Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management

Technical Report 75

Decision support for modelling and monitoring assessments of coastal water impacts

Ian Ramsay
Claire Harris
Tony Howes

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CRC for Coastal Zone Estuary & Waterway Management

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Written by:

Ian Ramsay
Claire Harris
Tony Howes

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Indooroopilly Sciences Centre
80 Meiers Road
Indooroopilly Qld 4068
Australia

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Authors:

Dr Ian Ramsay (Queensland EPA)
Ms Claire Harris (Coastal CRC, based at The University of Queensland)
Associate Professor Tony Howes (The University of Queensland)

Project contributors:

Dr Ian Webster (CSIRO Division of Land & Water)
Dr Barbara Robson (CSIRO Division of Land & Water)
Graham McBride (NIWA New Zealand)
Daniel Spooner (NIWA Australia)
Russell Richards (Coastal CRC)
Dr Andy Steven, Dr Nick Marsh, Dr Claire McKenny, Brendan Farthing, Tory Grice, Phil Kingston, Paul Sherman, Cameron Schulz, Stephen Victory and Shawn Knox (Queensland EPA)
Russell Richards, Rachel Mackenzie and Regina Souter (Coastal CRC).

Reviewers:

Daniel Large (NSW Department of Environment and Conservation)
Professor David Hamilton (University of Waikato, New Zealand)
Mr Tony Weber (WBM Oceanics, Australia)
Dr James Udy (The University of Queensland)
Dr Nick Marsh (Queensland EPA)
Dr Arnold Dekker (CSIRO Division of Land & Water)

DSS software development:

Deb Gale (Queensland EPA)
Matt Koczorowski and Tim Mason (The University of Queensland)
Trevor Pickett (Queensland EPA)
Nick Murray (CSIRO).
Kate Moore (The University of Queensland)
Kerry Rosenthal, Donna Barchiesi and Jan Tilden (Coastal CRC)

Organisations and National Estuaries Network members:

Northern Territory Department of Natural Resources, Environment and the Arts
New South Wales Department of Environment and Conservation
New South Wales Department of Infrastructure, Planning Natural Resources
Queensland Department of Primary Industries and Fisheries
Queensland Environmental Protection Agency
South Australian Department for Environment and Heritage
Tasmanian Department of Primary Industries, Water and Environment
Victorian Environmental Protection Authority
Western Australian Department of Environment (Water and Rivers Commission)
Geoscience Australia
Commonwealth Scientific and Industrial Research Organisation.

For more details on the project or copies of the report, please contact:

Dr Ian Ramsay, Queensland EPA, (07) 3986 9277, ian.ramsay@epa.qld.gov.au. Postal address: EPA Building, 80 Meiers Road, Indooroopilly, Q 4068.

Foreword

This report was developed as part of the Coastal CRC project on Modelling, Monitoring and Management Interfacing for Waterways (3M Project) and was focussed on developing tools to support modelling and monitoring assessments of coastal water impacts.

The major products of the 3M Project are a decision support system (DSS), called the Modelling and Monitoring Assessment DSS (MAMA DSS) and help systems. The help systems hold all the information developed within the project as well as electronic searchable versions of key documents including ANZECC/ARMCANZ (2000B) *Australian guidelines for water quality monitoring and reporting*, Scheltinga *et al.* 2004 *Users' guide to estuarine, coastal and marine indicators for regional NRM monitoring* and pertinent modelling papers. The primary audience of the products is government officers involved in an environmental impact assessment (EIA) process, most likely at a state or federal level. The EIA process varies between states but is underpinned by the water quality management framework of the National Water Quality Management Strategy. The officers involved with assessing the EIA typically have a science background but may not have detailed knowledge of all areas of water quality modelling and monitoring.

One of the most challenging areas of coastal assessment is modelling, despite an increasing demand from politicians and the public to predict future changes. The use of modelling is arguably *ad hoc*, opportunistic and underutilised in many situations. The area of modelling is also highly technical, and modelling expertise available can be scarce or modellers' expertise may be limited to particular software or model types. This can contribute to poor communication between decision-makers and scientists involved. The 3M Project was undertaken to help address such issues, which also cover water quality monitoring and experimentation (physical trials in a laboratory or in the field).

The management focus was continually refined throughout the project, and in the end the key focus was on environmental impact assessment, particularly of point source activities as these typically require more detailed assessments and modelling. The document and the DSS were designed to demonstrate how integration could occur over the management, modelling and monitoring areas. Further work is possible in this area and as new techniques are developed the DSS will require updating. The tools are also designed to support the assessment process rather than be prescriptive and therefore it is hoped the information will remain useful for some time. The information was not designed specifically to support water resource planning, catchment management planning, stormwater management planning and numerous other management areas but still may provide some useful information in such cases.

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Summary

This report presents information to support environmental impact assessment (EIA) required for development approvals in coastal areas. The report covers the technical aspects of assessments that typically include a combination of computer modelling and field monitoring, rather than the EIA process itself. Experiments in the field or the laboratory are also considered as part of the assessment options. Government regulators involved in an EIA process are the primary audience of the document. The report therefore focusses on supporting the tasks of (i) choosing suitable assessment methods and approaches and (ii) reviewing existing assessments, as these are the stages (as compared to the application stage) where regulators are often involved.

The document is a stand-alone resource but can also be used in conjunction with decision support software called Modelling and Monitoring Assessment Decision Support System (MAMA DSS). The DSS also contains a help system that includes searchable and linked versions of a number of key documents relevant to assessments of aquatic environments, including: ANZECC/ARMCANZ (2000a) *Australian and New Zealand guidelines for fresh and marine water quality*; ANZECC/ARMCANZ (2000b) *Australian guidelines for water quality monitoring and reporting*; Scheltinga *et al.* (2004) *Users' guide to estuarine, coastal and marine indicators for regional NRM monitoring*; and nine key modelling papers. Some links to these documents are also provided in this report.

The steps that this document (and the DSS) is designed to support include: (i) defining the management context; (ii) selecting assessment options; and (iii) reviewing existing assessments. Each step draws information from four addendums that cover detailed facts on:

(1) Common management activities involved in the EIA process. This includes information about the potential pollutants from 33 point and diffuse source activities such as sewage treatment, mining and aquaculture.

(2) Modelling approaches used in the coastal system. This includes six hydrodynamic approaches (such as box models and one-, two- and three-dimensional approaches) and 18 water quality approaches (such as simple transport, sediment transport, dissolved oxygen and nutrient-phytoplankton-zooplankton models).

(3) Monitoring and experimentation methods for coastal systems focussing on nine monitoring and experimental methods and includes in-field monitoring, sampling and analysis, remote sensing and experimentation.

(4) Catchment information providing supporting information on linking catchment information to coastal assessments and potential data sources from catchment models that may be related to the government context.

The information in the addendums covers existing knowledge rather than new technical information and was either elicited from experts or compiled from literature.

1 Introduction and project background

Making management decisions within estuarine and marine environments can be extremely challenging. Decision-makers need to consider a range of scientific, social and economic issues and the science about these systems is complex and ever-evolving. It is increasingly expected that decision-making be carried out in a consultative and transparent manner, often in situations where there is inadequate information, limited resources and insufficient time. Organisations often have inefficient knowledge management systems and struggle with losing extensive knowledge when people change jobs or retire. One area where this is particularly true is environmental impact assessment (EIA) and review by government regulators. Strict timeframes are often required under legislation and there is limited time and opportunity to assess and request information.

Government regulators involved in EIA (note that this process may also be called other names such as Statement of Environmental Effects (SEE) or Development Approval) may be asked to comment on or even advise proponents of suitable assessment options such as computer modelling, field monitoring or experimentation. Government officers are also typically required to review the results from such assessments. Undertaking these tasks can be difficult given potentially complex environmental issues, the large range of techniques available and the need to consider the economics and the practicalities involved.

Decision-making about activities in the coastal zone is generally underpinned by information from monitoring and modelling. Modelling is a highly technical field and communicating modelling concepts and uncertainty is challenging, particularly to a non-expert audience. In addition, modelling expertise often lies outside government departments and can be scarce, with modellers' expertise often limited to particular software or applications. Although water quality monitoring is generally more widely understood than modelling, there are still many areas of monitoring that need to be more effectively and efficiently applied.

Although processes used by federal, state and local governments may vary, in general the EIA process generally includes the following steps: screening; scoping; examination of alternatives; impact analysis; mitigation and impact management; evaluation of significance; preparation of environmental impact statement (EIS) or report; review of the EIS; decision-making; and follow-up (IAIA 1999). The proponent undertakes the majority of these steps with input from regulators and stakeholders. This document does not cover all of these steps and assumes the user is familiar with the EIA process. However, further information on EIA can be obtained from the following sources: Australian

Government (2005a), NSW DUAP (2000), Vic DSE (2005), WA EPA (n.d.), NT NRETA (2006), Qld EPA (2006b).

This document is consistent with and underpinned by the National Water Quality Management Strategy (NMWQMS, Australian Government, 2005b). The framework for applying the guidelines at a local level is shown in Figure 1.1. EIA typically requires this process to be undertaken where there is a potential for impacts on the aquatic environment, although other aspects of EIA are also required and vary depending on the legislation and regulatory agency involved.

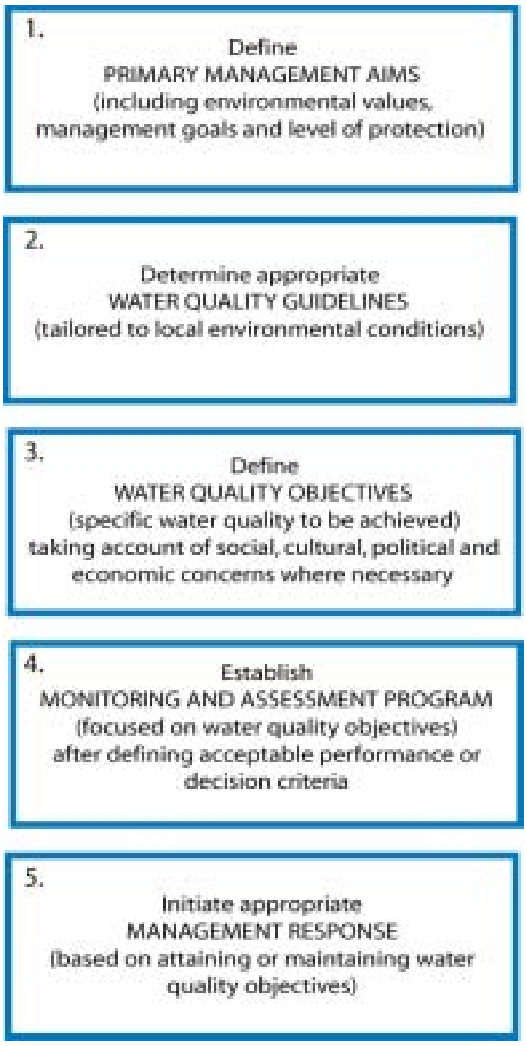

Figure 1.1 Framework for applying the National Water Quality Guidelines (from ANZECC/ARMCANZ 2000c)

Water quality assessments may be required at a number of stages through the EIA process and can be undertaken for a range of specific purposes. Most assessment is typically carried out in the monitoring and assessment stage of EIA (i.e. fourth box in Figure 1.1). These typically include a combination of computer modelling and field monitoring and may also include experiments in the field or a laboratory. Commonly the major type of assessment relates to predicting the environmental impacts of a single proposal, although assessments may be used to screen a number of potential proposals.

The information in this report is aimed to support water quality assessments required as part of EIA. Furthermore, it is focussed on supporting government regulators involved in directing assessment decisions and reviewing assessment results and the technical aspects of the assessment.

The document is a stand-alone resource but can also be used in conjunction with decision support software called Modelling and Monitoring Assessments Decision Support (MAMA DSS). The MAMA DSS is desk-top based software that helps the user involved in the EIA process to quickly obtain information relevant to the assessment to assist them. The software also contains a help system that includes searchable and linked versions of a number of key documents relevant to assessments of aquatic environments, including ANZECC/AMCANZ (2000a) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*; ANZECC/AMCANZ (2000b) *Australian Guidelines for Water Quality Monitoring and Reporting*; Scheltinga *et al.* (2004) *Users' Guide to Users' Guide to Estuarine, Coastal and Marine Indicators for Regional NRM Monitoring*; and pertinent modelling papers. Some links to these documents are also provided in this report.

1.1 Structure of report

This report is divided into three sections that include:

(i) **Assessment context**. This section of the report provides information on: the activity; potential stressors and release qualities to the environment; the assessment objective; environmental values, water quality objectives and indicators of waters potentially affected by the release; and conceptual understanding of the aquatic environment.

(ii) **Assessment options**. Screening assessment options important in the early stages of the assessment where more information is required about the aquatic ecosystem and potential effects of the development proposal. This section of the report supports the process of selecting one or screening a number of targeted water quality studies using modelling, monitoring or experimentation. Selection can be based on environmental indicators, potential stressors, environmental processes or known management issues.

(iii) **Assessment review**. Assessment review is relevant when all or part of EIA report has been prepared and requires review. The section of the report that supports this stage includes information on important factors that should be considered to ensure a proper assessment has been undertaken. The suitability for the specific assessment context is an important factor. For modelling assessments, other considerations are: model verification; spatial scale; time scales; calibration; validation; and scenario application. For monitoring assessments, other considerations are: spatial boundaries, scale and duration; frequency and sample site variability; quality assurance/control; and data analysis and interpretation methods.

These stages can be used sequentially or on their own. However, it is recommended that the assessment context always be considered first, as shown in Figure 1.2, as this will direct both selecting assessment options and reviewing assessments. Note that the activity of undertaking the assessment is not covered specifically in this report as the proponents often undertake this stage independently of government regulators. However, some information presented in this report may also assist with this stage.

Each stage draws information from four addendums that cover detailed information. Figure 1.2 shows how the addendums links to the rest of the document and the three stages. The information in the addendums covers existing knowledge rather than new technical information and was either elicited from experts or compiled from literature.

