National Water Quality Management Strategy

No. 7a

AUSTRALIAN GUIDELINES FOR WATER QUALITY MONITORING AND REPORTING

Summary

October 2000

Australian and New Zealand Environment and Conservation Council

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Contents

NOTE: The chapters of this Summary document briefly cover the same information as the corresponding chapters of the main Monitoring Guidelines. In this Summary, the main headings within each chapter are taken from the framework diagram in that chapter, while the minor headings are taken from the checklist for that chapter in the main document. Cross-references are provided to corresponding sections of the main document: e.g. MG 3.2.3 refers to section 3.2.3 (which is in Chapter 3) of the main Monitoring Guidelines; MG section A4.2 is in Appendix 4, and so on.

Acknowledgments

The document is a summary of the *Australian Guidelines for Water Quality Monitoring and Reporting.* As such, the acknowledgements for both documents are similar and are given in the main document.

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Preamble

The National Water Quality Management Strategy

The *Australian Guidelines for Water Quality Monitoring and Reporting* is a benchmark document of the National Water Quality Management Strategy (NWQMS). The NWQMS is a nationally agreed set of policies, processes and guidelines being developed jointly by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australian and New Zealand Environment and Conservation Council (ANZECC).

The NWQMS has also been endorsed by the Council of Australian Governments (COAG; see the Monitoring Guidelines Appendix 2), which represents all three levels of government in Australia. This endorsement includes the establishment of appropriate water quality monitoring and catchment management policies and community consultation.

The policy objective of the NWQMS is:

> to achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development.

The NWQMS covers 21 guideline documents (see Table 1 and MG Appendix 1).

Water Quality and Monitoring

Worldwide, the quality of surface and groundwater, estuarine and marine waters tends to decline because of human activities. Concerted management and action by government, community and industry can reduce or reverse the decline in water quality, and that is the basis of Australia's NWQMS.

Water quality must be measured (monitored) regularly and the results analysed, interpreted, reported and acted upon to achieve effective concerted management. Water quality monitoring is necessary to:

- reinforce environment protection policies and programs, and help control pollution;
- underpin the State of the Environment reporting and National Audit reporting;
- develop water quality standards and guidelines against which to assess monitoring data.

Australian Guidelines for Water Quality Monitoring and Reporting

The *Australian Guidelines for Water Quality Monitoring and Reporting* (the Monitoring Guidelines) provides a comprehensive framework and guidance for the monitoring and reporting of the quality of fresh and marine waters and groundwater. The document does not discuss drinking water, wastewater and effluents; they are covered by separate NWQMS guidelines documents. It should be used with other NWQMS documents, especially the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (the Water Quality Guidelines) technical paper no. 4 in the NWQMS series. Standard reference works and documented in-house procedures should also be consulted and followed, subject to strict attention to relevant criteria for quality assurance and quality control, and any monitoring programs resulting from the use of this Guidelines document should be consistent with relevant local and state regulations and by-laws.

To be continuously relevant to its users, the *Australian Guidelines for Water Quality Monitoring and Reporting* (the Monitoring Guidelines) and this summary version, like other NWQMS benchmark documents, will require ongoing review and revision. The present version was current up to October 2000. Users are invited to comment on the *Australian Guidelines for Water Quality Monitoring and Reporting* by contacting the offices listed at left. These addresses can also receive comments on the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (the Water Quality Guidelines), so users should name the document to which their comments apply.

Table 1. Technical papers of the National Water Quality Management Strategy, by category

Policies and Process for Water Quality Management	
Paper no. 1.	*Water Quality Management — An Outline of the Policies*
Paper no. 2.	*Policies and Principles — A Reference Document*
Paper no. 3.	*Implementation Guidelines*
Water Quality Benchmarks	
Paper no. 4.	*Australian and New Zealand Guidelines for Fresh and Marine Water Quality*
Paper no. 4a.	*An Introduction to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality*[S]
Paper no. 5.	*Australian Drinking Water Guidelines — Summary*
Paper no. 6.	*Australian Drinking Water Guidelines*
Paper no. 7.	*Australian Guidelines for Water Quality Monitoring and Reporting*
Paper no. 7a.	*Australian Guidelines for Water Quality Monitoring and Reporting — Summary*[S]
Groundwater Management	
Paper no. 8.	*Guidelines for Groundwater Protection*
Guidelines for Diffuse and Point Sources*	
Paper no. 9.	*Rural Land Uses and Water Quality — A Community Resource Document*
Paper no. 10.	*Guidelines for Urban Stormwater Management*
Paper no. 11.	*Guidelines for Sewerage Systems — Effluent Management*
Paper no. 12.	*Guidelines for Sewerage Systems — Acceptance of Trade Waste (Industrial Waste)*
Paper no. 13.	*Guidelines for Sewerage Systems — Sludge (Biosolids) Management*[#]
Paper no. 14.	*Guidelines for Sewerage Systems — Use of Reclaimed Water*
Paper no. 15.	*Guidelines for Sewerage Systems — Sewerage System Overflows*[#]
Paper no. 16a.	*Effluent Management Guidelines for Dairy Sheds*
Paper no. 16b.	*Effluent Management Guidelines for Dairy Processing Plants*
Paper no. 17.	*Effluent Management Guidelines for Intensive Piggeries*
Paper no. 18.	*Effluent Management Guidelines for Aqueous Wool Scouring and Carbonising*
Paper no. 19.	*Effluent Management Guidelines for Tanning and Related Industries in Australia*
Paper no. 20.	*Effluent Management Guidelines for Australian Wineries and Distilleries*

*The guidelines for diffuse and point sources are national guidelines that aim to ensure high levels of environmental protection that are broadly consistent across Australia.

[#]Paper not yet released in final form

[S]This document is available with its main document, but not as a separate item.

1. Water Quality Monitoring: Introduction

It is important that water quality be monitored so that water resources can be managed fairly, contaminants and their effects can be detected and controlled, and environmental protection policies and programs can be assessed. State of the Environment reporting and National Audit reporting rely on information provided by monitoring programs. Water quality guidelines and standards can only be developed with data from monitoring. The sampling of natural waters and waters that receive urban and industrial discharges, so as to measure their quality and compare it with water quality guidelines, is a form of monitoring and may refer back to the results of previous monitoring exercises.

