural physical processes only now. Carry out monthly sampling initially until an understanding of the amount of variation in these indicators is established.
- Undertake artificial seagrass monitoring every two years to measure epiphyte loads and provide an integrated measure of nutrient enrichment in Zones 1-3.

**Physical processes**

- Maintain regular access to wind, wave height, tide height and storm records from the Bureau of Meteorology and National Tidal Centre.

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## Appendix A. Assessment of data available for informing the EMP

This appendix exists as a separate document. Please refer to Dobbie et al. (2005), "Assessing Available Data for Informing an Integrated Environmental Monitoring Program", CMIS Report Number 05/97

## Appendix B: Stocktake of indicators of seagrass health and distribution

| Indicator | Objective | Spatial scale | Monitoring method | Temporal scale | Seagrass species utility: (*Amphibolis*, *Posidonia*, both, all species ) | Comments |
|---|---|---|---|---|---|---|
| Shoot density | Seagrass health | Local | Quadrat sampling | Ideally annually or bi-annually as used as early indicator of change | *Posidonia* | Key indicator of health. Best indicator of recruitment or loss (according to the ACWS Scientific Committee)<br><br>A minimum of eight 25 x 25 cm quadrats per site. (Hugh Kirkman pers. comm).<br><br>Choice of site locations important. Should probably place some close to the nearshore edge as may expect changes to occur there first → early indicator.<br><br>Fixed quadrats preferred for identifying change (benchmarking)<br><br>Importance of conducting at same time of year to avoid seasonal effects. The best times to sample are probably summer or autumn. In late autumn Posidonia sheds it leaves, while in winter it is logistically more difficult. |
| Plant density<br><br>(Number of primary stems per $m^2$) | Seagrass health | Local | Quadrat sampling | Ideally annually or bi-annually | *Amphibolis* | |
| Leaf length / canopy height | Seagrass health | Local | Quadrat sampling | Ideally annually or bi-annually | *Posidonia* | The length of randomly selected leaves or shoots is measured in each quadrat. May use |

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| | | | | | | the maximum length.<br><br>The canopy height was not a favoured measure of the ACWS Scientific committee, though it was recognised as a potentially useful indicator of habitat health for other marine species |
| Leaf area index | Seagrass health | Local | Quadrat sampling | Ideally annually or bi-annually | *Posidonia* | Area of leaf relative to area of bottom. Incorporates a number of other indicators so potentially more time-consuming. |
| Leaf extension rates | Seagrass health | Local | Quadrat sampling | Ideally annually or bi-annually | *Posidonia* | Wood & Lavery (2000) choose 25 shoots from each of 5 quadrats per site and punch holes in shoots/ leaves. The extension rates are measured 21 days after. While the horizontal growth is very slow, Posidonia has very fast leaf turnover rates that enable growth to be assessed by leaf extension rates over a short period of time (a month or so). |
| Leaf heads (number of heads per plant, and number of leaves per leaf head) | Seagrass health | Local | Quadrat sampling | Ideally annually or bi-annually | *Amphibolis* | Number of leaf heads per plant, and number of leaves per leaf head. |
| Epiphyte load | Seagrass health / pressure | Local | Quadrat sampling | Ideally annually or bi-annually | *Posidonia*<br>*Amphibolis* | Difficulty in deciding what to measure - % cover, p/a, biomass, species composition.<br><br>Present even in 'normal' conditions so not necessarily useful. Also very time consuming.<br><br>Placing 'artificial' seagrass at these sites and measuring epiphyte loads on them might be the most sensible way to proceed. The ability to strip leaves over time allows a consideration of temporal component. |

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| | | | | | | Loads on artificial substrates could be used as a proxy.<br><br>A qualitative measure from transect may be possible but it is difficult to provide guidelines and ensure they are applied in a consistent manner. (What about photographs taken at fixed locations for future comparison?). |
| Species composition | Change to distribution | Local | Quadrat or along transect. | Every 3-5 years | All species | Assess species composition in fixed quadrats at selected sites or along fixed transects.<br><br>Given the slow growth of *Posidonia* and *Amphibolis* there is little likelihood of detecting any change over the short term. Aim to monitor over the medium term, probably every 3-5 years.<br><br>If however this is measured as part of measuring other indicators then may be useful to measure as frequently as required for other indicators. |
| Root biomass | Seagrass health | Local | Quadrat sampling | | | Destructive. Not useful for *Posidonia* in particular. Avoid. |
| Rhizome presence | Seagrass health | Local | Quadrat sampling | Ideally annually or bi-annually | *Posidonia* | Examine below ground presence of rhizomes. Existence indicates potential for regrowth. Absence may be early indicator of permanent bed loss?<br><br>Probably not feasible over wide region. Time consuming plus potentially destructive (or at least highly disturbing). |
| Local percentage cover. | Seagrass health | Local | Quadrat sampling | Ideally annually | | Take photographs at a number of fixed positions at each site and determine the percentage of cover. |