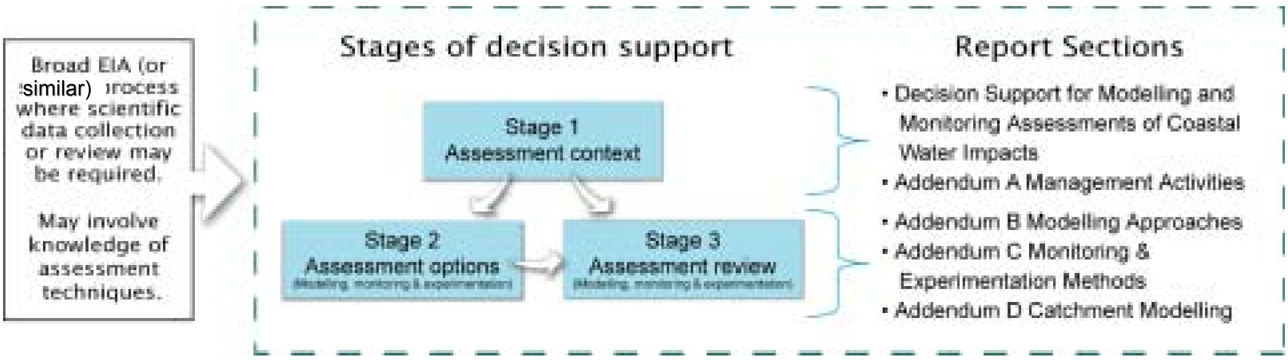

Figure 1.2 Stages of decision support provided by this report and related addendums

Throughout this report, ‘boxes’ featuring a fictional case study can be found in each main section. This case study provides an example of how an environmental officer may use the decision support information to choose and review water assessments. This case study provides only general guidance, as all cases will vary depending on specific circumstances. An assessing officer should use professional judgment to consider local information and site-specific issues.

2 Assessment context

Water quality assessments can differ depending on the management objectives, the locality and type of activity being assessed and the changes being proposed. For example, an environmental assessment might focus on the current and/or future situation, one activity or a number of activities, one part of the catchment or all of the catchment. Only through understanding the nature of each development activity, the specific assessment objectives and characteristics of the environment for each case can an assessment be tailored to the decision-maker's specific needs. In this report, these things are referred to as 'the assessment context' and are discussed in more detail below. It is recommended that the assessment context is well understood prior to either selecting assessment options (Stage 2) or reviewing an assessment (Stage 3).

This section provides information that can assist with the assessment of major point and diffuse source activities typically involved in EIA. These activities could include either point or diffuse sources of pollution. Point source activities are the primary focus of this report. They may involve releases of a substance/pollutant to coastal waters from one or a number of defined locations and often occur regardless of rainfall. Point source activities commonly occupy a small geographical area and have a concentrated output from one point. Pollution from diffuse source activities, on the other hand, does not originate from a single, definable point, but originates from numerous undefined locations and movement into watercourses is typically driven by rainfall.

Information is provided to help the reader define their activity types and then the key or possible stressors to the environment from those activities. A knowledge base (a repository of expert and synthesised knowledge) is provided on each activity in Addendum A and is summarised in Table 2.1. Advice is also provided on predicting the stressors likely to originate from each activity. This includes data from literature in addition to a summary of techniques typically used. Describing the environment and scheduling environmental values is an important part of the process but is not dealt with in detail in this report or in MAMA DSS.

2.1 Development activity information

One important requirement of good water quality assessment is a sufficient knowledge of the activity type and the likely stressors involved. Although this needs to be defined on a case-by-case basis, information is provided in this section about typical release characteristics for a number of key activities. This will help decision-makers to screen or check information provided to them and also to ensure an adequate focus is provided on areas of potential concern.

Table 2.1 Information available in Addendum A to help define the assessment context

Information category	Description or information covered
Activity types and likely pollutants	Factors affecting concentrations and loads, techniques used to predict concentrations and loads, typical releases, typical concentrations, links to further information, references. Categories: sewage systems, aquaculture, mining, chemical, power supply, paper/hardboards manufacture, general point source, rural activities, managed forests, natural bush, urban and water use.
Quantifying releases to the environment	Potential techniques for quantifying the concentrations or loads of releases to the environment. Information is also provided on typical concentrations and loads and factors affecting these.
Environment considerations: Environmental values examples	Some examples of environmental values (EVs) set for different states and territories of Australia. (EVs are also known as protected environmental values and beneficial uses in some states and territories.)
Environment considerations: sample monitoring examples	Nineteen examples of monitoring from Australia that could provide useful background information for water quality assessments and potential sources of data. Information covers: program coordinator; inception date; water bodies monitored; a brief program overview; program objectives; water types; indicators; methods; related guidelines, design; reporting and review; data synthesis tools; links; and references.

2.1.1 Activity types

Activity types that typically affect coastal waters in Australia have been investigated and categorised in Table 2.2 and include a range of potential point and diffuse sources. Broad category groups as well as specific activity types are provided.

The point source activities presented may include a dry weather release or runoff resulting from rainfall. Nonetheless, it is assumed here that the stormwater is generally managed, treated and released to waters from known points. A good example of this is in the mining industry, where all overland water falling on a site is directed to a tailings or treatment dam. The diffuse source activities presented are broadscale and were not broken down further as diffuse management was not the primary focus of this report.

Table 2.2 Point and diffuse source activities described in Addendum A

Point source activities		Diffuse source activities	
Activity group	**Activity**	**Activity group**	**Activity**
Sewage systems	– Sewer overflow (raw sewage)	Rural activities	– Broadacre agriculture
	– Sewage treatment discharge		– Grazing
Aquaculture	– Prawn pond discharge		– Intensive agriculture
	– Fish & crustacean pond discharge	Managed forests	– Plantation
	– Sea cage impacts	Natural bush	– Dense urban
Mining	– Coal mining (open cut)	Urban	– Suburban
	– Metal mining (open cut)		– Development
Chemical	– Petrochemical refinery discharge		– Roads
	– Vegetable oil refinery		– National park
	– Vegetable and fruit processing	Water use	– Stormwater
	– Fertiliser factory discharge		– Water storage
	– Desalination plants		– Water treatment
	– Tannery		
Power supply	– Power station discharge		
Paper/hardboards	– Pulp mill/hardboard discharge		
General point source	– Abattoir discharge		
	– Sugar mill discharge		
	– Dredging		
	– Composting/soil conditioner		
	– Dairy factory		
	– Brewery/distillery		

2.1.2 Key potential stressor types

Potential stressors on the environment (often called hazards in a risk assessment context) are classified as those pollutants or physical changes from an activity that will potentially affect the aquatic environment or other environmental values if permitted and not managed. The stressors relevant to EIA have been categorised in this report based on broad stressors typically experienced in the environment and are shown in Table 2.3. Each activity was rated for these stressors as a ‘likely stressor’, ‘potential stressor’ or ‘unlikely stressor’ and is provided in Table A1.1 of Addendum A.

All possible measures should be undertaken to reduce, minimise or eliminate potential stressors prior to a release to the environment. In some cases, a release is inevitable (be it due to catastrophic events, system failures or accepted practice), in which case the following information will be useful.

Table 2.3 Key potential stressors relevant to EIA

Stressor*	**Description/reference**	**Typical industries where stressor is a 'key stressor'**
Aquatic sediments (changed)	Change to load, distribution/movement patterns, settlement/resuspension rates, grain size of suspended or settled sediments. The ANZECC/ARMCANZ (2000a) stressors of turbidity and suspended particulate matter are also included within this category.	Sewer overflow (raw sewage), prawn pond discharge, fish & crustacean pond discharge, sea cage impacts, coal mining (open cut), metal mining (open cut), dredging, broadacre agriculture, grazing, intensive agriculture, plantation, dense urban, suburban development, roads, national park, stormwater, water treatment.
Pathogens	Bacteria, viruses, protozoans or fungi which cause disease.	Sewer overflow (raw sewage), Sewage treatment discharge.
Biota removal/ disturbance	Removal, loss or disturbance of individual organisms (plant or animal) of a specific species, not areas of habitat.	Coal mining (open cut), metal mining (open cut), desalination plants, dredging, water storage.
Excess fresh water (changed)	Localised or point source discharge of fresh water (not diffuse catchment runoff).	
Excess salt (hypersalinity)	Localised or point source discharge of salt or salty water.	Desalination plants
Freshwater flow regime (changed)	Changes to pattern/amount of catchment waters entering estuarine and coastal systems.	Sewage treatment discharge, coal mining (open cut), metal mining (open cut), power station discharge, stormwater, water storage.
Habitat removal/ disturbance	Removal, loss or disturbance of large areas of habitat, such as those listed in the 'key habitats' indicator profile.	Coal mining (open cut), metal mining (open cut), dredging.
Hydrodynamics (changed)	Changes to local patterns of waves, currents or tidal exchange.	Dredging, water storage.
Litter	Human made rubbish/debris.	Stormwater.
Nutrients (changed)	Change to load, bioavailability and concentrations of nutrients.	Sewer overflow (raw sewage), sewage treatment discharge, prawn pond discharge, fish & crustacean pond discharge, sea cage impacts, fertiliser factory discharge, abattoir discharge, dairy factory, broad-acre agriculture, grazing, intensive agriculture, plantation, dense urban, suburban, development, roads, national park, stormwater.

* Based on Scheltinga *et al.* 2004 stressors except for where noted.

Table 2.3 (continued) Key potential stressors relevant to EIA

Stressor*	**Description/reference**	**Typical industries where stressor is a 'key stressor'**
Organic matter (changed)	Organic matter is carbon-based material derived from plants or animals (e.g. decaying plant matter or animal wastes). It can be in either dissolved or particulate forms.	Sewer overflow (raw sewage), sewage treatment discharge, prawn pond discharge, fish & crustacean pond discharge, sea cage impacts, vegetable and fruit processing, pulp mill/hardboards discharge, abattoir discharge, sugar mill discharge, dairy factory, brewery/distillery.
Pest species	An invasive organism (plant or animal) that is detrimental to an ecosystem.	Prawn pond discharge, fish & crustacean pond discharge, sea cage impacts.
pH (changed)	Acidity or alkalinity of water.	Coal mining (open cut), metal mining (open cut), petrochemical refinery discharge, power station discharge, pulp mill/hardboards discharge, brewery/distillery, water treatment.
Toxicants	A toxicant is a chemical capable of producing an adverse response (effect) in a biological system at concentrations that might be encountered in the environment, seriously injuring structure or function or producing death. Examples include pesticides, metals and metalloids, alcohols, alkanes and alkenes, aromatic hydrocarbons, phenols and xylenols and biotoxins. Source: ANZECC/ARMCANZ 2000a	Coal mining (open cut), metal mining (open cut), petrochemical refinery discharge, fertiliser factory discharge, desalination plants, tannery, power station discharge, pulp mill/hardboards discharge, roads, water treatment.
Water aesthetics/ light climate (changed)	This stressor includes changes to the natural light climate underwater and changes to natural water aesthetics. Changes to light climate can be the result of stressors impacting the environment that do not fall under other categories. Light climate/water aesthetics may also change as a result of other stressors (such as change to habitat resulting in greater light penetration or subtle changes to water colour that could have effects on underwater light climate). Changes to the natural water aesthetics such as smell, colour and odour can impact on human and animal use of the water (e.g. recreational and drinking water values). Source: adapted from ANZECC/ARMCANZ 2000a	Sewer overflow (raw sewage), dairy factory.
Water temperature (changed)	Local and surface water (sea, estuary) temperature.	Power station discharge, pulp mill/hardboards discharge, dairy factory, brewery/distillery.

* Based on Scheltinga *et al.* 2004 stressors except where noted.

2.1.3 Quantifying releases to the environment

Once likely stressors are identified, the next important step is to try and estimate the quantity or nature of the release that causes those stressors. This can be difficult, especially in the case where the activity has not yet commenced. Techniques typically used include pilot-scale testing, computer modelling or using results of similar activities elsewhere. It is noted that some stressors are a result of physical damage from construction or operation of an activity rather than from effluent release. These also have important effects and have been considered here.

Pilot testing and other experimentation techniques are discussed in more detail in Addendum C. In addition to ensuring good experimental procedures and practice, any scale-up effects need to be incorporated into predictions.

Specific activity models for point sources are frequently available, for example, to simulate different types of sewage treatment or aquaculture sea cage operation. Activity models are also available for various stormwater and wastewater management units such as artificial wetlands and septic tanks. Most activities generating diffuse source pollution are simulated using catchment models, which are used to simulate such processes as stormwater treatment, agricultural pollutant runoff and sediment generation. Of course, the general quality assurance principles of modelling need to be applied (discussed in Addendum B) to ensure results are reliable and any uncertainties have been properly considered.

Specific information on typical techniques used to predict concentrations and loads of releases for various activities is provided in Addendum A. Further information on catchment modelling is provided in Addendum D, Catchment Hydrology CRC's documents on model choice (2005a & 2005b) and Catchment Hydrology CRC's Modelling Toolkit (http://www.toolkit.net.au).

Information on typical concentrations from various activities is provided in Addendum A. This information should be used in context, noting the factors that usually affect concentrations and loads from these activities. Links to further information on releases from various activities is also provided.

2.1.4 Objective of the assessment

The specific objectives of the water quality assessment should be defined before undertaking environmental studies. Water quality assessments may be required at a number of stages throughout the EIA process and can be undertaken for a range of purposes including: describing the existing environment (where relevant to the assessment of impacts), predicting environmental impacts from the proposed development, proposing relevant alternatives to the proposed development and their consequences, identifying likely (predicted) Improvements from mitigation activities and a developing a program for monitoring impacts.

The details of the assessment objective relate to the activity type and potential stressors on the environment (described above), waste treatment or management and release timing and locations. The assessment may focus on one or a number of options (often called scenarios) and current or possible future activities.

2.2 Environment considerations

There are a number of important receiving environment considerations when choosing or reviewing an assessment. The environmental indicators of interest typically vary depending on the pressures on the system as well as the values or characteristics of the environment being assessed.

These are briefly mentioned below but are not covered in any detail in this report or MAMA DSS. Links to information from other sources are provided in Table 2.4.

An important step in describing the environment for an EIA is checking previous studies and available environmental data in the geographical area of interest. This will ensure that any future assessment does not ‘reinvent the wheel‘ and that significant time and resources are saved. A review of previous studies can also be used to help identify knowledge gaps and consider previous recommendations. Some useful databases and information sources about previous studies and data are included in Table 2.4.

Assessments of a similar nature in other geographical locations may also be of value. Examples of assessments (predominantly undertaken in Australia) are provided in Sections 1 and 3 of Addendum A for monitoring and experimentation examples and under each modelling approach category in Addendum B for modelling examples. It is important to know the reason why an assessment was undertaken, as assessments will generally be tailored to the activities and stressors involved and specific management objectives. Related assessments may be sourced from published work or contact with relevant state or local authorities, regional or catchment management organisations or water service providers.