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. An effective monitoring program is designed to measure and report on, or provide understanding about, a particular situation or set of issues; it is carefully planned initially, to ensure its objectives are achieved.

Monitoring programs are run by state and local government bodies, industrial groups and independent consultants, the community (Waterwatch) and research or management groups from universities and Commonwealth agencies (see MG Appendix 3). A national framework has been developed for monitoring water quality and for reporting the outcomes, with the aim of improving water monitoring in Australia and helping the programs be more consistent with each other. Then monitoring data can be compared across regions and over time, to save money and build up ‘the big picture’.

Community monitoring of water quality

Community monitoring of water quality occurs throughout Australia.

Waterwatch Australia is a national network of more than 50 000 people who share a vision of healthy waterways. Waterwatch promotes water quality monitoring as a tool to involve the Australian community in land and water management at the local and catchment scales.

Community-collected data are collated using a Waterwatch Australia Data Management System, and can be used for teaching students about healthy waterways, as an early warning of water quality problems, or for State of the Environment reporting.

Waterwatch Australia is an umbrella program providing a national focus for the states’ community monitoring programs.

Regional coordinators have been appointed to assist community groups to collect water quality data, to provide a focal point for the collation and interpretation of data and to facilitate the feeding of the collected information into local and catchment management planning processes, and provide training and support to the rest of the community. Contact details are provided in the main Monitoring Guidelines (see MG section A3.4).

Water quality investigations are expensive and few organisations have the resources to monitor over a large geographical area or a long period of time. Resources have to be targeted to meet specific regional needs. Ideally, each monitoring program is set up in awareness of and in cooperation with other past and present monitoring programs across the country. The resulting information can then be compared, integrated or collated to report trends. For example, many data for environmental indicators for the State of the Environment reporting process are available from data sets managed by Commonwealth, state and territory agencies and data sets managed by Environment Australia. However, consistent national protocols and methods are needed to ensure the data can be interpreted easily. The Monitoring Guidelines can assist in the collection of such data.

The components of the monitoring program design need to be interactive to ensure that the information is delivered in the required form and is correct and timely, and that the program is cost-effective. At all stages of a monitoring program, the monitoring team should be checking back to the objectives — looking at the results in the light of the objectives and vice versa. Then, if necessary, the program should be reassessed. There should not be a simple unthinking progression from the initially-set objectives to the final reports.

The Monitoring Guidelines: Summary

This document is a summary of the *Australian Guidelines for Water Quality Monitoring and Reporting* (the Monitoring Guidelines). Both this summary and the main Monitoring Guidelines set out a framework that leads the reader through all aspects of a monitoring program: setting monitoring program objectives; designing monitoring studies and an effective sampling program; the laboratory analyses; the choice of suitable data analyses in conjunction with monitoring and sampling program design; and reporting of the results and conclusions. Four case studies illustrate the monitoring process for river, groundwater, estuarine and marine situations.

The design of monitoring programs should be iterative: each of the elements needs to be refined as other elements are considered. The framework diagram below sets out the sequence of topics dealt with in chapters 2–7 of both this summary and the main Monitoring Guidelines.

The intention has been to make the Summary a brief but practical guide, while the main Monitoring Guidelines provides background discussion as well as practical guidance. Unlike the main document, the text of the Summary's chapters is arranged as an expanded checklist, based on the items in the checklists provided in the main document grouped under major headings taken from the framework diagrams. Therefore, many of the subsection headings differ between the two documents.

The Monitoring Guidelines has been written for use by personnel with at least basic technical training in all levels of government, water authorities, consultant groups, tertiary institutions and industry, and in community groups including the Waterwatch program. It is based on current best practice monitoring approaches, so will continually need updating as statistical, field and laboratory approaches change.

The Monitoring Guidelines is not intended to be a prescriptive document; rather, it describes approaches and attitudes that have been shown to be effective in water quality monitoring; it offers guidance only.

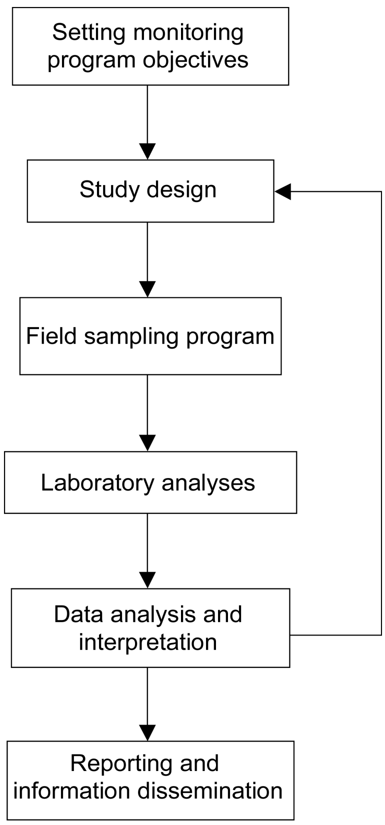

Figure 1. Framework for a water quality monitoring program

2. Setting Monitoring Program Objectives

When a monitoring team plans a water quality investigation or monitoring program, it must state its objectives clearly; otherwise it will not be able to fully address the more detailed questions of how to undertake the investigation. The objective of an effective monitoring program is to provide information and knowledge about an issue, preferably for the least cost, to inform those who have commissioned and will use the data. The diagram below shows a suitable process for setting objectives.