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| Seagrass extent | Change to distribution | Local | Fixed transects/ fixed markers at inshore and offshore boundaries | Annually | | Could conduct in association with beach profile transect sampling, however current beach profiles may not extend to seagrass extent. |
| Presence/absence transects (Diver) | Change to distribution | Transects | Fixed transects | 1-3 years | | Measure presence or absence at specific points along a fixed transect. No consideration of intensity. Quick and repeatable. An alternative, and possibly more efficient way, would be to run along a transaction and note when there are cover changes<br><br>May provide useful calibration / verification data for aerial photography / remote sensing. |
| Presence/absence transects (Dual frequency side scan sonar) | Change to distribution | Transects | Fixed transects | 1-3 years | | Dual frequency sonar primarily used for detailed bathymetry along transects. May however also be used to identify the presence of seagrass on the seafloor.<br><br>Ground truthing may be required. Accuracy still needs to be established. |
| Video transects | Seagrass health / change to distribution | Transects | Fixed transects | 1-3 years | | Merit of this approach still needs to be established. May provide good visual record of transect but will be difficult to process accurately for features.<br><br>Link with diver transects. |
| Aerial photography | Change to distribution | Broad | --- | ~ every 5 years | | Useful for measure of spatial extent but does not determine species differences. Works best in shallow, clear waters.<br><br>Ground truthing is essential<br><br>May be affected by sun glint, turbidity, rectification procedures, …<br><br>Resolution may be an issue for some tasks.<br><br>Important to consider choice of useful metrics (% change, cluster sizes, …) |

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| | | | | | | Recommend that this be carried out fairly regularly. While we are only interested in broad scale changes over a longer period of time (say 5 years) if we take more regular photos we may be able to separate seagrass from detritus (e.g. 4 images per year every 5 years).<br><br>Southern extremes of ACWS region have not always been covered as part of flight paths<br><br>New technologies like the digital photography provided by the Vexcel ultracam may offer further improvements. |
| Airborne remote sensing (CASI) | Change to distribution | Broad | --- | ~ every 5 years. | | Will provide broad spatially exhaustive measure of seagrass distribution. Works best in shallow, clear waters.<br><br>Currently used to classify into 5 functional areas.<br><br>Calibration data is essential although multiple readings in same year will help verification.<br><br>Higher resolution (up to 35cm) than aerial photography. Not affected by sun glint. Also wider electro-magnetic spectrum may improve ability to distinguish seagrass from algae etc.<br><br>Less costly than aerial photography (?)<br>Temporal scale depends on cost.<br><br>Importance of choosing useful metrics (% change, cluster sizes, …)<br><br>Most value in clear shallow waters as reflectance may be affected by turbidity and depth.<br><br>May surpass aerial photography in the future. Necessary to simultaneously measure both to |

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| | | | | | | allow an effective transition.<br><br>Might make sense to consider a number of important 'sites' for high resolution investigations. Intersect with transects / fixed quadrats for calibration and weight of evidence.<br><br>Recommend that this be carried out fairly regularly. While we are only interested in broad scale changes over a longer period of time (say 5 years) if we take more regular images we may be able to separate seagrass from detritus (e.g. 2-3 images per year every 5 years). |
| Swath mapping | Change to distribution | Broad | | 10 years | | Swath mapping primarily gives detailed bathymetry (largely in zones 2) but can also provide a texture map for the bottom. Will require detailed validation and testing to establish how useful texture is as surrogate for seagrass presence.<br><br>It will be subject to some similar challenges to remote sensing and aerial photography (e.g. calibration). May be possible to combine in some way. |

## Appendix C: Pressures on seagrass health and distribution

| Pressure | Indicators/ Monitoring methods | Currently monitored | Motivation | Spatial scale | Temporal Scale | Comments |
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| **Sediment stability** | | | | | | Sediment stability affects turbidity through resuspension and also affects the security of seagrass roots |
| | Beach profile /rod lines monitoring - Transects (perpendicular to beach) | Y | Changes to profile lead to less stable sediment and thus changes to pressures on seagrass | Local<br><br>Mainly Zone 2, but also some monitoring in Zones 3, 4 and 5. | annual | Bathymetry from fixed transects of rod lines. |
| | Dual frequency side scan sonar transects (parallel to beach) | Y | | Local<br><br>Currently Zones 2 and 3. | annual | Bathymetry from fixed transects. |
| | Swath mapping | Y | | Broad<br><br>Largely Zone 2 and up to 3 km off-shore. | 10 years | Detailed bathymetry and texture data. Generates large amounts of data to track changes in bathymetry and seafloor composition/classification to a fine resolution. |
| | Sand relocation records | Y | Change to relocation needs may reflect change to sediment stability / hydro-dynamics | Local | As required. | Quantity of sand relocated may be a surrogate for hydrodynamic effect. |
| | Particle size | N | Change to PSD | Transects | ≥ annual | May help describe sediment movement along the |