Table 2.4 Potential information sources to assist in describing the environment

Information	References and links
Environmental values: water quality objectives and indicators	• ANZECC/ARMCANZ (2000a) Water quality guidelines * (and Table 2.5) • Coastal CRC's website: *What are your environmental management goals?*: http://www.coastal.crc.org.au/ozcoast/infopages/visionemg.html • Coastal CRC's website: *How do you develop draft water quality objectives?*: http://www.coastal.crc.org.au/ozcoast/infopages/visiondraftWQO.html • Coastal CRC's website: *What types of indicators are there?*: http://www.coastal.crc.org.au/lg/environmentalindicators.html • NSW EPA website: *Using the ANZECC guidelines and water quality objectives in NSW:* http://www.environment.nsw.gov.au/water/usinganzeccandwqos.htm • NSW EPA website: *Marine water quality objectives for NSW ocean waters*: http://www.epa.nsw.gov.au/water/mwqo/index.htm • NSW EPA website: *Water quality and river flow objectives*: http://www.epa.nsw.gov.au/ieo/index.htm. Information about WQOs as well as a database of the numerical trigger values for various indicators developed for 35 catchments of NSW • NT NRETA website: *Beneficial use:* http://www.nt.gov.au/nreta/naturalresources/water/beneficialuse/index.html • Qld EPA (2006b) *Queensland water quality guidelines* * • Qld EPA website: *Scheduled EVs and WQOs under the EPP water:* http://www.epa.qld.gov.au/environmental_management/water/environmental_values__environmental_protection_water_policy_1997/#gen3 • Scheltinga *et al.* (2004) *Users' guide for estuarine, coastal and marine indicators for regional NRM monitoring* * • Tas DPIWE website: *Protected environmental values for Tasmanian surface waters*: http://www.dpiw.tas.gov.au/inter.nsf/WebPages/EGIL-53L3KY?open • Vic EPA website: *State environment protection policies to protect Victoria's water environment* : http://www.epa.vic.gov.au/water/epa/policies.asp • *Water quality targets online*—Report and online tool particularly aimed at natural resource management groups (DEH 2002): http://www.deh.gov.au/water/quality/targets/index.php
Information on key hydrodynamic, physical, chemical or biological processes Water body types and features	• ANZECC/ARMCANZ 2000a Water quality guidelines * • OzEstuaries http://www.ozestuaries.org/ • Relevant experts and stakeholders.

* Included in the IWADSS help system.

Table 2.4 (continued) Potential information sources to assist describing the environment

Information	References and links
Previous studies and data availability (Australian portals to maps and data)	• OzEstuaries database: http://dbforms.ga.gov.au/pls/www/npm.ozest.search • Australian Coastal Atlas: http://www.deh.gov.au/coasts/atlas • Australian Natural Resources Atlas (http://audit.ea.gov.au/ANRA/atlas_home.cfm) and Australian Natural Resources Data Library (http://adl.brs.gov.au) (initiatives of the National Land and Water Resources Audit). • Qld Department of Primary Industries & Fisheries: CHRIS Web (http://chrisweb.dpi.qld.gov.au/chris) is a site providing maps and GIS data on fish habitat areas and commercial and recreational catches. Also available is metadata such as where to get coastline maps, monitoring program sites and maps of seagrass meadows. CHRIS Web also forms part of the Queensland node of the Australian Coastal Atlas. • Victorian Water Resources Data Warehouse (http://www.vicwaterdata.net) which includes data and reports on monitoring of water flow and quality undertaken by catchment management authorities, the Environment Protection Authority and individual organisations. • The Regional Data Net Project (RDN) is an initiative of the Victorian Department of Sustainability and Environment (DSE) and aims to improve access to GIS information for catchment management authorities and regional DSE and Department of Primary Industries staff. One tool from this project is the Catchment Activity Management System which allows organisations to report to funding bodies on the environmental activities (e.g. restoration, monitoring or research) they are undertaking. • Australian Water Data Infrastructure Project, Department of Agriculture, Fisheries and Forestry (through http://www.daff.gov.au).
Using conceptual diagrams	• ANZECC/ARMCANZ 2000b Monitoring guidelines *. • Coastal CRC website: http://www.coastal.crc.org.au/ozcoast/infopages/models.html and http://www.coastal.crc.org.au/wetlands/conceptual.html • Integration and Application Network (University of Maryland): http://ian.umces.edu/images/iannewsletter5lge.jpg and http://ian.umces.edu/conceptualdiagrams_page.php • National Park Service, US Department of the Interior: http://science.nature.nps.gov/im/monitor/ConceptualModels.cfm

* Included in the IWADSS help system.

2.2.1 Environmental values, water quality objectives and indicators

Understanding environmental values and water quality objectives is an essential part of any EIA. The concept of environmental values is part of the National Water Quality Guidelines Strategy documents and is also embedded in most state environmental legislation. Environmental values are defined under the ANZECC/ARMCANZ (2000a, Section 2.1.3) *Guidelines for fresh and marine water quality* as:

> *…values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and that require protection from the effects of pollution, waste discharges and deposits. Several environmental values may be designated for a specific water body.*

Descriptions of environmental values may be obtained from scheduled information in legislation, state agency documents or regional water quality strategies or catchment plans. A generic set of environmental values as defined in the ANZECC/ARMCANZ (2000a) guidelines are included in Table 2.5 with reference to key documents.

Table 2.5 Key documents for defining environmental values and water quality objectives

<table>
<tr><th>Generic environmental value</th><th>Further detail (as described in some documents)</th><th>Reference</th></tr>
<tr><td>Aquatic ecosystems</td><td>Surface waters [1]</td><td>ANZECC/ARMCANZ 2000a (Vol. 1, Ch. 3 and Vol. 2) *</td></tr>
<tr><td rowspan="5">Primary industries</td><td>Irrigation</td><td rowspan="5">ANZECC/ARMCANZ 2000a (Vol. 1, Ch. 4 and Vol. 3) *</td></tr>
<tr><td>General on-farm water use</td></tr>
<tr><td>Stock drinking water</td></tr>
<tr><td>Aquaculture</td></tr>
<tr><td>Human consumers of aquatic foods</td></tr>
<tr><td rowspan="3">Recreation and aesthetics</td><td>Primary recreation</td><td rowspan="3">Guidelines for managing risks in recreational water (NHMRC 2005) *, ANZECC/ARMCANZ 2000a (Vol.1, Ch. 5) *</td></tr>
<tr><td>Secondary recreation</td></tr>
<tr><td>Visual recreation</td></tr>
<tr><td>Drinking water</td><td></td><td>Australian drinking water quality guidelines (NHMRC, 2004) (Synopsis here: http://www.nhmrc.gov.au/publications/synopses/eh19syn.htm)
ANZECC/ARMCANZ 2000a (Vol. 1, Ch. 6)
Victorian drinking water guidelines: http://www.health.vic.gov.au/environment/water/d-water-guide.htm</td></tr>
<tr><td>Industrial water</td><td></td><td>None available</td></tr>
<tr><td>Cultural and spiritual values</td><td></td><td>None available</td></tr>
</table>

* The guideline is available in the DSS help system

[1] Tasmania's State Policy on Water Quality Management (1997) includes the delineation of surface water, groundwater and coastal water http://www.dpiw.tas.gov.au/inter.nsf/Attachments/LBUN-53S33A/$FILE/waterqua.pdf

Environmental values are typically determined through a process that incorporates social and economic considerations with stakeholder involvement (see ANZECC/ARMCANZ 1998, Qld EPA 2006a or Coastal CRC: http://www.coastal.crc.org.au/ozcoast/infopages/visionev.html).

Some examples of where the process of determining environmental values has been incorporated into policy include: Victoria's State Environment Protection Policies (SEPP), Queensland's Environmental Protection Policy (EPP) for Water and Tasmania's State Policy on Water Quality Management.

Environmental values (EVs) have been determined in every state and territory of Australia. Links to the government websites to find out more can be found at: http://www.coastal.crc.org.au/ozcoast/infopages/visionevexist.html or see Table 2.4 for New South Wales or Queensland links. Water Quality Objectives (WQOs) are statements or water constituent concentrations established to protect the EVs. WQOs are derived from suitable indicators and guideline values. WQOs are the most stringent levels of indicator considering guidelines for the protection of all EVs.

The ANZECC/ARMCANZ (2000a) guidelines provide default trigger values and a risk-based approach for developing and applying water quality guidelines. For aquatic ecosystem protection, guidelines may be based on either biological effects or reference sites. The guidelines provide trigger values for toxicants based on available biological effects data. A decision process for applying guidelines is provided and considers factors such as local modifiers, bioavailability and direct toxicity assessment. The reference-based guidelines commonly apply to physicochemical indicators and are based on long-term monitoring of unimpacted reference sites (e.g. monthly sampling over two years). Reference-based guidelines are best suited for areas and water types of similar nature to the reference sites. In some cases, where regional guidelines are not relevant, such as for ephemeral streams, local reference-based guidelines are usually required.

To choose water quality guideline numbers it is necessary to have an understanding of waterbody types. ANZECC/ARMCANZ (2000a) uses the following categories for reference-based trigger values: upland rivers; lowland rivers; freshwater lakes & reservoirs; wetlands; estuaries; marine (inshore and offshore). Default trigger values for toxicants, are classified as either freshwater or marine water.

The ANZECC/ARMCANZ (2000a) guidelines recommend considering locally developed guidelines trigger values in the national guidelines. For example, the Queensland Water Quality Guidelines (Qld EPA, 2006b) provide regionally specific, reference-based guidelines for Queensland areas and would be used instead of the national guidelines, where it is appropriate. The Queensland Water Quality Guidelines further split reference-based water types into upper, mid and lower estuary and split marine inshore into enclosed and open coastal waters for some regions.

The indicators that should be considered in the assessment will be affected by a number of factors including the environmental values and water quality objectives (discussed above) and the potential stressors and characteristics of the environment. Common indicators used to assess the condition of the aquatic environment under different stressors are shown in Table 2.6. Further information on choosing indicators can be obtained from the links provided in Table 2.7.

Table 2.6 Indicators commonly used to assess the condition of the aquatic environment under different stressors

Potential stressors	Typical indicators
Aquatic sediments (changed)	Animal or plant species abundance, sediment type, sedimentation/erosion rates, turbidity
Bacteria/pathogens	Pathogens/bacterial or protozoan counts
Biota removal/disturbance	Animal or plant species abundance, extent or distribution of subtidal macroalgae, extent/distribution of key habitat types, macroalgae, pest species (number, density, distribution), seagrass depth/range
Excess fresh water (hyposalinity)	Salinity
Excess salt (hypersalinity)	Salinity
Freshwater flow (changed)	Dissolved oxygen, extent/distribution of key habitat types, mouth opening or closing, sedimentation/erosion rates, stratification, water current patterns
Habitat removal/disturbance	Animal or plant species abundance, extent/distribution of key habitat types
Hydrodynamics (changed)	Dissolved oxygen, extent/distribution of key habitat types, mouth opening or closing, salinity, sedimentation/erosion rates, stratification, water current patterns
Litter	Presence or extent of litter
Nutrients (changed)	Algal blooms or chlorophyll a, animal or plant species abundance, benthic microalgae, dissolved oxygen, epiphytes, macroalgae, seagrass depth/ range, total nutrients in the sediment, total nutrients in the water column
Organic matter (changed)	Carbon balance, total organic carbon, biochemical oxygen demand, dissolved oxygen, sediment carbon, sediment oxygen demand
Pest species	Animal or plant species abundance, pest species (number, density, distribution)
pH (changed)	Animal or plant species abundance, pH or alkalinity of water, sediment pH
Toxicants	Toxicants in biota, toxicants in the sediments, toxicants in the water column, water-soluble toxicants in the water column, direct toxicity assessment
Water temperature (changed)	Algal blooms or chlorophyll a, animal or plant species abundance, benthic microalgae, carbon balance, coral bleaching, dissolved oxygen, epiphytes, extent or distribution of subtidal macroalgae, extent/distribution of key habitat types, macroalgae, pathogen counts, seagrass depth/range, sediment temperature, stratification, water current patterns, water temperature
Water aesthetics/Light climate (changed)	Algal blooms or chlorophyll a, animal or plant species abundance, benthic microalgae, clarity, colour, epiphytes, extent or distribution of subtidal macroalgae, extent/distribution of key habitat types, light regime, macroalgae, seagrass depth/range, visual/aesthetic change

Note: The indicators: benthic algae, epiphytes and macroalgae could include measures of biomass, diversity or health

Table 2.7 Key links to further information about choosing indicators

Document and related topics	**Key section of the document**
ANZECC/ARMCANZ (2000b)	
Checklist for selection of measurement parameters (indicators) (e.g. validity, diagnostic value, responsiveness, reliability, appropriateness).	Table 3.4
Physical and chemical measurement parameters.	3.5.1
Ecotoxicological assessment.	3.5.2
Ecological assessment – e.g. diversity indices, biotic indices, rapid biological assessment, functional feeding group measures, stream community metabolism (ratio of gross primary production to respiration).	3.5.3
Rapid biological assessment (RBA) based on macroinvertebrate abundance (the AusRivAS program).	Box
Scheltinga *et al.* (2004)	
Indicators framework for selecting indicators based on natural resource management (NRM) problems or issues and environmental stressors.	Section 3
Information on indicators, including: rationale, links to 'issues', detailed monitoring methods (e.g. frequency, data analysis), links to further indicators and matters for NRM targets.	Section 4

2.2.2 Conceptual understanding of the environment

It is generally accepted that an important task is conceptualising the system that will be assessed. Conceptualising the system may involve exploring sources of pollution in a catchment, pathways for pollutants into the aquatic system, known processes of breakdown or accumulation. For an EIA process water bodies potentially affected by the activity being explored should be included. For each water body, the environmental processes (e.g. flushing or stratification) need to be considered as they can vary significantly from case to case and will affect the assimilation of the pollutant.

One useful technique to assist conceptualising the system is to develop a conceptual diagram (also known as a conceptual model) such as in Figure 2.1. Often a conceptual diagram can be used to explain the assumptions or relationships between components simply and effectively to the user. Links to information about developing conceptual diagrams can be found in Table 2.4.