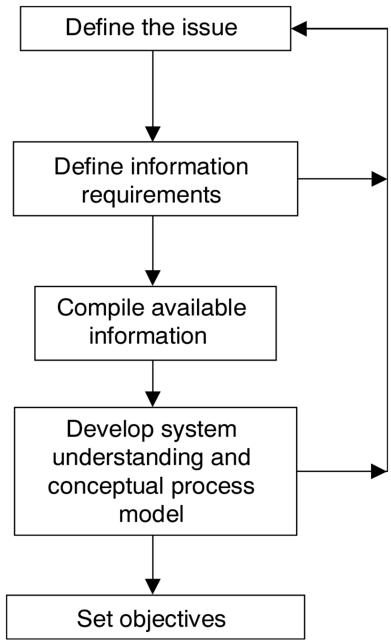

Figure 2. Framework for setting monitoring program objectives

Checklist and Framework for Determining Information Needs and Monitoring Program Objectives

Define the Issue (see MG 2.2)

What problem has caused the monitoring program to be planned? Underlying the problem are the *issues* or questions that must be tackled. Water quality management issues in Australia typically fall into four categories:

- the long-term management, protection and restoration of aquatic ecosystems so they can fulfil their environmental values;
- contaminants, their sources and fates in aquatic ecosystems, the magnitude of the problem and the actions that need to be taken to protect the environmental values;
- the performance of management strategies;
- conformity with water quality guidelines.

These sorts of issues have driven many monitoring programs in the past.

Many monitoring programs have set out to collect information relevant to the environmental values (formerly called 'beneficial uses') of a water body. 'Environmental values' is the general term for the uses that can be made of a waterbody: e.g. for drinking, for urban water needs, as water supply for primary industries (irrigation, stock drinking water, agriculture and aquaculture), for recreational use and aesthetics, and for aquatic ecosystems.

Define the Information Requirements

Have the identities of all the information users been ascertained, so that information is obtained that will address all the stakeholders' needs?

The stakeholders are all those people who have an interest in the waterbody or the monitoring program. They include the end-users of the information and those who commission the monitoring program, and the monitoring team itself. Other stakeholders may be individual residents, community groups, industry groups, a government jurisdiction; they may be found in the local area or downstream or upstream of the area where there is a problem.

Discussions with the stakeholders should aim to identify the information they require about the waterbody. Perhaps they want to know how to stop algal blooms forming locally, or perhaps the fishing has declined in recent years, damaging tourism. Examination of the information requirements should enable the underlying issues for this monitoring program to be identified or narrowed down.

Compile Available Information (see MG 2.3)

Has all the available information relating to the issue or problem been collected, checked, and put into a common form?

After determining the issues that underlie the monitoring program, the next step is to collect the available information relating to the issue at hand. Depending on the issue, this step could entail a review of relevant previous monitoring information collected either for the site of interest or for other locations. Other information could come from interviews and observations and evidence gathered by members of the local community. A third source of information, for example, could be a comprehensive survey of current international understanding as described in the media (including media archives) or in books and journals.

Have knowledge gaps been identified and the information obtained, or have the limitations and restrictions of not having that information been evaluated?

Does the knowledge assembled from the previous step make a rounded picture of the waterbody? If not, the gaps need to be identified and filled if possible. If the information is not available, how well can the monitoring team function without it?

Has an analysis been undertaken to identify the essential information required?

Now, the monitoring team begins to decide upon the particular questions that the program must tackle. These become the objectives of the monitoring program. This step is only really possible if the team has some preliminary understanding of the ecosystem they are working on. That understanding can initially be derived from the information they have just collected, and it is best formalised in a conceptual process model of the system being examined.

Develop System Understanding and Conceptual Process Model (see MG 2.4)

Has a shared conceptual process model of the system been developed and made explicit?

A conceptual process model can form the basis of the proposed monitoring study because, while designing it, the team members identify the unique key processes of the system they will monitor. The processes define the relationships such as 'cause and effect' and 'how the system works'. The major processes that affect water quality 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 dominant processes may change as the previous processes reach some limiting condition. Different flow, mixing, chemical and redox regimes will turn alternate processes on and off.

The conceptual process model need only be a simple box diagram that illustrates the components and linkages in the system to be monitored (see MG 2.4.1 for pictorial examples of conceptual models). The model presents the factors that are perceived to be driving the changes in the system and the consequences of changes to these factors.

Conceptual process models are important in defining the 'why' questions. They illustrate the monitoring team's knowledge of an aquatic system. Conceptual models can be particularly powerful when the monitoring team argues about them and therefore comes to a shared understanding of the ecosystem that is the basis for the study.

Have the assumptions underlying the model been made explicit?

Has the monitoring team articulated the assumptions underlying the model? Has it identified the gaps in information supporting these assumptions? Incorrect assumptions may lead to incorrect conclusions being drawn about information needs.

It is important to be aware that the conceptual model being used might be wrong, and also that data that seem inconsistent can be important. The conceptual process models should be modified as information is collected and reviewed. The assumptions underlying the notional conceptual model should be validated and, if necessary, the model should be changed to reflect any new perspectives.

Set Objectives (see MG 2.5)

Specific objectives

Monitoring of waters is commonly undertaken to meet one of the following general objectives:

- to measure the quality of ambient freshwater or marine water;
- to provide assurance that the water meets appropriate guidelines for its designated use;
- to investigate why the water may not be meeting such guidelines;
- to assess the loads of materials entering the water body from the catchment (export studies);
- to assess the loads of materials carried past various points, the transformations of materials and the rates of loss in-stream or over-bank, so that streamflow mass balances can be calculated;
- to characterise the biota within a river, estuary or coastal marine water body;
- to assess biological productivity;
- to assess the state of the resource as defined by a variety of measurement parameters or indicators (State of the Environment reporting, and National Audit reporting);
- to assess the effectiveness of actions for contaminant control, or restoration or rehabilitation of waters;
- to identify trends in the condition of the water body.

Are the objectives clear and concisely defined?

Once the monitoring team has defined the issue for monitoring, and agreed upon a conceptual process model, and, as a result, has further refined its understanding of the information that needs to be collected and why, it can finally write down a set of monitoring objectives that are specific and precise, measurable, result-oriented, realistic and attainable, meaningful, concise and clear, and understandable.

A monitoring objective can be framed as a hypothesis and based on a conceptual process model. The monitoring program can then test the hypothesis. This applies particularly to cause and effect studies, but a hypothesis can underpin monitoring for comparison with regulatory standards, and even State of the Environment monitoring. Hypothesis testing is actually a test of the conceptual model.

Hypotheses usually take the form of statements or suppositions based on available facts that can be subjected to a statistical evaluation after further data have been obtained, to determine whether they can be accepted (or rejected). It is not considered essential to formulate a hypothesis (see MG 6.4.2). The monitoring team must decide whether it will set hypotheses or not, because this decision will affect the data that need to be collected.