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| | distribution | | may reflect altered hydro-dynamics or sediment sources | | | coast although inferences may be confounded by sand relocation program. |
| | % Carbonate | N | Indication of biogenically available material. | Quadrat samples along transects | | PPM 1 task. |
| | Aerial photography / remote sensing | Y | Changes to the coastline or other discernible features may indicate altered physical processes at broad-scale level | Broad | 5 years | Aerial photography / remote sensing might be used to identify broad changes to the coastline caused by erosion/deposition. Might be seen as a surrogate for hydrodynamic processes at work. |
| | Automatic sediment loggers | N | | | | Use of sediment loggers may provide a good indication of sediment movement at specific locations over short (but continuous) time frame. Could be used to better understand local-scale hydrodynamic processes. All other measures of sediment stability are for gross changes over the long term. |
| | Sand dredging records | | Offshore sand dredging records may reflect changes to sediment stability / hydrodynamics. | | | Quantity of sand relocated may be a surrogate for hydrodynamic effect.<br><br>Outer Harbour channel widening/deepening project is dredging a lot of material. While the spoil zone is beyond seagrass meadows, this is still potentially an important pressure on coastal waters. |
| **Inputs** | | | | | | Affects of loads (total discharge and quality) on receiving waters<br>Discharged toxicants and nutrients deemed not critical (or perhaps more correctly, negligible) to overall seagrass health, although N should be |

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| | | | | | | measured. |
| | Loads from WWTPs | Y | Quantity and quality of contaminants being exported from WWTPs and stormwater outlets affects water quality. Any changes identified represent changes to pressures on seagrass, e.g. increased development in southern suburbs may lead to greater contaminant loads | Bolivar, Glenelg, Christies Beach (via Barkers inlet) | Monthly | Quantities of treated waste water.<br><br>Loads of contaminants such as suspended solids, nitrogen, phosphorus, biochemical oxygen demand, etc.<br><br>Pressure may be of particular interest near outlets.<br><br>SA Water monitor export from Christies Beach and Glenelg WWTPs. Compliance monitoring for treated effluent at Bolivar WWTPs but no regular monitoring of receiving waters. This is in place at Glenelg & Christies Beach.<br><br>The relative amount of $\delta^{15}N$ in treated water can be used to differentiate the sources of nitrogen inputs in marine systems (Bryars et al. 2006). Indeed, Bryars et al. (2006) state that seagrass is an ideal bioindicator and has been used extensively in nitrogen stable isotope studies to source and profile the movement of anthropogenic nitrogen in coastal waters. |
| | Loads from stormwater | Y | | | Weekly / Monthly/ Irregularly | Reasonably well measured, particularly for the metro area. Flow proportional composite weekly samples at major outlets. Monthly grab sampling at best for the smaller storm water outlets. Some call for greater standardization of approaches to help comparisons.<br><br>Improvement to end-of-valley outputs is necessary - some of the current measured loads are further up the catchment. Loads from the Field River are currently based on grab-sampling. There is a need to upgrade this river in particular to flow-proportional sampling |

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| | | | | | | Need for stormwater monitoring to be more event-driven than WWTP inputs. All year around for metro outlets. More rural sites tend to have a greater seasonal effect.<br><br>Former Catchment Water Management Boards do most of stormwater monitoring.<br><br>Pressure may be of particular interest near outlets.<br><br>Parameters measured vary but include nutrients, dissolved and total metal content, and historically, pesticide levels. |
| | Loads from rivers and other outlet discharge sites (including groundwater) | G-water Y<br><br>Other N | | | G/water every 1-6 months. | Loads from these inputs are not well understood and there is certainly a need to establish regular monitoring of such loads, especially from point source discharge sites on coast. |
| **Coastal Water quality** | | | | | | Water quality in coastal waters is what directly affects seagrass.<br><br>Nutrients are important but are absorbed so readily that it makes more sense to use integrated measures such as chlorophyll-a. |
| | Ambient jetty sampling | Y | Coastal water quality is known to directly affect seagrass health | 10 sites | Monthly (fortnightly in summer) | SA EPA measure faecal bacteria, heavy metal concentrations and turbidity.<br><br>Undertaken for compliance reasons |
| | Port Adelaide River / Barker Inlet. | Y | | tbd | tbd | SA EPA has a focus on monitoring the cumulative effects of industrialisation on marine life / sediments. |
| | Light loggers | N | Reduced light caused by higher turbidity or epiphyte loads is thought to be major | Local. Small number of sites and range of depths. | tbd | Used to generate data for PPM2 and EP1.<br><br>Could aim to place more permanent light or turbidity loggers along some fixed transects? Measure euphotic depth. |