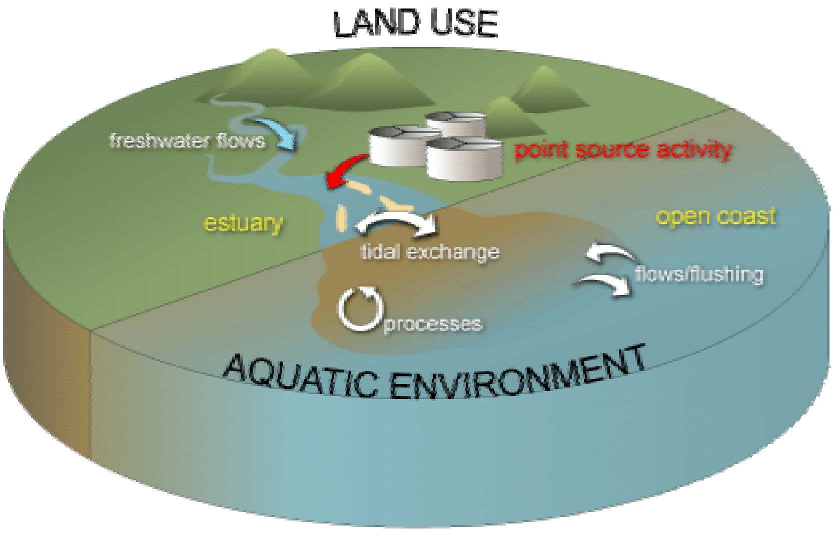

Figure 2.1 Example of a possible spatial analysis for assessment of a new activity that discharges to an estuary

The Coastal CRC has produced a number of conceptual diagrams and further information and examples of diagrams are available though http://www.coastalzone.org.au/ozcoast/infopages/models.html. The Wetlands Science-into-Policy Synthesis project produced conceptual diagrams capturing key wetland processes and threats agreed by managers and science experts. The project was shortlisted for Australia's biggest environmental award, the Banksia. The Coastal CRC also provides an online conceptual diagram builder through the link above where relevant icons can be dragged and dropped onto a base diagram and the diagram printed.

ANZECC/ARMCANZ 2000b (Section 2.4) provides information about designing conceptual diagrams and examples of different types of diagrams such as constituent cycling, chemical reactions and pathways and a mud map (spatial representation).

Useful tutorials in constructing conceptual diagrams are provided by the Integration and Application Network (IAN): http://ian.umces.edu. IAN provides over 1000 symbols and bases for compiling conceptual diagrams at no cost, as well as a forum for discussion and requesting custom-made diagrams.

Information on known physical, chemical or biological processes is important for an assessment and developing conceptual understanding. This may be available from generic information about specific water types (e.g. OzEstuaries), previous studies in the area or through consultation with experts. The major processes that affect water quality are broadly classified by the ANZECC/ARMCANZ

(2000b) monitoring guidelines as hydrodynamic, physical, chemical and biological and include:

- transport, flow, turbulence, flushing, mixing and stratification;
- precipitation, evaporation, wet and dry deposition;
- contaminant transport, sedimentation, burial, resuspension and diffusion; contaminant transformation, degradation, adsorption, desorption, precipitation, dissolution;
- sulfate reduction, methanogenesis organic diagenesis;
- bioturbation, bioirrigation;
- organism growth, primary productivity, grazing, succession;
- nutrient recycling, loss, transformation, recycling, ammonification, nitrification, denitrification.

The importance of key processes as well as techniques for the further investigation of key processes is discussed further in Addendum B.

BOX 1

Case study: Background*[0]*

Mike is an environmental officer from the Environmental Protection Authority. Mike has been contacted by a proponent who wants to build a new fruit and vegetable processing plant in the Applebee region. The proponent wants to discuss options for wastewater releases from the plant and the type of information they need to collect. They have some modelling data already but would like to do some further assessment, but do not know what type of assessments they need to undertake. Mike has decided to use the Decision Support System for Modelling and Monitoring Assessments, as well as his state policies and legislation, to help him advise the proponent.

Case study: Stage 1 – Assessment context

Mike has not had to assess many fruit and vegetable processing plants in the past. He examines the assessment context and sees that for fruit and vegetable processing plants organic matter is a key stressor—and likely to be of the greatest importance. But other stressors such as sediments, toxicants, changes to freshwater flow and changes to water temperature may need investigation. Mike looks at Addendum A and sees that direct measurement or mass balance equations could be useful for quantifying the potential loads to the environment. The quantities obviously depend on the processes used in the plant and the type of treatment being proposed. Mike encourages the proponent to have a clear understanding of their assessment objective. From discussions with the proponent it becomes clear that the assessment objective is to initially screen a number of alternatives for treatment and plant operation, based on water quality impacts.

Mike consults the ANZECC/ARMCANZ (2000b) guidelines to find the relevant default trigger values. He also checks whether the community in the area has assigned environmental values (EVs) and water quality objectives (WQOs) to that area. If there is something of great importance to the community and the health of the local waterways, then it should be considered for the development assessment. He does some further investigation and then records that EVs and WQOs have been determined for the area. The environmental values that were identified through the EV process in Applebee include aquatic ecosystems and recreation and aesthetics—particularly secondary contact and visual recreation.

Mike encourages the proponent to source latest science and at the same time Mike checks some of the online databases (provided in DSS) to find out what other science has been done. He finds that there is monitoring data and some remote sensing images for the region through Coastal CRC's Ozcoast website and the OzEstuaries database.

Mike also encourages the proponent to summarise current knowledge and subsequent gaps using a conceptual diagram of Applebee showing the region's important features, processes and management challenges. This also provides Mike with a basis for exploring the existing knowledge and explaining some of the issues to his supervisors.

3 Assessment selection

3.1 Introduction

A government officer may be asked to recommend or make comment on suitable assessment approaches prior to lodgment of development applications. Selecting from the many assessment techniques available can be an arduous task. Furthermore, there is often more than one approach or method that may be possible. This section provides information to assist in selecting or advising on suitable assessment options.

This document provides contextual information on modelling approaches and monitoring methods appropriate to water quality assessments. It includes:

- Six approaches for modelling hydrodynamics such as box models and one-, two- and three-dimensional models.
- Eighteen approaches for modelling water quality or water management situations (includes 13 process-based approaches and five non-process or statistical approaches), such as phytoplankton models, sediment transport models and empirical calculations.
- Nine monitoring and experimentation methods, such as human observation, *in situ* probes, remote sensing and laboratory experiments.

This section should only be considered after the assessment context is defined. For example, one important consideration is indicators and these need to be chosen carefully before choosing the assessment technique. Indicators to be assessed could be stressor indicators, structural indicators or process indicators. This section assumes these primary indicators to be assessed have already been decided and the subsequent step of selecting an assessment type then needs to be done. Note that this section is written as a guide to generate possible options rather than to select the single most suitable choice.

There are many ways to select a modelling approach or a monitoring method and this is discussed below. This section discusses choosing assessment options based on stressor indicators, structural indicators and process indicators, but these are not the only factors that may need to be considered. Selection of modelling approaches and selection of monitoring methods are discussed separately.

3.2 General guidance on choosing modelling approaches and monitoring and experimentation methods

There are many different things to consider when selecting a modelling approach or a monitoring and experimentation method. After the assessment context has been considered, it is important to consider what the key questions are that require further investigation. Taking a broad view and considering the many different options for modelling and monitoring and experimentation will ensure that an assessment program provides the required information.

In many cases, modelling approaches and monitoring methods have been chosen simply because they have been used before or are well known. This document aims to provide alternative ways of narrowing down assessment options, particularly coming from the management need.

Modelling software packages available on the market provide various combinations of processes or components and may be added to or particular functions ‘switched off’. However, all software packages have specific design requirements and limitations that may not be widely applicable to systems other than the ones they were designed for. There are many different factors to consider when selecting a model approach and the papers included in Table 1.1 of Addendum B are recommended reading for those wanting to learn about ecological modelling. These papers are also included in the MAMA DSS help system.

A good general rule is that a model should be the simplest possible representation of the system that captures all important features. In modelling terms, the word ‘parsimonious’ is used to describe the balance between the simplicity of the model versus the descriptive integrity of the model. It can be difficult to ascertain what level of complexity achieves this. By increasing the number of components and processes modelled, a higher level of conceptual realism can be achieved, but this comes at a cost; not only the cost of conceptual complexity, time and data required to set up and run the model, but also the cost of including an increased number of uncertain parameters in the model. Fulton *et al.* (2003) illustrate that the effectiveness of well designed ecological models in prediction may increase with complexity to a moderate level, but thereafter declines as complexity continues to increase. Perrin *et al.* (2001) also consider this problem and discuss it in mathematical terms. A model with a large number of parameters can achieve, with good calibration, a closer fit to any given set of observational data than a simpler model. This fit to the calibration dataset, however, is not necessarily reflected in improved predictive capacity—to the contrary, simpler models are often more readily applied to different conditions and more reliable in their predictions.

Data availability is a major consideration for model selection. All models require some data for setup, calibration and validation. In the absence of any data (and process understanding), physical models (also called experimentation in this report) may be the only option. Alternatively, gaining data required for modelling becomes an objective of the assessment and usually requires monitoring.

Certain monitoring methods may not be applicable to particular indicators or environmental situations. Also, spatial and temporal scales for data collection may mean that certain methods become more cost- and labour-effective.

The following sections discuss different ways of selecting water quality model approaches and monitoring/experimentation methods. This includes selection based on environmental stressors and issues and environmental indicators. Key processes of the system are also included for narrowing down hydrodynamic modelling options. The results are not meant to be prescriptive and may provide a number of possible recommendations. Further screening or research by the reader will be required.

3.3 Model approach selection

3.3.1 Modelling approaches overview

The modelling approaches discussed in this report are mathematical models (applied theories and assumptions used to derive mathematical relationships between variables). This report does not discuss in detail the differences between model characteristics except where relevant. The classifications were developed to group models together that aim to simulate similar processes and indicators or—in the case of statistical models—use the same general process to apply. This document does, however, distinguish between models designed to model hydrodynamics and those designed to model water quality or ‘biogeochemical’ processes or situations. These biogeochemical approaches are separated broadly into process-based approaches and non process-based (or statistical) approaches. Note that any of the water quality model types can be applied to any type of water body and combined with any hydrodynamic model type.

Mathematical models comprise applied theories and assumptions used to derive mathematical relationships between variables. In most cases, models are developed on a computer with a graphics component to represent these relationships and changes over time and space in a visual form. Models can be calibrated (or, in the case of statistical models, developed) using historical data from the real system and validated using independent additional data. These models have strong predictive power as they can reflect how changes in the system can be related to changes in inputs. This chapter introduces the broad mathematical modelling approaches commonly used for coastal waters. A general modelling glossary is included at the end of this document.

In this document, we use the term 'water quality' models to describe aquatic biogeochemical models—those that model biological, geological and chemical processes and components. Examples of approaches may include a range of variables such as nutrient concentrations, extent of macroalgae, dissolved oxygen concentrations, pH or transport of fish larvae. In this document, water quality models are most simply classified as process-based or non process-based models (Table 3.1). Although both types of approach are likely to be most valid within the range of data, process-based model approaches may have potentially greater predictive power than non-process model approaches, provided processes are captured accurately. Non-process model approaches have great potential in design and interpretation of monitoring data. It is important to be aware that any approach can incorporate parts or modules that use either a process or statistical base.

Table 3.1 Examples of model approach categories and the types of water quality models covered in Addendum B

Model characteristic classification	Model approach
Process-based	Simple transport, sediment transport, sediment water/nutrient, oxygen, NPZ, NPZC, NPZM, contaminant, pathogen, phytoplankton (population), population, food web, agent-based.
Non process-based	Empirical relationships, inverse nutrient, Bayesian belief networks, Fuzzy logic, artificial neural networks.
Hydrodynamic	Box and inverse exchange techniques, 1-dimensional horizontal, 1-dimensional vertical, 2-dimensional horizontal, 2-dimensional vertical, 3-dimensional.

3.3.2 Process-based models

Process-based water quality models simulate biogeochemical processes relevant to water quality. Process-based models predict water quality by starting with the initial conditions (e.g. concentrations at the start of the period being modelled) and simulating the effects of processes (such as denitrification, decay of detrital material and growth of algae) on those initial conditions.

Process-based water quality modelling approaches may be coupled with any hydrodynamic model approaches. Building process-based models requires an understanding of the important processes that control changes in water quality. As well as providing predictions, process-based models can help to quantify the roles of different processes, identify knowledge gaps, help guide water quality monitoring programs and verify the current understanding of the system functions. Process-based models require observational data for calibration and validation.

3.3.3 Non process-based models

Non process-based model approaches predict water quality through quantifying relationships between different water quality variables or between water quality variables and driving factors such as rainfall or temperature. Non-process approaches are developed by analysing observational data, usually without reference to the processes involved, except insofar as an understanding of processes can help to inform the types of variables included in the analysis. Non-process models sometimes draw attention to previously unnoticed relationships as well as providing predictions that can be used for management. Although expert knowledge can be (and usually is) incorporated into any modelling project, such as in parameter selection, non-process models can provide a structured way of including it. Bayesian belief networks, for example, provide a mechanism of incorporating expert knowledge and quantifying the likelihood of particular outcomes according to this collective knowledge (or belief).

3.3.4 Hydrodynamic models

Hydrodynamic models simulate the physical dynamics of water—i.e. flow and mixing—and provide (optional) structure for water quality models. Each hydrodynamic approach may also include models that simulate thermodynamics and the influence of salinity on density and hydrodynamics. The concentration of salt or changes in temperature may affect hydrodynamics by causing stratification or density-driven flows, in which case those variables/inputs need to be included.

The main outputs of a hydrodynamic model are velocity (true or average or exchange rates in a box model), depth and volume. A hydrodynamic model may also predict turbulence, mixing and bottom stress, which are important inputs for certain water quality models.

For more discussion of hydrodynamic models and the key factors for choosing hydrodynamic modelling approaches see Section 3.3.10 and Section 1.1 or Addendum B.

3.3.5 Modelling catchment processes and activities

Predictions are based on event mean concentrations or export rates from rainfall linked to land-use areas. Loads are generally only total nitrogen, total phosphorus and suspended sediment. Nutrient species are not included. These models are lumped (data is only related to time and is simplified by averaging over space) within a spatial grid or subcatchment area and not continuous (where data is related to space and time). Most catchment models provide only daily (such as EMSS) or longer (such as SedNet) time totals. Prediction can involve significant uncertainty and these models are best used for qualitative assessment given the limited options for validation. 'Back' calibration with hydrodynamic/ biogeochemical models or comparison of model outputs with flow and water quality observations from gauging stations may improve uncertainty.