Do the objectives specify what is to be achieved, and indicate when each stage is complete?

The development of useful objectives requires practice and experience. Typical objectives relating to nutrient dynamics and effects in aquatic systems might be these:

- to determine annual phosphorus loads to a specified lake from surface inflows, groundwater and sediment release (where the conceptual model has decided that all these sources are important);
- to determine the frequency of blue–green algal blooms in a number of specified water bodies over a defined period;
- to determine annual nutrient exports from a specified catchment to a specified river system.

A typical objective with respect to contaminants might be this:

- to determine if contaminant concentrations being released to a river under base flow from a specific industrial activity are exceeding water quality guideline trigger values[1] for the protection of aquatic ecosystems in the receiving waters beyond the mixing zone.

Note that the objective does not specify details such as sampling season or sampling frequency. Those are matters for the next stage, study design.

The setting of objectives commonly addresses management issues as well. This means that the resource manager needs to be involved in the negotiation of the monitoring program objectives. The resource manager must understand how the information to be collected will be used in the decision making process. If the only resources that the manager can make available are insufficient to meet the set objectives of the monitoring program, the program is not worth undertaking. The objectives may be rethought and more realistic objectives set.

Examples

(a) The Logan–Albert catchment case study provides one example of actual issues and resulting objectives (see MG section A4.2.1). An investigation of the aquifer that supplies groundwater to part of south-east Queensland was begun because the Logan–Albert catchment is being subjected to increasing pressure as a direct result of population growth. The objectives were to establish benchmark groundwater quality conditions for use in subsequent monitoring, to identify and understand the processes degrading groundwater quality in the aquifer, and to integrate the information obtained and provide advice to the responsible natural resource managers.

(b) Another example is the Great Barrier Reef case study (see MG section A4.4.1). In the last 140 years total nutrient input has increased by about 30% and this excess of nutrients has the long-term potential to damage the fragile ecosystem that exists within the Great Barrier Reef. The major objective of a long-term monitoring program set up by the Great Barrier Reef Marine Park Authority in 1992 was to investigate the long-term trends and regional differences in nutrient status of the waters that comprise the world's largest reef ecosystem.

[1] The revised Water Quality Guidelines (*Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, see Table 1, page 2), describes the use of guideline trigger values for assessing water quality for some uses.

3. Study Design

The study-design stage involves a series of linked decisions that formulate a detailed study design. This is a fundamental set of steps that ensures that the sampling and analysis programs are cost-effective, and also specifies data requirements. It takes place before sample collection starts, and again involves interaction with the end-users of information.

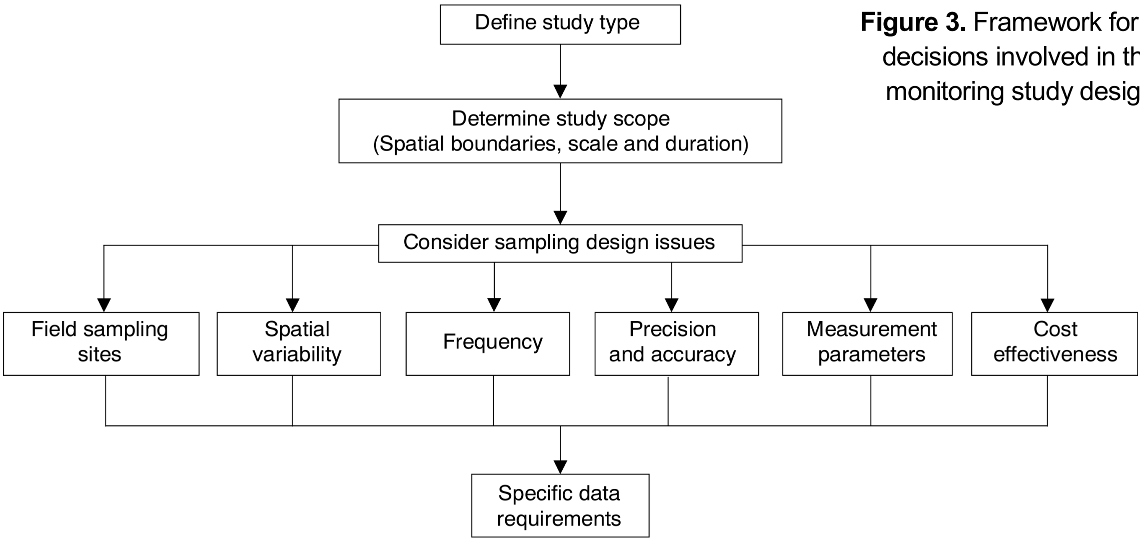

Figure 3. Framework for the decisions involved in the monitoring study design

Checklist and Framework for Designing a Monitoring Study

Define Study Type (see MG 3.2)

Has the study type been made explicit and agreed upon?

Three distinct study types can be identified: (i) descriptive studies; (ii) studies that measure change; (iii) studies that improve system understanding.

Descriptive studies gather data to document the state of a system. Typically they measure the distributions of constituents through a water body at various times. Monitoring for testing against a water quality guideline can be a descriptive study.

Descriptive studies repeated several times at the same locations can measure change or environmental impact. Typical study designs that measure change are the BACI (before–after control–impact) group (see MG 3.2.2.1). Other studies are designed to infer change by comparing the one site at different times, or different sites at the same time. All these study designs compare the values of parameters measured at both undisturbed sites and disturbed sites and draw inferences from the differences. Inferences should not be based solely on changes over time or changes over space unless there are no valid control or reference sites or pre-disturbance data.

Studies for system understanding aim to find out more about a particular system; for example, to better understand aquatic ecosystems and the physical, chemical and biological processes that operate in them (see MG 3.2.3). Sampling programs for these studies must be designed for this purpose from the start, and the monitoring team may need to manipulate the system in a controlled manner and measure its response. To guard against unexpected influences in these studies, the monitoring team should look for independent lines of evidence so that reliable inferences will be able to be drawn from the assembled results.

Determine Study Scope (see MG 3.3)

The scope of the monitoring study is determined by its spatial boundaries, scale and duration.