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| | | | driver of seagrass loss. Identifying any changes to the light regime are important. | | | Important to choose key locations.<br><br>Can we use sensor network technology? |
| | Remote sensing predictions of Chlorophyll-a, temperature, CDOM. | N | Chlorophyll-a is a surrogate for phytoplankton activity and constitutes a significant pressure on seagrass by reducing the available light.<br><br>Can be viewed as an integrated measure of nutrient loads.<br><br>Temperature also direct pressure on ecosystem.<br><br>Colour (or CDOM) more indirect but may indicate turbidity, staining from natural processes … | Broad | Satellite passes twice per day. | SeaWIFS has been replaced by MODIS. MODIS provides wider coverage of spectrum.<br><br>Cost effective. Can get access to archive data. Passes twice per day.<br><br>Propose to select a number of 'sites' for detailed assessment by remote sensing. Suggest to place some higher resolution sites (e.g. 250m) near the extent of jetties, some site offshore from WWTPs at Bolivar, Glenelg, Christies Beach and at the Torrens outlet, and some more regional (lower resolution) sites offshore at Barkers Inlet, Brighton and Sellicks Beach.<br>Needs more calibration data so that we can build a robust relationship between chlorophyll and radiance. |
| | Reef Health | Y (through Reef | Changes to reef health may | Site specific (local reefs) | Adhoc (but at least annually) | Reef health to be used as integrated indicator of water quality. Use measure like % brown algae. |

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| | | Watch) | indicate changes to water quality and pressures on seagrass. | | | |
| | Event-based sampling | N | Water quality changes in response to major events, both through inputs and physical processes. | Site specific | Event-driven | Aim to take water quality samples during and after major events to give more accurate appreciation of range in WQ. |
| | Offshore sampling | N | Water quality at ranges / locations at which seagrasses are present is a more direct measure of pressures placed on seagrass by coastal water quality. | Site specific | Ambient monthly / event | Suggest measuring turbidity, Secchi depth, Chlorophyll-a, temperature, salinity. Makes little sense to measure nutrients given they are so rapidly absorbed.<br><br>Take samples at ranges/depths that seagrass occurs or is expected to occur. Relates more directly to pressures on seagrass meadows.<br><br>Placing 'artificial' seagrass at specific sites and measuring epiphyte loads on them might be a sensible way to assess nutrient enrichment of coastal waters.<br><br>Could place automatic samplers near outlets from WWTPs as check. Event samples useful as well.<br><br>Could use remotely sensed images although this does not give breadth of indicators nor accuracy compared to "getting wet" approaches.<br><br>Could possibly be undertaken in conjunction with diver transects. |
| **Hydro-dynamic processes** | | | | | | It is important to understand and regularly update knowledge of physical processes at work in the Adelaide Coastal waters. It is hypothesized by |

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| | | | | | | some that while the initial seagrass losses may be nutrient driven, the sustained latter losses are more because of the ensuing changes to the physical processes. |
| | Regular monitoring of winds, tides, wave heights, storms | Y<br><br>Spatio-temporal sampling intensity should be considered more carefully in relation to other indicators being monitored. | Necessary for physical modeling and an understanding of the pressures they place on seagrass.<br><br>E.g. maps of bottom shear stress. | | Ambient (daily?) and event-based (current?) | May help drive physical modelling and explain changes in pressures.<br><br>Need to ensure access to relevant records from BOM, National Tidal Centre, etc. is continued.<br><br>Model need not be updated very regularly (say 5-10 years unless extreme event takes place). Might help describe reasons for any changes and help management put in place things to prevent further losses. |
| | Particle size distribution | N | | | | PSDs might give indication of how sediment is moving and timeframes involved. The sand relocation program will however make the identification of patterns more difficult. |
| **Coastal development** | | | | | | Increased development along the coast in the southern part of the region (Zone 4 specifically) is likely to increase anthropogenic pressure on inputs to the coastal waters in that zone.<br><br>Planning SA should have “Facts and figures” regarding current and forecast population increases for this region if needed. |

## Appendix D. Details of recommended essential seagrass monitoring

As seagrass is not currently monitored in an ongoing fashion, the following details of the recommended methods for essential monitoring of seagrass ensure that the seagrass component of our program is prescriptive and thus readily implemented.

### 1. Quadrat sampling

**Monitoring objectives**

- Assess seagrass health
- Obtain a benchmark for assessing degree of change
- Ground truth other monitoring technologies which don't require "getting wet".