Another form of catchment model is what could be called an activity model and is considered to be of a much smaller scale than a catchment model. Activity models could be categorised as those where an individual anthropogenic process or land-use activity is modelled. For example, the breakdown of nutrients in a sewage treatment plant and the related water quality throughout the treatment process could be modelled. Another example may be modelling of sediment and nutrient load export from a proposed housing development.

Catchment and activity models are not covered in any detail in this document. Links are provided to further information where applicable but more information can be found in Addendum D.

3.3.6 Selecting modelling approaches based on stressors

The potential stressors to the environment identified in Section 2 of this report should be considered further if a release or activity occurs without steps to mitigate potential impacts. The stressors used in the reports and included in the DSS are listed in Table 3.2. A stressor can be defined as 'a physical, chemical or biological component of the environment that, when changed by human or other activities, can result in degradation to the environment' (adapted from Scheltinga *et al.* 2004).

Generally, selecting modelling approaches would not occur without also considering indicators. Nonetheless, stressors are an important consideration in EIA-related studies as they ensure the assessment is focused on the specific key areas. Note that more than one may be required for the potential impact.

Definitions and further information for all terms in Table 3.2 can be found in Addendum B.

Table 3.2 Possible modelling approaches suitable for common environmental stressors

X = approach may be appropriate; blank cell = approach will rarely be appropriate (but may be in a few instances).

Stressor indicator	**Modelling approach**																		
	Hydrodynamic *	**Simple transport**	**Sediment transport**	**Sediment-water column**	**Dissolved oxygen**	**NPZ**	**NPZC**	**NPZM**	**Contaminant**	**Pathogen**	**Phytoplankton (population)**	**Population**	**Food web**	**Agent-based**	**Empirical**	**Inverse nutrient**	**Bayesian belief networks**	**Fuzzy logic**	**Artificial neural networks**
Aquatic sediments			X	X											X	X	X	X	X
Biota removal/ disturbance								X				X	X		X	X	X	X	X
Excess fresh water	X														X	X	X	X	X
Excess salt	X	X		X		X	X	X	X		X	X	X		X	X	X	X	X
Freshwater flow regime changed	X														X	X	X	X	X
Habitat removal/disturbance								X				X	X		X	X	X	X	X
Hydrodynamics changed	X	X													X	X	X	X	X
Litter		X													X	X	X	X	X
Nutrients						X	X	X	X		X		X		X	X	X	X	X
Organic matter			X	X	X	X	X	X							X	X	X	X	X
Pathogens		X								X					X	X	X	X	X
Pest species												X	X	X	X	X	X	X	X
pH changed				X			X		X			X		X	X	X	X	X	X
Toxicants		X							X						X	X	X	X	X
Water aesthetics/light climate changed		X		X				X				X	X		X	X	X	X	X
Water temperature changed	X			X	X	X	X	X	X			X	X		X	X	X	X	X

* Hydrodynamic model is included here to denote that the type of hydrodynamic model needs to be considered very carefully. For example, where salinity or temperature is an important factor for the particular indicator or stressor, effective modelling of hydrodynamic processes will be important.

3.3.7 Selecting modelling approaches based on environmental indicators

Selecting modelling approaches based on environmental indicators is probably the most common approach for EIA. Note that stressors, processes and issues involved may also affect the most suitable model approach for an application and these should also be considered (see other sections). Table 3.3 provides examples on modelling approaches suitable for different environmental indicators. The indicators in the table below have been gathered from Scheltinga *et al.* (2004) and ANZECC/ARMCANZ (2000b). Refer to Addendum B for details on each approach.

Table 3.3 Possible modelling approaches suitable for commonly used environmental indicators

C = approach or technique is commonly appropriate; P = possibly appropriate; blank cell = may not be appropriate.

Common environmental indicator	Modelling approach																	
	Simple transport	Sediment transport	Sediment-water column	Dissolved oxygen	NPZ	NPZC	NPZM	Contaminant	Pathogen	Phytoplankton	Population	Food web	Agent-based	Empirical	Inverse nutrient	Bayesian belief networks	Fuzzy logic	Artificial neural networks
Algal blooms or chlorophyll a			P		C	C	C			C		P		P	P	C	C	P
Animal or plant species abundance			P		P	P	C			P	C	C		P		P	P	P
Benthic microalgae		P	P				C				C	P		P		P	P	P
Carbon balance		C	C			C		P			C	P		P	P	P	P	P
Coral bleaching											C	P		P		C	C	P
Dissolved oxygen			P	C	C	P	P							P		P	P	P
Epiphytes		P	P				C				C	P		P		P	P	P
Extent/distribution of subtidal macroalgae			P				C				C	P		P		P	P	P
Extent/distribution of key habitat types		P			P		P	P		P	C	P		P		P	P	P
Light regime		P	P							P	P	P		P		P	P	P
Macroalgae			P				C				C	P		P		P	P	P
Mouth opening or closing		P												P		P	P	P
Pathogen counts	P								C					P	P	P	P	P
Pest species (number, density, distribution)	P						P			P	C	P	P	P	P	P	P	P
pH, alkalinity of water			P			C		C			P			P		P	p	P
Presence or extent of litter	P												P	P	P	P	P	P
Salinity	C		P	C	P	P	P	P		P	P	P		P	P	P	P	P
Seagrass depth/range			P				C			P	C	P		P		P	P	P
Sediment carbon			C	P		C				P				P	P	P	P	P
Sediment pH			P	P										P		P	P	P
Sediment temperature			P							P	P			P		P	P	P
Sediment type		P	P								P			P		P	P	P
Sedimentation/erosion rates		C	P											P		P	P	P
Stratification											P			P		P	P	P
Total nutrients in the sediment		P	C		P	P	P							P	P	P	P	P
Total nutrients in water column		P	C	C	C	C	C	P	P	C	P	P		P	P	P	P	P
Toxicants in biota		P	P					C			C	C	P	P	P	P	P	P
Toxicants in the sediments		C	P					C						P	P	P	P	P
Toxicants in the water			P					C				P		P	P	P	P	P
Turbidity (not due to phytoplankton blooms)		C									P			P		P	P	P
Visual/aesthetic change		P				C		C						P		P	P	P
Water current patterns	P	P	C	P	C	C	C	P	C	C	C	P		P		P	P	P
Water temperature											P			P		P	P	P

3.3.8 Selecting modelling approaches based on environmental processes

An understanding of key processes in the system can be particularly important when selecting a process-based model approach. For example, if uptake of toxicants by biota is important, particular algorithms, parameters and data will be required to model this process, and a contaminant model approach would probably be recommended. Table 3.4 provides guidance on selecting such approaches based on a range of physical, chemical or biological processes. The processes listed are included in Addendum B and the IWADSS. Refer to Addendum B for further details on each modelling approach. Further information on each process is included in Table B3.6 of Addendum B. Note that selection of a modelling approach for EIA may also require consideration of the stressor and structural indicators involved.

Table 3.4 Environmental processes commonly occurring in environmental systems and possible modelling approaches suitable for assessing them

A = all models (within this approach classification) include this process; M = most include this process; S = some include this process; R = process is rarely included.

Process to be modelled	Modelling approach												
	Simple transport	Sediment transport	Sediment-water column	Dissolved oxygen	NPZ	CNPZ	NPZM	Contaminant	Pathogen	Phytoplankton (population)	Population	Food web	Agent-based
Active movements of animals	S				S	S	S				S	S	S
Active vertical movements of phytoplankton					S	S	S			S			
Adsorption & desorption of dissolved nutrients (particularly phosphorus) onto suspended or settled solids			M		S	S	S						
Ammanox and dissimilatory nitrate reduction					R	R	R						
Bioaccumulation and uptake of constituents (contaminant and non-contaminant)			S		S	S	S	M		S		S	
Biochemical oxygen demand (BOD) plus CBOD, NBOD				M					S				
Biogeochemical currency												M	
Bioturbation (the effects of animals on sediments and release rates)			S										
Buoyancy of phytoplankton/pathogens									S	S			
Bubbling				S									
Burial of sediments/nutrients		S	S					M					
Chemical oxygen demand (COD)				S									
CO2 consumption by primary producers						S				S	S		
CO2 production due to respiration of plants and animals						S							
Contaminant effects on density of water								R					
Degradation and chemical breakdown								M					
Diffusion of dissolved substances between sediment pore water and the water column			S	S									
Effects of benthic and intertidal biota on sediment		R											
Entrainment		S											
Exchange of carbon dioxide with the atmosphere						S							
Flocculation, aggregation and coagulation		M											
General interactions between sediments and the water column			A		M	M	M	S					
Grazing of phytoplankton by zooplankton					M	M	M			S	S	M	
Growth, reproduction and mortality of macrophytes							A				S	S	S
Growth and mortality of animals							A				S	S	S
Hydrolysis and ammonification				M	M	M	M						
Light attenuation					M	M	M						
Mortality and/or respiration of zooplankton					A	A	A			S	S		
Nitrification and denitrification			A		M	M	M						
Nitrogen fixation					S	S	S						
Nutrient uptake by phytoplankton					A	A	A			A	S		
Nutrient uptake by benthic algae and rooted plants							S						

Table 3.4 (continued) Environmental processes commonly occurring in environmental systems and possible modelling approaches suitable for assessing them

A = all models (within this approach classification) include this process; M = most include this process; S = some include this process; R = process is rarely included.

Process to be modelled	Modelling approach												
	Simple transport	Sediment transport	Sediment-water column	Dissolved oxygen	NPZ	CNPZ	NPZM	Contaminant	Pathogen	Phytoplankton (population)	Population	Food web	Agent-based
Organic matter breakdown (mineralisation of organic material)			S	A	M	M	M						
Other chemical processes affecting redox state, sulphur and metals			S		S	S	S						
Oxygen transfer across the surface (re-aeration from the atmosphere)				S	S	S	S						
Photosynthesis				M	M	M	M				S	S	S
Physical transport, settling and resuspension of organic material and mixing			M	M									
Phytoplankton and pathogen loss process									A	S	S	M	
Phytoplankton growth					A	A	A			A	S	S	
Release and uptake of inorganic nutrients to or from the water column			A		M	M	M				S		
Respiration (animals and plants including phytoplankton)				S									
Resuspension of particulates		A	A		M	M	M	S		S			
Saltation		S											
Scouring		S											
Sediment oxygen demand (SOD)				M									
Settling of particulates		M	M		S	S	S	S	S				
Shoreline stranding	S							S					
Surface advection	S							S					
Survival or death of phytoplankton (or cyanobacterial akinetes) that have settled into the sediments			S							S			
Toxicology effects on biota								S					S
Transport of passive constituent	A												
Volatilisation (transformation to a gaseous state)								S					
Zooplankton growth					M	M	M				S		

3.3.9 Selecting modelling approaches based on environmental issues

Although environmental issues are less likely to be the primary driver for assessment of water quality, they could be a factor in selection. A modelling assessment is usually undertaken in response to awareness of a potential impact (such as nitrogen from a new discharge) or a known environmental issue (such as decline in condition, a marine pest invasion or an algal bloom). These latter issues are usually a result of existing pressures on the system. Table 3.5 shows a brief summary of typical environmental issues and the model approaches that may be used to assess them. There are often multiple approaches possible and the selection of the approach may depend on other factors not included in the table. Refer to Addendum B for details on each modelling approach.

Table 3.5 Possible modelling approaches suitable for different environmental issues

Environmental issue	Modelling approach*														
	Hydrodynamic *	**Simple transport**	**Sediment transport**	**Sediment-water column**	**Dissolved oxygen**	**NPZ**	**NPZC**	**NPZM**	**Contaminant**	**Pathogen**	**Phytoplankton (population)**	**Population**	**Food web**	**Agent-based**	**Non-process**
Algal blooms						X	X	X							X
Anoxic or hypoxic events					X										X
Contribution to greenhouse gases						X	X	X							X
Coral bleaching												X	X		X
Deoxygenation					X	X	X	X							X
Ecology or biodiversity						X[1]		X				X	X		X
Fisheries production								X					X	X	X
Flushing time/residence time	X	X													X
H2S (rotten egg gas)				X	X	X[2]									X
Harmful algal species (e.g. toxic blue-greens)						X[3]					X				X
Macroalgae extent/growth								X				X	X		X
Midges or mosquitoes	X[4]					X[5]						X			X
Nutrient incident/overflow				X		X	X	X	X			X	X		X
Organic matter incident/overflow			X	X	X	X	X	X	X						X
Oil spill		X		X					X						X
Predator-prey relationships												X	X	X	X
Saline discharge	X[6]	X										X			X
Seagrass cover								X					X		X
Shark attack (likelihood)														X	X
Siltation, erosion & river morphology changes			X												X
Spawning and recruitment (e.g. fish, prawns)		X												X	X
Stratification	X[7]														X
Temperature	X[8]			X	X	X	X	X	X	X		X	X		X
Tidal height/tidal propagation	X[9]														X
Turbidity (not due to phytoplankton blooms)			X												X

* All the non-process modelling approaches (e.g. empirical, Bayesian belief networks etc.) grouped together as non-process.

Footnotes: [1] Other work on linkages (e.g. relationships) required; [2] With sulphur cycle added; [3] With multiple phytoplankton groups; [4] To assess habitat ; [5] To assess productivity/food; [6] Including thermodynamics; [7] Hydrodynamic (1DV, 2DV or 3D) including thermodynamics; [8] Including thermodynamics, phytoplankton; [9] 1DH, 2DH or 3D.

3.3.10 Selecting hydrodynamic modelling assessments based on hydrodynamics

The hydrodynamics of a system being modelled are often an important model selection issue and needs to be considered for hydrodynamic modelling approaches and process-based water quality modelling approaches. In the simplest situations, a modelling assessment may involve just the use of a hydrodynamic model. This section includes general advice on selecting hydrodynamic modelling approaches using a decision tree (Figure 3.1). Table 3.6 presents a general guide for considering the level of hydrodynamic detail required depending on the waterbody type.

The key considerations for selecting a hydrodynamic model approach are choosing the spatial (dimensions), resolution (grid structure) and temporal (timesteps) factors. There is a trade-off between the detail of the hydrodynamic (and water quality, where relevant) processes simulated and the investment of time and computational effort.

Numerical hydrodynamic models usually divide the water body into a grid structure, with transport and mixing represented as exchanges of water between a grid cell and its neighbours. Hamilton *et al.* (1997) discuss useful criteria for selection of the number of spatial dimensions to include in water quality models. The decision tree in Figure 3.1 shows the detailed consideration required of a system to select the appropriate hydrodynamic modelling approach and related spatial dimensions.