Have the spatial (geographic) boundaries of the study been defined? (see MG 3.3.1)

The geographic boundaries should be based on the issue of concern and the ecosystem rather than on convenience and budgets. Will the necessary measurement parameters be spatially uniform? The larger the area to be monitored, the more variable, heterogeneous and patchy the measurement parameters may become. Extra replicates may be needed to achieve the same confidence in the results.

Has the scale of the study been agreed to? (see MG 3.3.2)

Scale refers to the geographic spread and length of time over which a system is observed; that is, the appropriate level of resolution to answer the questions of concern. Different processes operate at different scales: for example, the movement of sediment in a river system may take tens of years at the catchment scale; toxicant effects may occur over days and may be localised.

What opportunities are there for making measurements at various scales, and will the measurements be reliable and valid? How much will data collection cost at the various scales? Can the level of resolution of the study be fine enough to satisfy the program objective?

Has the duration of the study been defined? (see MG 3.3.3)

What is a reasonable time boundary or duration for the study? How long will it take for a sufficient variety of rainfall events (from droughts to floods) to be experienced to allow the monitoring team to study the system under extremes? Whatever boundaries it sets, the monitoring team needs to explain the logic behind its decisions.

Consider Sampling Design: sampling site variability, frequency (see MG 3.4)

Have the potential sources of variability been identified?

Variability, between sites and between times, determines the ideal number of sites, number of replicates and the frequency of sample collection. Typical types of variation are caused by:

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

A pilot study and past records of the sites and catchments under investigation will provide information about seasonal variations and local variations in parameters to be measured (e.g. sources of contaminants). The past records could be accounts of activities in the catchment, aerial photographs, plans and maps of land use, and oral or other descriptions of the sites and the catchments under investigation.

Artefacts can occur in the measurements. Human constructions (e.g. bridges, jetties) are one source of artefacts, and should be avoided if possible. When control or reference sites are included in the design, care needs to be taken to ensure that they are closely matched with the site being assessed. However, if sampling sites are too close together or samples are collected at too close a time interval they can be autocorrelated, making statistical analysis invalid if it assumes the sites are independent of each other.

Are there sufficient sampling stations to accommodate variability? What are the smallest differences or changes that need to be detected? Is replication adequate to obtain the desired level of precision in the data?

How many samples are needed for measuring each parameter at each site precisely on each sampling occasion; how many samples can the monitoring program afford to take? The team will base its answer to these questions on the results of the pilot study or on other reliable estimates of the variance and the costs of sampling. The appropriate level of replication must:

- minimise the risks of falsely detecting a disturbance or environmental impact when one has not occurred (giving a false alarm, a 'Type I error'), or alternatively missing an environmental impact if it has occurred (giving a false sense of security, a 'Type II error'); and
- detect differences or changes that are environmentally important — that is, the change must have ecological meaning to the system of concern.

The smallest differences or changes that must be detected determine the number of sampling stations and occasions needed. Groundwater quality is affected by the local geology and by pollution from surface land use; sufficient sampling stations are needed to account for the variability that these factors can introduce.

In *stratified random sampling*, different numbers of samples can be taken in each layer or section of the waterbody, in proportion to the variance of that stratum or its size. In *systematic sampling*, samples are collected at regular spacings or intervals of time. Only rarely will sampling be *random*, but when it is, the number of sites and the extent of homogeneous areas in which they may be located can be determined from the pilot study. Multivariate classification procedures can be used for grouping sites, to define homogenous areas.

Are the sites accessible and safe?

Safe access must be ensured under all conditions. If the sites are not safely accessible during the wet season, for example, the monitoring program cannot measure water quality in that season.

Can sites be accurately identified?

Sites need to be accurately identifiable so that they can be sampled repeatedly. Global positioning system techniques can be used to back-up careful records and descriptions of the sites.

Has spatial variation in sites been considered and have options been found to minimise this variation?

Measurement parameters can vary from place to place within a site, randomly or in strata. When measurement parameters are being sampled in the water column, it is sometimes assumed that the water is well mixed and that a mid-water or mid-stream sample will be sufficiently representative. This may not be the case. Even if the monitoring goal is just to measure the average concentration of a chemical in the water at a site, the sampling process must be planned so that the within-site variation is included in the estimate.

It is important for the monitoring team to recognise that stratification in the measurement parameter will affect the data being obtained. There are three options for dealing with such strata:

- restrict the scope of the inference to a particular stratum; for example, sample only one type of substrate but make the stakeholders aware that the inferences drawn are applicable only to that sort of substrate and cannot be generalised to unsampled strata within the sites; or
- divide the sampling effort among the strata; here the goal is to estimate the value of the measurement parameter for each site as a whole rather than for a stratum within the site; or
- make separate estimates for each stratum (if this is consistent with the study objectives).

Groundwater quality is almost always stratified vertically, and there can also be significant lateral variation in quality. There is much less dispersion of contaminants in groundwater than in surface waters, and so its natural spatial variability is potentially much greater than in surface waters.

On what basis is the frequency of sampling proposed?

The values of a particular measurement parameter may not vary at all time scales. If a measurement parameter has a predictable pattern (e.g. deoxygenation during thermal stratification, or migration at a certain time of day), the monitoring program must sample this measurement parameter at a frequency that suits this periodicity. At the other extreme, to measure the effects of highly variable and unpredictable disturbances (e.g. stormwater discharges), the monitoring program must sample at several time scales.

When the monitoring program aims to compare test data against particular guidelines or standards, it is important to sample very often to note the possibly brief occasions when the guideline is exceeded.

If concentration measurements are being used to calculate loads, it will be important to decide how to relate flow and concentrations, and on what time basis. In the majority of Australian rivers, most (70–90%) of the annual flow and constituents are discharged under high flow or event conditions even though these may prevail for only 1–10% of the time. Under these conditions, the dominant water quality processes are the transport and deposition of discharged material during the flow event, followed by in-stream remobilisation of deposited material in the 10–30 days following the event.

To solve the difficulty of sampling at all flow regimes, a range of robust and reliable automatic sampling devices can now be obtained.