**Indicators to measure**

- For sites/quadrats in *Posidonia* meadows
  - shoot density
  - leaf length / leaf area index
- For sites/quadrats in *Amphibolis* meadows
  - number of leaf heads or number of leaves per head
- For all sites/quadrats
  - species composition (% *Posidonia*, % *Amphibolis*, % Other)
  - % cover (quantify % or qualify e.g. 5-point scale such as none, some, half, most, all)

**Locations of sites**

- All zones.
- Concentration of sites in Zones 2 and 3 as they are the zones with seagrass most likely affected by anthropogenic and hydrodynamic factors now.
- In Zone 1 locations will need to be chosen according to seagrass existence.
- In all zones, advantageous to link sites to existing beach profile / rod lines as will enable investigation of the interaction with sediment stability in these zones, particularly the zones comprising inshore areas (1, 2, 3 and 3A).
- If link to beach profiles, subjectively choose a number of key sites along beach profile/rod lines. This selection is critical. We need to identify areas of higher risk (e.g. edge of feasible light regime, exposure to stormwater inputs etc) and areas where regrowth is more likely (e.g. midshore vs. nearshore given hydrodynamics). Careful selection will improve an 'early warning' indicator. It will also be important to balance sites chosen for these reasons with sites that are less likely to suffer impaired health.
- In Zones 3 and 3A we should choose sites to give an early detection of impaired health, while in Zones 1 and 2 we are seeking to stabilise seagrass losses. There is not much expectation of short term regrowth given the coastal dynamics / wave climate.
- Record GPS location to allow calibration with other monitoring technologies

**Number of sites and quadrats**

- Select a minimum of 4 sites in each of Zones 1, 2, 3 and 3A. Choose locations according to pressures in zones, condition of existing seagrass meadows, and management objectives in zones.
- Select a minimum of 3 sites in each of Zones 4 and 5. Choose locations according to condition of existing seagrass meadows in zones and management objectives for the zones.
- Choice of number of sites within a zone should take into account adequate replication to enable robust inferences to be made.
- For each site randomly choose a minimum of 10 (Bryars et al. 2006) 25cm x 25cm permanent quadrats. Random selection important to enable unbiased analysis and representative and robust inferences to be made.

**Frequency of sampling**

- Annually during summer or autumn. (Note: The best times of the year to assess health of *Posidonia* are spring and summer. In autumn *Posidonia* starts shedding leaves and in winter it is logistically difficult to sample. Also water/weather conditions best during the warmer months).
- Sampling should take place at approximately the same time each year to enable robust trend analyses to be undertaken.

**Other related information**

- Take video or photographic records of each quadrat/site. May allow visual comparison over time. Potential exists to classify image in future (e.g. % cover, species composition).
- Recommended equipment required to undertake sampling provided in Kirkman (2005)

**Summary**

| *Zones* | *Min. no. sites* | *Min. no. quadrats/ site* | *Frequency* |
|---|---|---|---|
| 1 | 4 | 10 | Annually in summer/autumn |
| 2 | 4 | 10 | |
| 3 | 4 | 10 | |
| 3A | 4 | 10 | |
| 4 | 3 | 10 | |
| 5 | 3 | 10 | |

## 2. Permanent markers at the edge of seagrass extent

### Monitoring objectives

- Assess change (recession or growth) to the inner and outer edges of seagrass extent
- Ground truthing of other monitoring technologies which don't require "getting wet".

### Indicator to measure

- Distance (in cm) of seagrass extent from permanent markers

### Locations of sites

- Identify areas in the study region thought to be at higher risk (e.g. exposure to stormwater inputs, greater wave intensity etc) and subjectively choose the locations of the permanent markers in those areas so as to help give an early warning indicator of any change. It will also be important to balance these higher risk sites by selecting sites in areas where regrowth is thought to be more likely. The reason for choosing any site for a permanent marker must be recorded.
- It will be important to link sites for permanent markers to beach profile / rod lines wherever possible so there is potential to investigate any interaction between changes to the distance from these markers and changes in the profile.
- Record GPS location to allow calibration with other monitoring technologies

### Number of sites

- Need sufficient replication within zone to enable robust inferences to be made. Also need to choose number of sites to provide sufficient coverage in order to confirm seagrass distribution map – obviously the more sites, the better the coverage.
- In each of Zones 1 and 2, recommend minimum of 4 sites mark the inner extent.
- In each of Zones 3 and 3A, recommend minimum of 4 sites mark each of the inner and outer extents.
- In each of Zones 4 and 5, recommend minimum of 4 sites mark the outer extent.

### Frequency of sampling

- Annually, at approximately the same time each year. Most cost-effective and resource/design efficient if sampled in spring/summer to coincide with timing of quadrat sampling.
- Sampling at approximately the same time each year enables robust trend analyses to be undertaken.

### Other related information

- Recommended equipment required to undertake sampling provided in Kirkman (2005)

### Summary

| *Zones* | *Min. no. sites* | *Frequency* |
|---|---|---|
| 1 | 4 (inner extent) | Annually in summer/autumn |
| 2 | 4 (inner extent) | |
| 3 | 8 (4 inner extent; 4 outer extent) | |
| 3A | 8 (4 inner extent; 4 outer extent) | |
| 4 | 4 (outer extent) | |
| 5 | 4 (outer extent) | |

## 3. Diver transects

**Monitoring objectives**

- To obtain a broader picture of seagrass meadow composition and distribution than allowed for through localised sampling of quadrats and permanent marker observations.
- Assess seagrass distribution and species composition.
- Obtain a benchmark for assessing degree of change
- Ground truth other monitoring technologies which don't require "getting wet".
- Continue history associated with this form of monitoring.