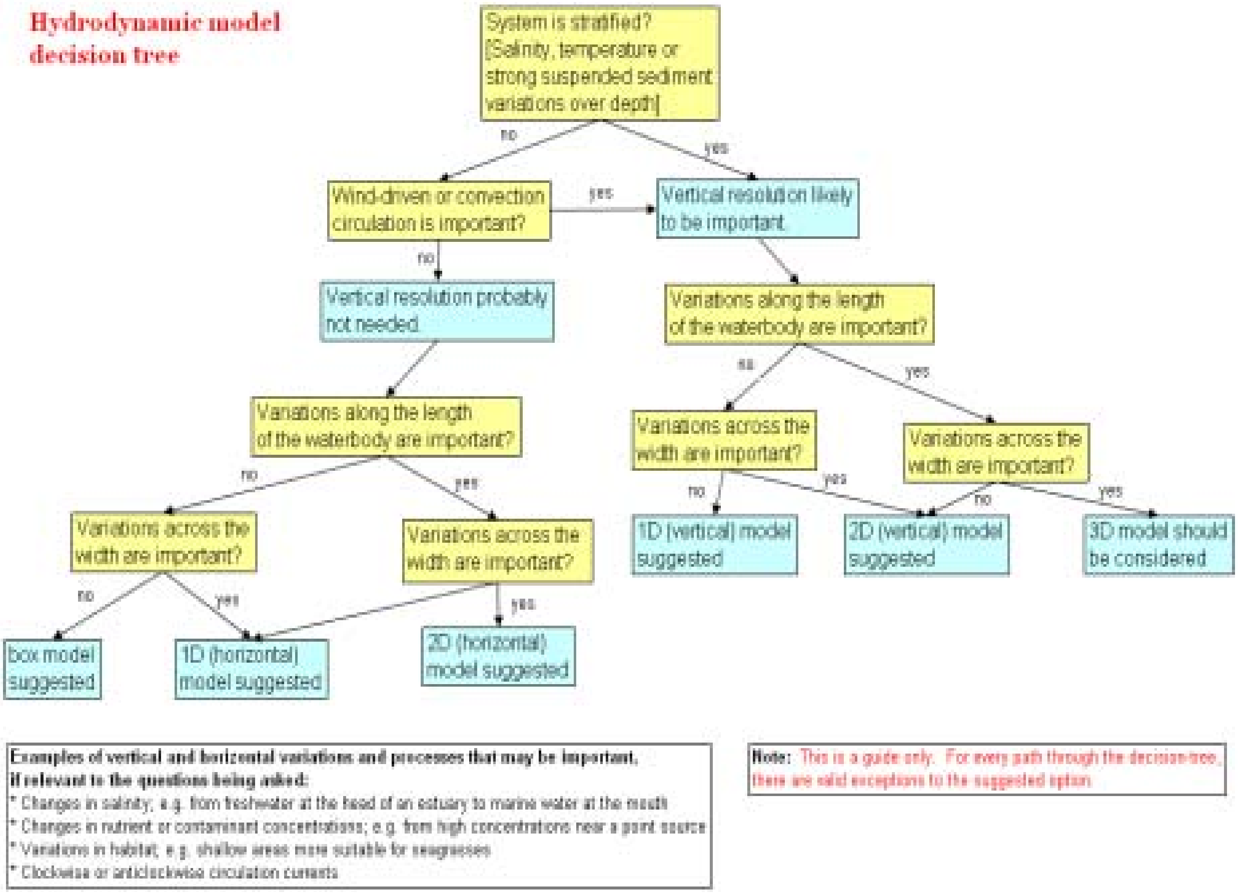

Figure 3.1 Decision tree for hydrodynamic model structure

The screening of a suitable hydrodynamic modelling approach may be based on understanding of waterbody types of the system rather than using the generic decision process shown in Figure 3.1, For example, 1D hydrodynamic models are often more applicable to estuaries than to embayments or open coastal waters. Table 3.6 presents generalised rules for the selection of hydrodynamic modelling approaches based on typical features of waterbody types around Australia.

Table 3.6 Possible hydrodynamic approaches for various water types

C = commonly appropriate, P = possibly appropriate (use caution: application-specific), L = less commonly appropriate (but may be in a few instances).

Water type	Hydrodynamic approach					
	Box and inverse	1DV	1DH	2DV	2DH	3D
Open coast	P	P	L	P	C	C
Embayment	P	P	L	P	C	C
Tide-driven estuary	P	L	C	C	C	C
Wind-driven estuary	P	C	L	C	P	C
Coastal lagoon	P	C	C	C	C	P
Tidal creek	P	L	C	P	C	P
Delta	P	L	P	L	C	C
Fresh water – riverine	L	L	C	C	C	C
Fresh water – lakes/dams	P	C	L	C	L	C
Fresh water – wetlands	C	P	P	C	C	C

The amount of time or computational effort available should also be considered but may not be as important as considering the important processes as discussed above. In general, the higher the resolution, the more time it takes to run a model. Higher resolution may mean more grid cells of smaller size, representing more dimensions. Using a higher resolution model may increase the accuracy but also increases the time required for the model to run (see Table 3.7). Higher resolutions may not be warranted if insufficient data is available to validate this level of detail.

Table 3.7 Relationship between resolution and run time for hydrodynamic options for an estuary 20 km long, 2 km wide and 10 m deep

Model dimension	Grid cell resolution		Multiplication factor for run time (run time = A)
	Grid cell length (m)	Grid cells	
1DH	100	200	A
	1000	20	0.1 x A
2DH	100 x 100	4000	20+ x A
3D	100 x 100 x 1	40,000+	200+ x A

Decreasing the timesteps (the equal time between each step of simulation) will also increase the time taken for the model to run. However, increasing timesteps may be limited by the numerical solving method as well as the management application.

Increasing the number of variables to be transported by the hydrodynamic model also increases the time taken for the model to run. A model that considers only salinity and momentum will be much faster than a similar model that also transports heat, oxygen, three or more phytoplankton groups, six different forms of nitrogen and phosphorus and a range of suspended solids types.

A model with high resolution, many variables and small timesteps (e.g. hourly) will therefore take the longest time to run. Although computer power is improving, the computer processing speeds can still be a factor to consider, particularly with large 3D models. Therefore, a user should choose a model considering all of these factors weighed against the needs of specific application.

Hydrodynamic approaches could be further analysed according to technical details of implementation such as grid structure (rectilinear versus curvilinear grids; sigma coordinate versus z-coordinate grids; Eulerian versus Lagrangian representations), turbulence closure algorithm or method of integration. The choices to be made at this level require significant expertise and experience in hydrodynamic modelling or mathematics. A full consideration or explanation of these divisions is beyond the scope of this document.

3.4 Monitoring and experimentation method selection

As the classification of monitoring methods is quite broad, further work will be required to refine the method to exact techniques or equipment. Table 3.8 outlines some sources for more detailed information on monitoring techniques, equipment such as probes and monitoring program design.

Table 3.8 Key links to further information about monitoring and experimentation programs

Source	Description	Specific reference
ANZECC/ARMCANZ (2000b) monitoring guidelines	Selecting sampling methods and different types of sampling equipment (e.g. bottles, pumps, grab samplers).	Sections 4.3 and 4.4
Scheltinga et al. (2004)	Monitoring method descriptions (e.g. location, frequency, approximate costs) for monitoring the indicators included.	Section 4
Alliance for Coastal Technologies web search engine	Specific sensors or probes can be researched based on physical, chemical and biological parameters as well as sensor type (e.g. fluorometer), platform (e.g. buoy or boat) or manufacturer.	http://www.act-us.info/tech_db.php
Coastal CRC Remote Sensing Toolkit and Coastal Water Habitat Mapping Toolkit	Information and decision support for choosing sensors suitable to different coastal environments and for seeing what environmental variables can be mapped with particular remote sensing techniques.	http://www.coastalzone.org.au/rstoolkit http://www.coastalzone.org.au/cwhm/toolkit
Environmental indicators for national state of the environment reporting – Estuaries and the sea	Recommended indicators for assessing the state of the environment. Includes description, rationale, methods and analysis.	Ward *et al.* (1998): http://www.ea.gov.au/soe/coasts/pubs/estuaries-ind.pdf

3.4.1 Monitoring and experimentation methods overview

'Water quality monitoring is the systematic and careful collection and analysis of samples, observations and *in situ* measurements with the aim of providing information and knowledge about a water body' (ANZECC/ARMCANZ, 2000b, p. 3, Summary document). Monitoring can obtain quantitative data to help in understanding a system, analysing trends and calibrating models that can then be used for predictive applications.

Monitoring and experimentation techniques used for assessments are generally described as a part of the monitoring design process. For example, ANZECC/ARMCANZ (2000b) outlines a monitoring process divided into setting monitoring program objectives, study design, field sampling program (which includes determining sampling methods such as field collection, autosampling or remote sensing), laboratory analysis, data analysis and interpretation. There is a substantial amount of information published to aid in designing monitoring programs.

This section focusses on selection based on environmental indicators or stressor indicators. Specific guidance based on stressor indicators is not provided but could provide useful information particularly for experimentation approaches.

Groups involved in monitoring the water environment use many different types of techniques. In addition to the parameters to be measured and the location or water type, techniques are often chosen based on prior experience or the popularity of the method. This document presents nine broad categories of monitoring and experimentation methods. The classification for methods has been designed to help decision-makers think broadly about the options available to them. In this way, different or emerging methods may be considered as a possible option.

These categories are discussed briefly in Table 3.9 and in more detail in Addendum C.

Table 3.9 Monitoring and experimentation methods discussed in this report

Method	Description	Examples
Human observations	The human observation category includes data observations collected through visual observation and human judgment.	Estimates of ground cover; estimates of wind speed or cloud cover; and identification of species numbers.
Probe in situ	A very common approach to monitoring, the probe in situ category includes any electronic device that can be used to measure the level of an indicator instantaneously while in the field.	Temperature, conductivity, turbidity, pH and dissolved oxygen probes such as a Hydrolab™ multi-parameter probe.
Field tests (non-probe)	Field tests (non-probe) are classified here as chemically or biologically based tests carried out in the field to measure some indicators (not using electronic probes).	Portable laboratory equipment such as turbidimeters, spectrophotometers, simple presence/absence techniques for faecal contamination such as the H2S paper test, litmus paper test for pH and Winkler titration kits for dissolved oxygen.
Visual recording and sonar	The main focus of this category is recording to capture still or moving images of the water and related features within the field using predominantly photographic, video, radar or sonar techniques. The images are often analysed later.	Recording of coral transects in the field to determine species coverage.
Sample and analysis	This common approach relies on a sample being physically extracted from the field and analysed or identified at a later time, typically in a laboratory.	Collection of algae for $^{\delta}$N analysis.
Autosample and analysis	Automatic sampling devices automatically take samples on a time or flow basis and need to be located next to the sampling location. Samples are generally stored in the device until later analysed, typically within a laboratory.	
Remote sensing	This approach covers monitoring using digital sensor imagery (photography or digital) from aircraft or satellites.	Chlorophyll a concentration, coloured dissolved organic matter (CDOM) , total suspended matter (Tripton), algal blooms
In situ experiments	Experiments are carried out in situ while manipulating certain conditions or stressors or adding chemicals to the environment. Field experiments can also isolate specific processes occurring in specific areas.	Stream shading can be increased (by removing vegetation) or decreased (using shade cloths) to determine the effects of the light climate.
Laboratory experiments	In this approach, samples are taken from the field and tested in a controlled laboratory environment that seeks to mimic field conditions, while removing effects of other factors, such as diurnal fluctuations of temperature. Laboratory experiments can be done to test physical, chemical and biological processes and responses.	Recording algal growth in response to different nutrients.

3.4.2 Selecting monitoring or experimentation methods based on environmental indicators

Selection of monitoring and experimentation methods based on structural indicators is probably the most commonly used, although consideration of stressors and processes may also help (not provided in this report). The environmental indicators of interest typically vary depending on the pressures on the system as well as the values or characteristics of the environment being assessed (see Section 2.2). Table 3.10 provides guidance on selecting monitoring and experimentation methods covered in this document based on common environmental indicators. Refer to Addendum C for details on each approach.

Scheltinga *et al.* (2004) provides further information on types of monitoring.

Table 3.10 Suitable monitoring and experimentation methods used to assess common environmental indicators

C = method is commonly applicable; P = it is possibly applicable; blank cell = method is unlikely to be applicable or rarely used.

Common environmental indicators	Monitoring or experimentation method								
	Human observation	**Probe (*in situ*)**	**Field tests (non-probe)**	**Visual recording & sonar**	**Sample & analysis**	**Auto-sample & analysis**	**Remote sensing**	***In situ* experiment**	**Laboratory experiment**
Algal blooms or chlorophyll a	C	C	C	C	C		C	P	C
Animal or plant species abundance	C		C		C			C	C
Benthic microalgae	P			C	C		C	P	C
Carbon balance					C	C	P		
Coral bleaching	P			C				P	C
Dissolved oxygen		C	C					P	C
Epiphytes	P			C	C		C	P	C
Extent/distribution of subtidal macroalgae	C	C	C		C		C		
Extent/distribution of key habitat types	C		C	P			C		
Light regime	C	C			C		C		P
Macroalgae	P			C	C		C	P	C
Mouth opening or closing	C	C		P			C		
Pathogen counts		C	C		C		C		C
Pest species (number, density, distribution)			C		C			C	C
pH, alkalinity of water		C	C		C			P	C
Presence or extent of litter	C			P			P		
Salinity		C	C		C	C		P	P
Seagrass: depth, range	C	C	C	C	C	C		C	P
Sediment carbon					C	C	P	P	C
Sediment pH		C	C		C			P	C
Sedimentation/erosion rates		P		P	C	C	C		P
Sediment temperature	C	C	C				C	P	C
Sediment type	C			C	P		C		P
Stratification	C	C	C	P			C		C
Total nutrients in the sediment			C		C	C		C	C
Total nutrients in the water column			C		C	C		C	C
Toxicants in biota			C		C	C		C	C
Toxicants in the sediment			C		C	C		C	C
Toxicants in the water			C		C	C		C	C
Turbidity (not due to phytoplankton blooms)	C	C		C			C		P
Visual/aesthetic change	C		C	C	C		C		P
Water current patterns	C	C	C	P			C		P
Water temperature		C	C				C	P	P

3.4.3 Selecting monitoring or experimentation methods based on stressors

A monitoring assessment may be undertaken in response to awareness of a potential stressor on a system. Table 3.11 summarises typical environmental stressors and the monitoring and experimentation methods that may be used to assess them (Scheltinga *et al.* 2004). There are often multiple methods possible and the selection of the approach may depend on other factors not included in the table such as the specific structural indicators of interest. Refer to Addendum C for details on each approach.