Consider Sampling Design: measurement parameters and cost-effectiveness (see MG 3.5)

Have the measurement parameters been chosen? Are they relevant? Do they have explanatory power? Can they be used to detect changes and trends? Can they be measured reliably, reproducibly and cost-effectively? Are the parameters appropriate for the time and spatial scales of the study?

The choice of measurement parameters will depend on the values ('environmental values') assigned to the water body (ecosystems, drinking water, recreation, industry, agriculture, aquaculture), and therefore on the objectives of the study. Normally these collectively will describe the state or health of the waterbody to be monitored. The attributes listed in Table 2 should be considered.

Physical measurement parameters include flow, temperature, electrical conductivity, suspended solids, turbidity, and colour. Chemical measurement parameters include a range of general measurements such as pH, alkalinity, hardness, salinity, biochemical oxygen demand, dissolved and total organic carbon. These are generally considered routine measurements in most investigations. In addition, other major controls on water chemistry include main anions and cations, and nutrient species (phosphate, nitrate, nitrite, ammonia, silica). These, together with the physical measurement parameters, will determine the stability, chemical forms and bioavailability of a range of minor and trace contaminants or toxicants such as metals, metalloids, and specific organic compounds. See MG 3.5.1 for more detail.

A whole-environment approach can be used, focusing on biological monitoring (effects) with measurements of physical and chemical data (causes) to aid interpretation of the biological data (see MG 3.5.3). This applies especially when the objective is to protect aquatic ecosystems or to assess ecosystem health or some change from a reference condition. Biological assessment consists of ecotoxicological and ecological measurements and is non-specific; it responds to the sum of the contaminants in the system. Taxonomic groups that have been used or proposed as indicators of ecosystem health include macroinvertebrates, macrophytes, fish, algae, bacteria, protozoa and fungi. The National River Health Program is currently using rapid biological assessment (RBA) based on macroinvertebrate abundance (the AUSRIVAS program, see MG Box 1) to assess the health Australia's rivers. Any group the team chooses to use must be relevant to the objectives of the study and be cost-effective. Studies may need to use quantitative assessment rather than RBA to achieve their objectives.

Some taxa are particularly susceptible to certain contaminants and so provide a sensitive tool for early warning, via bioassays. Biomarkers — measurable levels of biochemical products in an organism's body — can show that it has been exposed to a contaminant.

Ecological assessment aims primarily to measure the structure and function of biological communities (see MG 3.5.3). It principally involves field-based measurements of the abundance and diversity of species, community structure and function, and how these are altered as a consequence of known or unknown stressors and their modifiers in both waters and sediments. Macroinvertebrates, fish, and diatoms appear to be actually or potentially the most useful groups for the bioassessment of water quality. Bacteria, protozoa and fungi have not been widely used in ecosystem health studies, but bacteria and protozoa have been used extensively to test that waters are safe for human use. Before choosing a particular taxonomic group as a measurement parameter of water quality or ecosystem health, the monitoring team should check that the taxonomic group fulfils these four criteria:

- the response measured reflects the ecological condition or integrity of the site, catchment or region to be monitored;
- approaches to sampling and data analysis can be highly standardised;
- the response can be measured rapidly, cheaply and reliably;
- the response has some diagnostic value.

A completely different approach uses stream community metabolism, based on the movement of organic carbon through an ecosystem. The measurement parameter here is the ratio of gross primary production (P) to respiration (R); see MG 3.5.3.9.

Table 2. Checklist for selection of measurement parameters

Relevance	Does the measurement parameter reflect directly on the issue of concern
Validity	Does the measurement parameter respond to changes in the environment and have some explanatory power?
Diagnostic value	The measurement parameter must be able to detect changes and trends in conditions for the specified period. Can the amount of change be assessed quantitatively or qualitatively?
Responsiveness	Does the measurement parameter detect changes early enough to permit a management response, and will it reflect changes due to the manipulation by management?
Reliability	The measurement parameter should be measurable in a reliable, reproducible and cost-effective way.
Appropriateness	Is the measurement parameter appropriate for the time and spatial scales of the study?

Has the cost-effectiveness of the study design been examined? (see MG 3.7)

It is preferable for the cost of sampling programs to be as small as possible while still meeting the stated objectives of the monitoring study. Cost-effectiveness considerations involve trade-offs between loss of statistical 'power' (i.e. the capacity of a program to discriminate between various hypotheses) and the cost of data acquisition. It is necessary to determine all the resources and associated costs required, thereby ensuring the study can be carried out. Costs of data acquisition are determined by:

- the number of sampling stations, sampling occasions and replicates;
- the cost of collecting samples (staff, transport, consumables);
- the cost of analysis;
- the cost of data handling and interpretation (cost of reporting).

Cost-savings can result from collaborative monitoring, for example when local councils pool resources with other water managers to comprehensively monitor a particular waterbody.

Specific Data Requirements

Once the decisions have been made about the study type, study boundaries and measurement parameters, the data requirements need to be summarised. The data requirements include the measurement parameters, scale, geographic locations and length of study, frequency, accuracy and precision. These serve as the 'concrete' instructions for the decisions that have to be made about techniques required for data analysis and for the design of specifically tailored sampling and analysis programs.

Example of a Study Design

An extensive ongoing monitoring program was initiated on the Murrumbidgee River, NSW, downstream of Canberra (see MG section A4.1.1). The study objective was to monitor the water quality and aquatic ecology of the Murrumbidgee River and its associated catchment in relation to efforts to ameliorate eutrophication in the Upper Murrumbidgee River and Burrinjuck Dam.

The monitoring area was the catchment and streams upstream of Canberra, and the catchment area and streams downstream to and including Burrinjuck Reservoir.

To respond to study objectives, it was necessary to monitor:

- the mass of contaminants discharged from the catchment during non-point source discharges, expressed as a function of depth of runoff, and land use and management practice;
- the mass of contaminants discharged from point sources, expressed as a function of discharge rate and treatment facility;
- the transport losses by sedimentation, or the gains by re-suspension or microbial remobilisation, as a function of distance downstream from the discharge point, travel time, and flow rate or reach loading;
- the algal response to the composition, concentration or load of nutrients, and mixing and light conditions;
- the modification to algal composition and biomass as a result of zooplankton grazing.