**Indicators to measure**

- Presence / absence of seagrass
- Coverage (categorical response such as patchy, dense, etc.)
- Species composition
- Record responses at 1 m intervals along a fixed transect of length 100-200 m. The alternative is to traverse the length of the transect and mark only where the cover changes for efficiency. Both methods will give information on the fragmentation of the meadows (i.e. whether the meadow is comprised of alternating patches of sand and seagrass).

**Locations of transects**

- All zones.
- Link to beach profile / rod lines so can investigate interaction with sediment stability in Zones 2, 3 and 3A. Choose locations so that a balance of early detection of recovery and early detection of impaired health.
- In Zones 1, 4 and 5 choose locations according to management objective. In other words, in Zone 1 we should allocate more resources to an early detection of recovery, while in Zones 4 and 5 we should choose sites to give an early detection of impaired health.
- Subjectively choose a number of key sites in which to place transects along the beach profile lines. This selection is important. Need to identify areas of high risk (e.g. edge of feasible light regime, exposure to stormwater inputs etc) and areas where regrowth is more likely (e.g. midshore vs. nearshore given hydrodynamics). Careful selection will improve an 'early warning' indicator. It will also be important to balance these sites with some that are less likely to suffer impaired health.
- Record GPS location to allow calibration with other monitoring technologies

**Numbers of sites**

- In all zones, recommend monitoring a minimum of 3 permanent transects.

**Frequency of sampling**

- Annually, at the same time each year. Most cost-effective and resource/design efficient if sampled in summer/autumn to coincide with timing of quadrat sampling
- Sampling at approximately the same time each year enables robust trend analyses to be undertaken.

**Other related information**

- Align diver and video transects to reduce costs and help with classification of imagery.

**Summary**

| *Zones* | *Min. no. transects* | *Frequency* |
|---|---|---|
| 1 | 3 | Annually in summer/autumn |
| 2 | 3 | |
| 3 | 3 | |
| 3A | 3 | |
| 4 | 3 | |
| 5 | 3 | |

## 4. Video transects

**Monitoring objectives**

- To obtain a broader picture of seagrass meadow composition and distribution than allowed for through localised sampling of quadrats and permanent marker observations.
- Assess seagrass distribution and species composition.
- Obtain a benchmark for assessing degree of change
- Ground truth other monitoring technologies which don't require "getting wet".
- Continue history associated with this form of monitoring.

**Indicators to measure**

*Video transects:*

- Take underwater video footage along transects (length subjective and depends on prevailing conditions on day of survey but Bryars et al. 2006 surveyed seagrass quality along drift transects of approx. length 400 m and surveyed outer limits of seagrass along drift transects of approx. 100-200 m in length)
- Processing (i.e. classification of footage) is likely to produce the same indicators for diver transects.

**Locations of transects**

- All zones.
- Link to beach profile / rod lines so can investigate interaction with sediment stability in Zones 2, 3 and 3A. Choose locations so that a balance of early detection of recovery and early detection of impaired health.
- In Zones 1, 4 and 5 choose locations according to management objective. In other words, in Zone 1 we should allocate more resources to an early detection of recovery, while in Zones 4 and 5 we should choose sites to give an early detection of impaired health.
- Subjectively choose a number of key sites in which to place transects along the beach profile lines. This selection is important. Need to identify areas of high risk (e.g. edge of feasible light regime, exposure to stormwater inputs etc) and areas where regrowth is more likely (e.g. midshore vs. nearshore given hydrodynamics). Careful selection will improve an 'early warning' indicator. It will

also be important to balance these sites with some that are less likely to suffer impaired health.

- Record GPS location to allow calibration with other monitoring technologies
- Aligning diver and video transects will help reduce costs and with classification of video imagery.

**Numbers of sites**

- In all zones, recommend monitoring a minimum of 3 permanent transects.

**Frequency of sampling**

- Annually, at the same time each year. Most cost-effective and resource/design efficient if sampled in summer/autumn to coincide with timing of diver transect sampling
- Sampling at approximately the same time each year enables robust trend analyses to be undertaken.

**Summary**

| ***Zones*** | ***Min. no. transects*** | ***Frequency*** |
|---|---|---|
| 1 | 3 | Annually in summer/autumn |
| 2 | 3 | |
| 3 | 3 | |
| 3A | 3 | |
| 4 | 3 | |
| 5 | 3 | |

## 5. Aerial photography

**Monitoring objectives**

- Assess seagrass extent / distribution.
- Determine changes to regional coastline (and pressures caused by physical processes at work).
- Continue long history of this form of seagrass monitoring.