Generally, selecting monitoring methods would not occur without considering structural indicators. Nonetheless, stressor indicators may be an important consideration in an EIA-related assessment to help choose similar methods to address multiple stressors. There may be a number of advantages (such as cost and logistics) to using the same monitoring method. Even for a single stressor, it provides a way of exploring alternative methods without the detail or knowledge of specific structural indicators.

Table 3.11 Possible monitoring and experimentation methods typically suitable for different environmental stressors

X = method is commonly applicable; blank cell = method is uncommon.

Stressor indicators	Monitoring or experimentation method								
	Human observation	Probe (in situ)	Field tests (non-probe)	Visual recording & sonar	Sample & analysis	Auto-sample & analysis	Remote sensing	In situ experiments	Laboratory experiments
Aquatic sediments		X		X	X		X	X	X
Biota removal/ disturbance	X			X	X		X	X	X
Excess freshwater		X			X	X			
Excess salt	X	X			X	X			
Freshwater flow regime changed		X	X		X				
Habitat removal/disturbance	X			X			X	X	X
Hydrodynamics changed		X			X			X	
Litter	X			X			X		
Nutrients		X			X	X	X	X	X
Organic matter			X		X	X	X	X	
Pathogens			X		X	X		X	
Pest species	X				X		X	X	X
pH changed		X	X		X			X	X
Toxicants		X	X		X	X		X	X
Water aesthetics/light climate changed	X	X	X	X			X	X	X
Water temperature changed		X				X	X	X	X

BOX 2

Case study: Stage 2 – Choose assessment

By using some of the key stressors obtained from reviewing the assessment context section of the *Decision support for modelling and monitoring assessments* report (nutrients, pH changed, pathogens, toxicants and organic matter), Mike is able to look at the assessment options for environmental stressors. He is presented with possible modelling approaches and monitoring and experimentation methods.

Mike then investigates the further information on each modelling approach and monitoring method using Addendums B and C, respectively. He notes where some of the other projects have used nutrient-phytoplankton-zooplankton models.

Mike also sees that remote sensing is an option for looking at organic matter.

4 Reviewing assessment

4.1 Introduction

This section provides information to assist the process of reviewing water quality assessments that use modelling approaches and monitoring methods. Reviewing of assessments will generally occur after the assessment is completed and a report or other information has been produced.

This section should only be used in conjunction with Section 2 of this document on assessment context. In particular, an understanding of the activity, potential stressors involved and the environmental values, water quality objectives and indicators is essential. The assessment objective is another important part of the assessment context, discussed briefly here. Background information on modelling approaches and monitoring and experimentation methods is provided in Section 3. Reviewing modelling and monitoring/experimentation assessments is discussed separately and a list of review questions is provided for each. The approach/method categories are not exhaustive and more detailed guidance will generally also be required.

4.2 Reviewing modelling assessments

There is limited published information that will assist with reviewing a modelling assessment. This section provides broad guidance that is largely focussed on process-based models, although it will LAO provide some guidance for non process-based (statistical) models, as similar scrutiny is required although different terminology is usually used. The user should work through each of the questions listed in Table 4.1 and explained in the following sections to determine how well they are addressed for each assessment. General information provided in Addendum B should also be considered for reviewing modelling assessments.

Table 4.1 Checklist for reviewing water quality *modelling* assessments

1.	Has the model been verified to ensure that calculations are correct?
2.	What setting-up data was used? Check initial conditions, boundary conditions and other input data.
3.	Check the spatial scale and grid size for the model. Are they appropriate for the application?
4.	Are the timescales and timesteps used appropriate?
5.	Is the approach used suitable for the assessment context?
6.	Is the approach used suitable for the stressors, environmental indicators, process indicators and hydrodynamics involved?
7.	If the software used is an off-the-shelf package, is it suitable for the application?
8.	Has the model been adequately calibrated? What variables are predicted well?
9.	Are the parameters used appropriate? Was a sensitivity analysis undertaken?
10.	Was the model validated on an independent data set? What variables are predicted well?
11.	What scenarios are used for the simulations? Is the baseline appropriate?
12.	What conclusions are made? Are these valid given model assumptions and uncertainty?

4.2.1 Assessment context

The suitability of a modelling approach will be determined by the assessment context. The type of activity being assessed and the nature of the release will affect the assessment. For example, continuous release from a sewage treatment plant will be assessed differently to event-based release from a mine. Similarly, the potential stressors from the activity need to be assessed. Understanding the assessment objective is important as it affects the scope of the work. For example, an objective to screen a number of options may require a less sophisticated or validated model than one that is used to predict quantitative environmental impacts.

The environmental considerations should also be reviewed and the environmental values and water quality objectives for the system will affect the indicators and spatial context of the assessment. The suitability of the monitoring assessment will also be underpinned by conceptual understanding of the system, particularly in relation to important physical, chemical and biological processes. This is particularly important for process modelling. In this case, information on the conceptual representation of the system should also be provided to the person assessing the modelling application.

4.2.2 Stressors, indicators, processes and hydrodynamics

The suitability of the model approach used should be checked against each of the key stressors, indicators, processes and hydrodynamics involved or of interest. Tables 2.3 to 2.7 should be used to check this suitability. Based on the conceptual understanding of the system and the specific model approach application, a number of assumptions will apply. These assumptions should be noted including the implications for use of the model and suitability for simulating particular stressors, indicators or process models and hydrodynamic condition. These are important when interpreting data and drawing conclusions from the results of the assessment.

Note that the time taken for a model to run is important, not only because it places a practical limit on the resolution of the model and the number of scenarios that can be run, but also because calibration may require the model to be run many times. Short run times also allow repeated runs to facilitate estimates of uncertainty in the model predictions, to indicate which parameters or algorithms the model is most sensitive to, or to provide a probabilistic analysis of the risk of unfavourable outcomes. Recommending greater variables and parameters to be modelled and simulating more indicators and processes may increase simulation length and time.

4.2.3 Software coding

Table B3.7 in Addendum B provides a general classification of modelling software that is commonly used in Australia. The Council for Regulatory Environmental Modeling (CREM) within the US EPA also provides access to information on over 100 models through:
<http://cfpub.epa.gov/crem/knowledge_base/knowbase.cfm#overview>.

This table may also assist in trying to check the adequate application of software for quality assurance purposes. Note that in many cases, model code is changed to suit the application it is being used for, and further investigation on how the modelling was carried out may be required.

4.2.4 Model verification

Model verification can mean different things to different people. Here we use verification to mean a process to determine if the numerical model or computer model is a true representation of the model developer's conceptual description and specification and associated mathematical model. In one sense, we are asking: are the equations programmed and used correctly? Assessing this requires using sound and established software engineering techniques. For commercially available software and previously developed software, information on verification may already be documented. For newly developed software, model verification may be of greater importance. Regardless, information on verification can be requested.

4.2.5 Set-up data including initial conditions, boundary conditions and other input data

Set-up data is required to define bathymetry (shape of stream bed or ocean floor) within the model, provide initial conditions, boundary conditions and input data.

Boundary conditions are needed to describe the inputs to the models over the time period of the simulation at the boundaries of the model system. They may be tides, heights, flows and water quality data. Depending on the boundaries of the model, these may be from catchment runoff, tidal or non-tidal streams and seaward boundaries. Point source discharges could also be considered as a boundary condition or may be called input data. Data are also sometimes provided by other models (e.g. nested models, catchment models etc.) or measurements (e.g. tidal gauges). The source and reliability of each should be checked.

Initial conditions are required for all variables spatially throughout the system at the start of a model run. This may include water quality concentrations and water depth. The model may be run for a period of time from these initial conditions with constant inputs to obtain an appropriate 'steady-state' condition (variables not changing with time) that could then be used as the new initial conditions. An important question may be whether the simulation was sufficiently at steady state at the beginning of the scenario runs.

4.2.6 Spatial scale and grid size

The appropriate spatial scale of the model application will usually depend on management context, the assessment objectives and the conceptualisation of the system. For example, the assessment in close proximity to an activity, often called the 'near field', may be used for designing diffusers or assessing the extent of mixing zones of contaminants. These models are often conservative and mainly take into account mixing effects only. Small grid sizes are generally used. Models simulating further distance from an activity, often called 'far field', may be used in systems not well flushed to determine potential changes to environmental indicators. Assimilation due to biological or chemical processes is generally more important in this case. Larger grid sizes are usually used.

Consideration of simulation time is important when choosing spatial scale and grid size. Some models are run ‘nested’ together so that only a small part of the model needs to be run each time, thus saving simulation time. This is generally accepted practice as long as the changes caused by the nesting process do not significantly affect the results. Recommendations for simulating greater spatial extent and more detailed grid size should consider the effect on simulation time.

4.2.7 Timescales and timesteps

Timescales should be assessed for their suitability. Models should ideally be calibrated and validated over the timescale of interest for simulations—longer if possible. For example, a model intended to predict seasonal and interannual variations should be tested against field observations (at least monthly, preferably weekly) covering at least one year, but preferably enough to cover the episodic nature or flow—perhaps at least one ‘wet’ and one ‘dry’ year. Simulation runs should also start at steady-state conditions.

The length of the timestep used by a numerical model depends on the timescales of the physical (and biogeochemical) processes involved. Timesteps used in hydrodynamic models vary from around a minute to an hour, although box models used to drive simple water quality models may use a timestep of a day, a week or even more. Shorter timesteps are needed where the system is highly variable over time; such as if there are sharp gradients in density or concentrations of dissolved substances over a year due to large rainfall fluxes. Using a timestep that is too long can lead to numerical instability and errors in the model. Sophisticated hydrodynamic model software will choose a timestep automatically and vary the timestep as needed during the model run. Consideration of simulation time is also important when making recommendations on scale and timesteps.

4.2.8 Model calibration

Calibration refers to the process of fitting parameter values to achieve the best possible model results. More specifically, this involves comparing model output to measured data and adjusting model parameters and coefficients to improve the model fit while maintaining the realism (and integrity) of the model and its output. An issue is which parameters have been adjusted or fitted to achieve this. Most commonly, this calibration process is done by trial and error, by comparing the results of one or a few runs at a time and depends a great deal on the expertise and experience of the person doing the calibration. If the run time of the model is sufficiently short (such as may be the case for a box model or a 1DV model), sophisticated statistical techniques can be used to provide a more robust calibration. Generally, due to the number of parameters and long simulation times, these techniques are rarely applied. One possible approach is to greatly reduce the resolution of the simulation by decreasing the number of grid points used—an example of this approach (Chaloupka 2001) can be seen at<http://www.coastal.crc.org.au/bremer/ecosystem_dynamics.html>. Calibration procedures and results should be provided and show visual comparison of fits and the data used. (Request if not provided.)

Hydrodynamic model calibration may involve comparing water levels, current speeds and directions, salinity measurements and dye tracking data. Tidal heights and flows are normally used to achieve calibration for the tidal cycle. Important consideration for calibration includes location and number of data points, accuracy of calibration, testing of dimensionality where appropriate, required level of agreement and the degree of adjustment needed. Typically, the model resolution, the bathymetry and floor roughness coefficient are adjusted to improve agreement. The quality of the hydrodynamic model transport can be assessed and optimised by comparison between predicted and observed salinities, dye tracking experiments and, in some cases, by comparison between predicted and observed values for a constituent which can be considered to be passive (such as in a simple transport water quality model approach).

For calibration, it is important to choose parameters that are set up to change with all likely scenarios. For example, salinity is often used as a calibration parameter; however in some cases this is not appropriate, such as in the application of the model RMA11 in south-east Queensland (Bell & Amghar, 2001). This model could capture *either* the recovery of salinity in the estuaries after a flood event *or* the steady-state salinity profile in the estuaries, but not both, as different coastal processes were occurring in the two cases. This meant that salinity could not be used as a calibration parameter in that study.

Water quality model calibration may involve comparing water quality related variables throughout the model area. Seasonal variation or wet/dry condition can be important for certain variables. The reaction rates and coefficients in model equations are typically adjusted to improve agreement. Model inputs from point source discharges and catchment runoff need to be specified accurately to allow agreement. Each of the factors can (and should be) checked.

4.2.9 Parameters and sensitivity testing

A model can usually be fitted to measured data by adjusting parameters. In general, the less parameters are adjusted from previous application, the more confidence can be obtained from the model application. If parameters are adjusted during calibration, they should not be outside an acceptable range. A list of some parameters available from Chapra (1997) and Bowie *et al.* (1985) is provided in Table B3.9, of Addendum B. Parameter values can in some cases be defined by field and laboratory process studies of the system being simulated, but in general must be calibrated within a range known from previous studies to be reasonable.

If little information is available on parameters—that is, if they have unclear upper and lower limits—sensitivity analysis may be used. Sensitivity analysis is a systematic process of adjusting parameter values (adjusted within their expected values) and monitoring how the model results vary (its sensitivity). Sensitivity analysis provides information on the implications of setting parameters at high or low levels on other model variables. In some cases, model outputs may not be sensitive to changes in particular parameter values in which case the set value of the parameter will not be critical. In other cases, the model outputs will be much more affected by parameter values.

Many hydrodynamic models include calibrated diffusivity and roughness coefficients that will vary between water bodies while sediment transport models may have several parameters that need to be adjusted. These parameters represent elements that may vary (or there is variation in the reported values) and cannot be calculated from first principles. Biogeochemical or water quality models may include anything from a couple to a few hundred different parameters, reflecting the greater complexity and uncertainty of biological and ecological processes compared to purely physical processes. In this case, the selection of suitable parameters for calibration requires a judicious approach. It is also important to check the model sensitivity to both boundary and initial conditions.

Parameter values can in some cases be defined by field and laboratory process studies of the system being simulated, but in general must be calibrated within a range known from previous studies to be reasonable. The selection of suitable parameters can be greatly assisted by conducting a sensitivity analysis. This provides an indication of which parameters will cause the greatest (and conversely the least) change in model output and may then be targeted as important parameters for calibration. It is important to check the model sensitivity to both boundary and initial conditions.

4.2.10 Model validation

Model validation is the process of demonstrating the accuracy of the model by checking the model's predictions against observations of the real system. Generally, validation should not involve adjustment of parameters. More important than for calibration, the data used for validation should reflect the timescales, periods and important environmental changes required for the assessment. Validation procedures and results should be provided to allow for checking of model performance and data sets used.