Phosphorus concentrations were a major theme within this study because this nutrient's concentrations were related to algal counts and were also used to identify the point-source and non-point-source contaminant sites within the catchment. Turbidity interacted with the relationship between phosphorus concentrations and algal counts. Apart from the external sources of phosphorus, it was possible that the lake sediment would need to be analysed. All these types of relationship were determined as part of the study design.

4. Field Sampling Program

With the basic outline of a sampling program decided, it is now necessary to refine the details of how to collect, preserve and prepare samples of waters, sediments and biota. Some parameters will have to be measured in the field rather than sampled. In all instances, there should be documented protocols for field measurements and for sample handling, and these should be followed closely. Quality control and quality assurance are important; they require planning because they are not easy to achieve in the field. A framework for field sampling is shown in Figure 4.

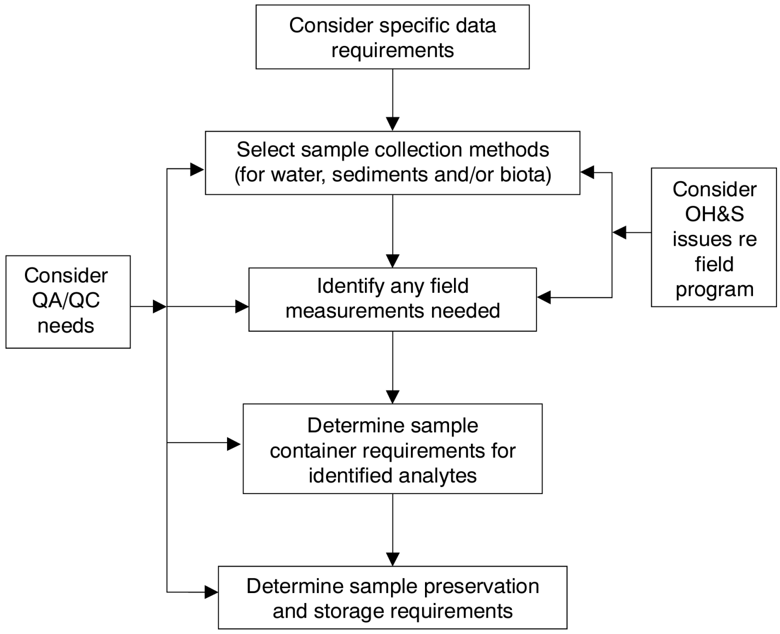

Figure 4. Framework for designing a sampling program

Checklist and Framework for Designing Sampling Programs

Consider Specific Data Requirements

The measurement parameters need to have been decided upon and the data requirements stated (see Chapter 3 above) before the sampling program can be designed.

Identify any Field Measurements Needed (see MG 4.2)

Some parameters (e.g. flow, temperature) can only be measured in the field, while for other parameters (e.g. dissolved oxygen, redox potential and possibly pH), field measurements are highly desirable because the value of the parameter can change in the sample after collection.

Select appropriate field measurement techniques, including calibration procedures

The reliable sensors that are available nowadays make it often convenient to measure many parameters in the field, obtaining on-the-spot values that can be checked immediately.

How are the positions of sampling sites to be recorded?

It is essential to make careful and thorough descriptions of the position of each of the sampling sites, the means of access to them, the sites themselves and the exact spots from which samples were taken. Key on-shore reference points can be identified, or the global positioning system (GPS) can be used. Measurements by GPS are now becoming reasonably precise (to within 20 m). For exact positioning of sample sites, differential GPS will be required. With high quality receivers and differential GPS the accuracy can be to within 1 m of the position or location. However, it is important to use a single coordinate system and to record which coordinate system is used, especially its datum and projection.

What ancillary field observations are to be taken?

Comprehensive field records are vital. The records must note at least: the position of a sampling site; the condition of the water body and the weather during measurement and sampling; the time of measurement; descriptions of the measurements and any associated samples taken, their labels and other details about them, including who took them; all field data and instrument calibration data; and any incidents. An example field record sheet is included at the end of this section. Video or photographic records are highly desirable for future reference. Observations or information on the conditions at the time of sampling may explain unusual data that otherwise might be attributed to problems in measurement, sampling or analysis.

Select Sample Collection Methods (see MG 4.3)

Selection of a sampling method, whether for biological or physical or chemical parameters, should be guided by the objectives of the monitoring program, the local conditions, the safety of the field staff, the acceptability of the method, and commonsense. Sampling and measurement can be done by hand, or by automatic sampler, or by integrated samplers, or by remote sensing. The choice of sampling method depends on the parameter to be measured and the nature of the information required. All the methods or equipment used must meet the relevant Australian and/or ISO standard.

Will the sampling device collect a representative sample?

Surface waters (as opposed to groundwater) can be sampled using (i) bottle samplers for shallow waters, (ii) pumping systems for surface to medium (10 m) depths, (iii) depth samplers (50 m to >100 m depending on design), (iv) automatic samplers, or (v) integrating samplers. Automatic samplers may not be appropriate for sampling bacteria, pH or other variables that are likely to change significantly between the time of collection by the automatic sampler and retrieval from the field for analysis. Membrane-based passive samplers are effective for the time-integrated sampling of hydrophobic contaminants. They partition the sampled contaminant between water and a lipophilic solvent enclosed in a semi-permeable polymeric membrane, thereby indicating its bioavailability.

Groundwaters can be sampled after the construction of a bore or other access hole. Possible equipment includes displacement pumps, submersible pumps, suction pumps, down-the-hole grab samplers, and balers. Groundwater sampling should generally be carried out by experienced field staff or in close consultation with experts, to ensure sample integrity. To retrieve a representative sample, these principles should be considered:

- the sampling equipment should not change the water quality in any way; particular effort should be made to avoid cross-contamination between bores and sampling equipment;
- sufficient water should be removed to ensure that the sample is newly derived from the aquifer itself rather than from water that has sat in the bore; and
- the methods of collection and storage in bottles and transportation to the laboratory should be suitable for the type of analysis required.