**Indicator to measure**

- Presence / absence of seagrass

**Locations of sites**

- Broad coverage of entire region i.e. all zones.
- Subjectively choose a number of focus areas for high resolution investigation / classification of imagery. It makes sense to place these focus areas so that they align with some of the quadrat sampling sites (validation data) and areas that are more likely to show changed seagrass health (either declined or improved). Careful selection of the focus area may also improve our 'early warning' indicator. It will be important to choose some focus areas that are less likely to suffer altered health.

**Frequency of sampling**

- Every 5 years, though multiple images (e.g. 4 over a year) might be commissioned at the sampling time to enable the identification of confounding drift material like detritus and improve image classification. The classification may also be improved by classifying the image as bare sand or not as there is more confidence in getting those categories correct.

**Other related information**

- Important to have simultaneous measurement of aerial photography and airborne remote sensing in order to allow future calibration.
- Ground truthing is an essential component and needs to be carried out as part of the aerial photography.
- Metrics used to investigate photographs / images need careful consideration and documentation so they are applied consistently over time.

## Appendix E. Details of essential monitoring for other key components

Protocols for non-seagrass components of the recommended EMP largely exist or require amendment (see Section 6 for details). As such, we recommend contacting the relevant agencies to obtain specific details of that monitoring. This appendix describes monitoring protocols for those essential non-seagrass components that require additional monitoring.

### 1. $\delta^{15}$N survey

**Monitoring objectives**

- Establish a regular nitrogen isotope ($\delta^{15}$N) survey in seagrass leaves to help differentiate the sources and magnitude of anthropogenic nitrogen inputs into Zones 1-3.

**Indicator to measure**

- $\delta^{15}$N in seagrass leaves which, because of leaf turnover, may be a valuable integrated measure of nutrient enrichment within the previous year. Focus on *Posidonia* leaves given wider presence.

**Locations of sites**

- Concentrate effort in Zones 1-3 given these areas are subject to the greatest nutrient (nitrogen) enrichment.
- Ensure sites are appropriately located to detect nutrient enrichment from major nutrient sources (e.g. from Bolivar and the Port Adelaide River, Glenelg WWTP and the Torrens outfall)
- Would be sensible to coincide the artificial seagrass sites with nearby site assessments of sediment stability (beach profile lines), seagrass health (quadrat, transect sampling) and coastal water quality wherever possible to enable important interactions to be identified.

**Number of sites**

- It is recommended that a minimum of 4 sites in each of Zones 1-3 be sampled. At each site, 3-4 replicate seagrass samples should be taken. Ideally a much greater number of sites should be sampled in a spatial array that enables the mapping of alongshore and offshore nitrogen 'plumes.'

**Frequency of sampling**

- Annually, and at a similar time of the year, until there has been a sound baseline understanding of $\delta^{15}$N levels established. At that point it might be measured less frequently but used to investigate changes to pressures, e.g. improvements to outputs from WWTPs.
- It will be important to consider the prevailing currents in summer and winter.

**Methodology**

- At each nominated site divers need to collect leaf clumps from a small number (e.g. 4) of replicate seagrass plants in the vicinity of the site. It is important that these replicates are not too close together to avoid any local effect that may be present. Bryars et al. (2006) recommends replicates are located at least 2 m apart.
- The collected leaf samples need to be bagged, labeled and frozen prior to analysis.

- At the time of analysis, the leaves for each replicate sample need to be thawed and washed thoroughly.
- A small number of leaves (3-4) are then randomly selected from each leaf clump and cleaned of epiphytes. All samples are then freeze-dried and ground to a powder before analysis using a mass spectrometer.
- Nitrogen isotopic abundances are reported as $\delta^{15}N$.
- Produce a map showing the spatial distribution and magnitude of anthropogenic nitrogen influences.

**Other related information**

- Sites placed where there is no (or at least minimal) anthropogenic impact may provide an important comparison (and a pseudo measure of reference condition). For instance, sites located on the western side of the Gulf of St Vincent or off of Kangaroo Island may be useful.
- There may be potential to use this method to isolate inputs from other sources, e.g. heavy industry. Initial work should therefore focus on determining the $\delta^{15}N$ signatures of various nitrogen sources (e.g. Penrice, Torrens River, as well as WWTPs) to aid with interpretation of seagrass $\delta^{15}N$ maps. Bryars et al. (2006) describes the $\delta^{15}N$ survey conducted as part of the Adelaide Coastal Waters Study in detail.
- By producing detailed spatial maps of $\delta^{15}N$, the success of management strategies that reduce nitrogen inputs can then be explored and quantified through comparing changes in the maps over long time frames (years).

## 2. Regular offshore water quality sampling (and event-based sampling)

**Monitoring objectives**

- Establish a regular midshore and offshore monitoring program, either grab sampling or via automatic water samplers. Focus on indicators of light and nutrients.