A model with many parameters that has been calibrated and validated against a week-long data set during a dry season is unlikely to perform well when used to simulate a period of several years, including flood events. A proper model validation should ideally include as many of the variables that the model simulates as possible and should use a separate set of data than that used for model calibration. Unfortunately, given the limited data often available and the strong data requirements for calibration of biogeochemical models, validation against an independent data set is surprisingly uncommon. Planning in advance to get efficient validation data should be considered.

4.2.11 Scenario application

Scenarios are sets of different conditions run by the model to represent different management actions or environmental conditions. Each scenario has a different set of input data used to represent and test various hypothetical or real situations. The results of each scenario are typically compared to one another or a baseline scenario that is typically the current or *status quo* situation. Often, the baseline scenario results are validated. The input data for each scenario should be checked along with the source of this data. The data may be, for example, worst-case maximums for toxicants or long-term averages for nutrients. The data may be from design-estimated, pilot-scale or modelled data. Sophisticated activity models are available to simulate wastewater treatment plants, industrial processes and catchment load export and may provide the most reliable (or only) source of input data for receiving environment models. Evidence of calibration and validation of these models should also be obtained and documented where appropriate.

It is important that outputs of the models are presented in a clear and transparent fashion to allow easy interpretation. Depending on the purpose of the assessment, the appropriate data may be extracted from the full dataset. The spatial location and time periods for presented results are important decisions and may depend on the guidelines, water quality objectives or other benchmarks used to assess outputs. All key variables of interest should be presented in graphical or tabular form.

4.2.12 Conclusions

The conclusions of the study should be checked against the assumptions and limitation of the model and the accuracy inferred from calibration and validation (i.e. errors and uncertainty). In the absence of validation the results may be unfounded. In this case, results may only be suitable for qualitative comparisons of management options at best. For process models, if the model does not include key processes related to a certain water quality parameter then it is unlikely predictions will be accurate (this can usually be checked by looking at calibration and validation results). For non process-based methods, application will generally be limited by data for fitting and have limitations for predicting into the future.

4.3 Reviewing monitoring and experimentation assessments

The section is provided to help guide the process of reviewing water quality monitoring and experimentation assessments. There is very little published literature designed to assist with such assessments. Most publications focus on the design and application, such as the *National guidelines for monitoring* (ANZECC/ARMCANZ 2000b) and the *Users' guide for indicators* (Scheltinga *et al.* 2004). Nonetheless, these documents may assist with the review and are referred to where appropriate in this section.

Table 4.2 shows a list of questions to be considered when reviewing a monitoring and experimentation assessment. Further information on each of these is subsequently provided.

Table 4.2 Checklist for reviewing water quality *monitoring* assessments

1. Is the assessment suitable for the management context?
2. Is the method used suitable for the stressors, indicators, processes and water types involved?
3. Check the spatial boundaries, scale and duration of the assessment: Are they appropriate for the application?
4. What is the frequency and sample site variability? Are there sufficient sampling sites?
5. What quality assurance/quality control measures have been used (e.g. sampling protocols, training and competency, sample integrity, controls and data storage)? Is this documented? Are they appropriate? Were recommendations from these QA/QC procedures implemented? Has calibration and error analysis for the technique been undertaken?
6. What data analysis and interpretation method is used? Are these appropriate and have they been applied properly?
7. What conclusions are made? Are these valid given monitoring and experimental assumptions and errors involved?

4.3.1 Management context

The suitability of a monitoring and experimentation assessment will be determined by the assessment context. The type of activity being assessed and the nature of the release will affect the assessment. For example, continuous release from a sewage treatment plant will be assessed differently to event-based release from a mine. Similarly, the potential stressors from the activity need to be assessed and will influence the indicators that need to be measured. Understanding the assessment objective is an important factor as it affects the scope of the work. For example, an objective to investigate the cause of specific water quality issues may have a very different spatial and temporal focus compared to an objective to identify trends in the condition of a water body.

Other assessment objectives may also be adopted for the specific purpose of designing the program—such as choosing the number of sites or site locations—and would involve short-term, spatially intensive sampling. The environmental considerations should also be reviewed and the environmental values and water quality objectives for the system should be clearly defined, as these will determine appropriate indicators and locations. The suitability of the indicators assessed, particularly in experimentation studies, will also be underpinned by conceptual understanding of the system in relation to important physical, chemical and biological processes.

Table 4.3 shows the applicability of methods to different time frames.

Table 4.3 Typical application of monitoring and experimentation approaches for different assessment time frames

C = commonly applicable; P = possible, depends on application)

Timing	Human observations	Probe (*in situ*)	Field tests (non-probe)	Visual recording and sonar	Sample and analysis	Autosample and analysis	Remote sensing	Experiment (*in situ*)	Experiment (laboratory)
Past					P		P	P	P
Current	C	C	C	C	C	C	C	C	C
Future								C	C

4.3.2 Stressors, indicators, processes and water types involved

The suitability of the monitoring and experimentation method should be checked against the stressors and relevant indicators and/or processes. In many cases, the method or techniques will obviously be suitable. However, in some cases this will be as straightforward, for example, with remote sensing. To check suitability, refer to Table 3.10 for environmental indicators and Table 3.11 for environmental stressors. It should be noted that environmental processes and water types involved can also affect the suitability of monitoring and experimentation assessments even though no information is provided in this report on these areas.

Based on the conceptualisation of the system and the specific monitoring method application, a number of assumptions may apply. These assumptions should be noted, including the implications for use of the monitoring. These are important when making conclusions on the results of the assessment.

Refer to Addendum C for further information.

4.3.3 Spatial boundaries, scale and duration

The *National guidelines for monitoring* (ANZECC/ARMCANZ 2000b) state that the spatial boundaries are important because inappropriate boundaries might focus the study away from important driving or consequential factors. For investigations into the effects of catchment activities on rivers, lakes and estuaries, for example, the spatial boundaries would normally be those of the catchment. A study may include tributary creeks or the broader catchment or be restricted to the major receiving waters. The logic behind any decision to restrict spatial boundaries of the study should be clearly explained.

The spatial and temporal ranges over which a system is monitored should be set by the appropriate level of resolution to answer the questions of concern. Different hydrodynamic, physical, chemical and biological processes operate at different scales. Major considerations other than the assessment objectives include scale of the phenomenon under investigation, the spatial and temporal uniformity of measurements, the amount of samples (replicates) required to provide statistical confidence. Any request for further sampling should consider the likelihood of collecting reliable and valid measurements and the cost of data collection at that scale.

The duration of the study will be affected by the variability of the release, the assessment objectives (e.g. focus on seasonality or dry/wet weather, current condition versus long-term trend), the natural variability and the statistical confidence required for assessment. For determining reference site condition, the *National guidelines for water quality* (ANZECC/ARMCANZ 2000a) suggest a minimum of two years of monthly samples.

Refer to Section 3.3 of ANZECC/ARMCANZ (2000b) and Section 4 in Scheltinga *et al.* (2004) for more information on spatial boundaries, scale and duration.

4.3.4 Frequency and sample site variability

The guidelines for monitoring (ANZECC/ARMCANZ, 2000b) state that both temporal and spatial heterogeneity is probably the most significant aspect to consider in the design of sampling programs. Variability of data will determine the number of sites, number of replicates and the frequency of sample collection. Limited sample collection often results in data that are too variable to reveal an impact, disturbance or trend.

The guidelines for monitoring list the following causes of variation:

- spatial variability because the environment is heterogeneous
- time dependence, temporal, seasonal effects
- disruptive processes
- dispersion of chemical contaminants.

It is typical for any ongoing monitoring program to have a pilot study, with a short period of spatially and temporally intensive monitoring to determine the nature of the system and temporal and spatial variability. A representative profile of the system should be provided by the subsequent sampling regime and frequency for each measurement indicator. The numbers of replicate samples should provide the precision required for the statistical analyses.

The guidelines for monitoring state that the pattern of sampling in space and time is very important. Major considerations include the need and use of random sampling, representativeness during sampling and a sampling method that minimises errors. These and other sampling issues are discussed further in the guidelines.

Further information on patterns of sampling, sample site selection and sample frequency are provided in Section 3.4 of ANZECC/ARMCANZ (2000b) and Section 4 of Scheltinga *et al.* (2004).

4.3.5 Quality assurance, quality control and documentation

Quality assurance (QA) and quality control (QC) are an essential part of any monitoring program. They apply to sample taking, analysis (whether *in situ* or in the laboratory) and to data management and reporting.

Quality issues for sampling include sampling protocols, sample containers, sample preservation and storage, use of blanks or controls, standards and documentation. These issues are discussed in detail in Chapter 4 of the guidelines for monitoring (ANZECC/ARMCANZ, 2000b). Similar issues apply to laboratory analysis and include methods choice, traceability of results, certified reference materials and internal evaluation samples, proficiency testing and performance audits. Accreditation authority or other types of certification can be obtained for individual analytical techniques or overall sampling and laboratory procedures. The National Association of Testing Authorities (NATA) is Australia's national laboratory accreditation authority providing accreditation to internationally recognised standards. QA/QC in laboratory analysis is discussed in more detail in Section 5.5 of ANZECC/ARMCANZ (2000b) guidelines for monitoring.

The procedures and equipment used for both sampling and analysis are very important to undertaking monitoring and experimentation. Procedures may be based on national standards or equipment-specific procedures, and equipment relates both to probes/sensors and meters for *in situ* measurement or laboratory equipment for sample analysis. The suitability and accuracy of equipment should be checked along with the suitability or limitations of procedures used. Refer to Sections 4.2, 4.3 and 5.3 in the guidelines for monitoring (ANZECC/ARMCANZ, 2000b) and Section 4 in Scheltinga *et al.* (2004) for more information.

Calibration checks and estimates of measurement error are listed separated here even though typically an integral part of the QA/QC process. The reason for this is that they should be considered carefully when reviewing interpretation of data. Viewing control charts can be a useful way of checking this. Further information on measurement errors for analytical protocols is provided in Section 5.5.5 of (ANZECC/ARMCANZ, 2000a) guidelines for water quality.

4.3.6 Data analysis and interpretation

Data analysis and interpretation is underpinned by statistical methods commonly used for the analysis of water quality data. Chapter 6 of the guidelines for monitoring (ANZECC/ARMCANZ, 2000b) provides a useful introduction to data analysis and interpretation. Key considerations may include data preparation, censored data, data integrity, data reduction, data visualisation, control charting, data coercion (transformations), checking distributional assumptions, trend detection and smoothing. Other important parts of statistical analysis include inference (e.g. testing hypotheses or comparing to guidelines), exploring relationships or looking at changes in space and time. Technical details of more advanced statistical procedures are provided in Appendix 5 of ANZECC/ARMCANZ (2000b) guidelines for monitoring. Section 4 of the users' guide for indicators Scheltinga *et al.* (2004) also provides useful information on data analysis and interpretation.

4.3.7 Assessment conclusions

The conclusions of the study should be checked against the assumptions and limitations of the monitoring assessment and the errors and uncertainty involved. For descriptive studies that test conditions against water quality guidelines, the ANZECC/ARMCANZ (2000a) guidelines for water quality recommend a minimum of two years of monthly data. For studies that measure change, often significantly more data will be required. Regardless, valid control or reference sites data is required to interpret change. In the case of monitoring human activities, data prior to the change (also called pre-disturbance data) is essential.

BOX 3

Case study: Stage 3 – Review assessment

Mike receives an environmental assessment of a new desalination plant and using the decision support system to aid his review of the work, particularly in terms of a release of brine (concentrated sea water).

He steps through the checklist for the monitoring. From the information provided he realises one of the major processes and likely impacts will come from poor mixing and stratification as a result of the release. He notes that the monitoring program does not include much work on water quality profiles.

Glossary

Calibration: Calibration refers to the process of fitting parameter values to achieve the best possible model results (within the range known to be realistic). More specifically, this involves comparing model output to measured data and adjusting model parameters and coefficients to improve the model fit while maintaining the realism (and integrity) of the model and its output.

Coastal lagoon: A small, shallow basin that has very low (or negligible) freshwater input.

Conceptual diagram: A statement of the content and internal representations which are the user's/developer's concept of the system to be modelled. It may include logic and algorithms and explicitly recognise assumptions and limitations.

Delta: A river that is directly connected to the sea via a channel(s). It may be either tide-dominated or wave-dominated.

Embayment: Typically comprises a bedrock-lined coastal indentation.

Freshwater lake/dam: Surface waters that receive freshwater flows only from local rainfall and groundwater.

Freshwater river: Non-marine waters that flow in one direction at least part of the time. They can be permanent or ephemeral, wide or narrow, deep or shallow, straight or sinuous, have open or confined floodplains or, as in many cases, be a combination of many styles in different parts of the system. During dry periods, rivers can be reduced to a series of disconnected pools, while during wet periods, the main river channel connects to the floodplains, billabongs and riverine wetlands. In many rivers and streams, groundwater discharge contributes substantially to base flow. From *Australia state of the environment report 2001*(Australian Government 2002)

Freshwater wetland: Wetlands include swamps, marshes, billabongs, lakes, saltmarshes, mudflats, mangroves, coral reefs, fens, peat lands or bodies of water—whether natural or artificial, permanent or temporary. Water within these areas can be static or flowing, fresh, brackish or saline (http://www.deh.gov.au/water/wetlands/about.html). A summary of different definitions used around Australia (and internationally for the Ramsar Convention) are provided at: <http://www.deh.gov.au/water/policy/incentive/appendix2.html>.

Open coast: Marine water bodies that are in direct contact with major ocean currents (for continental Australia these are the East Australian Current, the Leeuwin Current and the South Equatorial Current) and that are little influenced by coastal landforms such as embayments, estuaries and deltas. Using the OzEstuaries framework, open coast could be thought of as the area oceanward from the inner continental shelf (which is the area from the shore to the mid-shelf and is up to 50 m in depth).

Tide-driven estuary: A bedrock coastal embayment that has been partially infilled by sediment, in which tidal currents are the dominant force shaping the gross geomorphology.

Wind-driven estuary: A bedrock coastal embayment that has been partially infilled by sediment, in which waves are the dominant force shaping the gross geomorphology.

Tidal creek: Wide, funnel-shaped coastal waterways that have very low (or negligible) freshwater input.

Validation: Model validation is the process of demonstrating the accuracy of a model by checking the model's predictions against observations of the real system. Generally, validation should not involve adjustment of parameters. More important than for calibration, the data used for validation should reflect the timescales, periods and important environmental changes required for the assessment. A proper model validation should ideally use an independent data set than that used for model calibration, although in practice this is often not possible.

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