**Indicators to measure**

- Light (attenuation, turbidity, total suspended solids, Secchi depth, colour)
- Nutrients (total nitrogen, oxidized nitrogen, ammonia, total phosphorus, phosphates)
- Other (chlorophyll-a, temperature and salinity).

**Locations of sites**

- Concentrate effort in Zones 1-3 given they are subject to greatest anthropogenic influences (which we may be able to control) and less so in Zones 4 and 5 which are now largely subject to natural physical processes only.
- Ensure some representation of coastal water quality near major pressures (e.g. Bolivar and the Port Adelaide River, Glenelg WWTP and the Torrens outfall) and existing seagrass areas. There is some call to take samples close to areas where seagrass is marginal (either it exists but is on the edge and is under more pressure or where it has been previously lost but may be likely to show signs of regrowth) because changes to coastal water quality may be more likely to have an impact there.
- Coincide sites with nearby site assessments of sediment stability (beach profile lines), seagrass health (quadrat, transect sampling) and epiphyte loads on artificial seagrass to enable important interactions to be identified.

**Number of sites**

- It is recommended that a minimum of 4 sites for each of Zones 1 to 3 be taken by grab sampling from a small boat.
- If permanent automatic samplers are employed, a smaller number of sites (e.g. 2 or 3) may be monitored given the outlay involved.

**Frequency of sampling**

- It is recommended that regular ambient monthly monitoring be conducted for the first 2-3 years of the monitoring program. At that time, the data collected will help inform the appropriate sampling intensity and whether some parts of the year may be sampled at differing frequencies.
- Event-based sampling is more difficult and really only feasible if automatic samplers can be placed off the metropolitan coast. Grab sampling during events poses safety concerns and is complicated by the time sampling needs to occur (i.e. it may often be overnight or on public holidays). Ideally, automatic samplers could be triggered to take more samples during major events.

**Other related information**

- Standardized collection protocols should be adhered to. These will be analogous to the ambient jetty sampling program administered by the SA EPA.

## 3. Epiphyte load monitoring on artificial seagrass

**Monitoring objectives**

- Nutrients uptake by plants and phytoplankton is often so quick that high levels are not observed in direct measures of water quality. Integrated measures such as epiphyte loads, which are likely to grow during periods of elevated nutrients, are often seen as a valuable integrated measure of eutrification and coastal water quality. While epiphyte loads may be directly measured on seagrass, measuring epiphyte loads on artificial seagrass (plastic strips) have the advantage of allowing a consistent measure over time, being efficient to work with and being non-destructive.

**Indicator to measure**

- Epiphyte loads / counts on artificial seagrass, (most likely) assessed as a mean dry weight.

**Methodology**

- Artificial seagrass strips of a consistent length and width are attached to a metal frame (star dropper). It is important that the artificial seagrass is able to move fairly freely.
- The star dropper is secured to the sea floor using pegs.
- At least 3 star droppers with attached artificial seagrass should be used for each site.
- The artificial seagrass is left for a fixed period of time (e.g. 2 months).
- A single leaf is randomly sampled from each star dropper at each site, removed, bagged, appropriately identified and taken back to the laboratory for analysis.
- The mean dry weight of epiphytes on a standard section of artificial seagrass is calculated.
- New artificial seagrass is placed at the site for each new sampling period.
- Bryars et al. (2003) used artificial seagrass on Kangaroo Island and describes a monitoring procedure in detail. This protocol draws directly from that approach.

**Locations of sites**

- As for the off-shore coastal water quality program it makes sense to concentrate effort in Zones 1-3 given they are subject to greatest anthropogenic influences. It may also be sensible to have several sites located outside of the Adelaide coastal waters region and in unexpected conditions to allow broader comparisons to be made.
- It will be important to ensure artificial seagrass sites represent the coastal water quality near major pressures (e.g. Bolivar and the Port Adelaide River, Glenelg WWTP and the Torrens outfall) and existing seagrass areas.
- It will also be sensible to coincide the artificial seagrass sites with nearby site assessments of sediment stability (beach profile lines), seagrass health (quadrat, transect sampling) and coastal water quality wherever possible to enable important interactions to be identified.
- The star droppers with artificial seagrass for each site should be placed randomly within vicinity of the site. It is important that these replicates are not too close together to avoid any potential local effect that may be present.

**Number of sites**

- It is recommended that a minimum of 4 sites for each of Zones 1 - 3 is sampled.

**Frequency of sampling**

- Initially every two years at a same time of the year.
- It is possible to revisit the sites several times in any one year to improve the accuracy of measurements and obtain some understanding of temporal variability. For example, we might put artificial seagrass in place, and then visit and sample after 6 weeks, and then return a further 6 weeks later (i.e. after 12 weeks) and randomly sample a second leaf for analysis from each star dropper.
- In subsequent years new artificial seagrass is placed at the sites of interest and the procedure will begin again.