Sediments often are surveyed to determine the composition and concentration of contaminants in them, as well as the numbers of organisms located at various depths. There are two broad-based sediment classifications: *suspended sediments* and *bottom sediments*. In water quality terms, suspended sediments are generally dealt with as part of the water column, although specialised sampling techniques are required to obtain representative samples. The benthic organisms in bottom sediments are investigated as measures of aquatic health, pollution or contamination, and as part of the ecology of aquatic systems. They must be removed from samples that have been taken to assess sediment and pore water only. Sampling equipment includes sediment corers, grab samplers or dredges. The redox state of the sediment must not change in sampling and storage. Particle size distribution is another important factor that will affect contaminant distribution (see MG 4.3.5).

The *aquatic organisms* typically sampled comprise plankton, bacteria, periphyton, protozoa, algae, fungi, macrophytes, macroinvertebrates, benthic macroinvertebrates and algae, bivalves and fish. Methods include grab sampling, netting, trapping, scraping and electrofishing with nets, traps, brushes, and other suitable equipment (see MG 4.4).

Do disturbances occur in the environment being sampled? Will the sample be altered by contact with the sampling device?

The sampling device should not significantly disturb the environment being sampled or alter the samples taken; if it does, the samples will not reflect what 'was' or 'is'. This is a particular problem in sediment and groundwater sampling. Contaminant-enriched fine particles of sediments can be lost as grab samplers are pulled to the surface, for example; and the redox state of the sediments (oxic or anoxic) can change irreversibly on contact with air. Also, the construction of a bore and the effects of sampling procedures inevitably disturb the environment from which groundwater samples are taken.

Will the sample device contaminate the sample? If yes, how is the sample device to be cleaned?

The sampling of waters for trace and ultratrace contaminants is increasingly a requirement for monitoring studies, especially for comparison with regulatory standards. Non-contaminating equipment is essential for these measurement parameters, and it should be cleaned with acids for sampling metals, or cleaned with detergents and solvents for sampling organic compounds.

What are the effects of the sampling device being in contact with media other than the sample of interest?

If the sampling device comes into contact with media other than the sample of interest, sampling errors may be caused. For example, to collect sub-surface water samples for hydrocarbon analysis, the device must enter the water closed or it will pick up hydrocarbons from the water surface microlayer; and when sampling shallow water, the device should not stir up bottom sediment.

How are samples to be collected to prevent contamination?

Sampling protocols should be followed carefully. An alert person or team wearing plastic disposable gloves can avoid sample contamination by using plenty of plastic sheet to cover work areas and wrap equipment, and by preventing inputs of dust, powder, skin, hair, sunscreen, etc. Protocols must describe the basic precautions for avoiding contamination: e.g. use decontaminated containers to store reagents for use in the field; pre-clean all field equipment to the same standard as the containers; if containers were filled with water as part of the preparation protocol, empty them well away from and downstream of the sampling location before rinsing them with sample and refilling.

Determine Sample Container Requirements for Identified Analytes (see MG 4.3.6)

Will the sample container contaminate or affect the stability of the sample? If so, how are these problems to be overcome? What size sample containers are required?

Protocols for sampling will be specific to each matrix and constituent, and will specify the sample collection device, type of storage container and preservation procedures; also the types and numbers of quality control samples to be taken.

For metals, the preferred sample containers are fluorocarbon polymers, PTFE (Teflon) or FEP, and high-density polyethylene. High quality bottles are recommended, e.g. Nalgene, because these have good closures that prevent sample leakage. For samples to be analysed for selenium, bottles made of polycarbonate and some types of polyethylene are not suitable. For nutrients, polyethylene (low or high density) sample bottles are the most favoured type. Glass is not favoured because there can be high concentrations of trace metals in the glass and it has the potential to adsorb ions, e.g. phosphate.

Before going into the field, sampling staff should check with their analytical laboratory to ensure bottles have been appropriately cleaned and prepared.

Determine Sample Preservation and Storage Requirements

For samples that must be collected in the field and then analysed in a laboratory, fixative, preservatives and cold storage during transport can minimise changes. For example, oxidation in sediment samples can be minimised if they are frozen at –20°C (see MG 4.5).

Consider Other QA/QC[2] Needs (see MG 4.6)

Are procedures in place to track samples and field data?

During sampling or field measurements, it is important to record the samples taken, their labels and other details about them. All field records must be completed before leaving a sampling station.

What program is in place to identify, measure and control errors? Have sampling protocols been written?

Sampling errors can be minimised by ensuring that correct procedures have been followed during the field sampling, transport and storage. Sampling protocols need to be written and adhered to: they must include detailed descriptions of the procedures for collecting, labelling, transporting and storing the samples and necessary ancillary field data specific to each matrix and constituent.

The protocol must also specify the types and numbers of quality control samples to be taken. Before this protocol can be written, the nature of errors, both systematic and random, and the level of accuracy desired must be assessed (e.g. by a pilot study). The exact locations of sampling sites, transects and any sub-sites must be recorded in the sampling protocol.

How are sampling staff to be trained and how is their competence to be tested?

Protocols should specify how sampling staff are to be trained to use sampling equipment, and should anticipate problems that may occur in the field: e.g. loss of sample containers, low volumes of sample, occurrence of foreign objects, impossible conditions for sampling a site. Before sampling staff are permitted to do reportable work, they should demonstrate competence in field procedures. As a minimum this would include being able to adhere to protocols, being able to avoid contaminating samples, and being able to calibrate field instruments and make field observations. Some field staff may also have vehicle handling or bush skills.

Can the integrity of the sample be guaranteed?

Clear and distinctive sample labelling is important. After collection, it is important to maintain the integrity of each sample and to ensure that it does not become contaminated, or change between collection and analysis.

It is usually necessary to preserve the samples to retard biological, chemical and physical changes. Matters for consideration to ensure successful preservation and storage include selection and decontamination of sample containers, selection of a preservation technique and the time lapse

[2] QA/QC: quality assurance/quality control; see glossary page 39

acceptable between sample collection and analysis. Choices available will depend on the variable to be measured. Complete and unequivocal preservation of samples is a practical impossibility. At best, preservation techniques only retard chemical and biological changes that inevitably take place after sample collection. Chemical preservatives should be avoided, if possible, because they may contaminate samples or interfere in chemical or biological analysis. If preservatives are used they should also be taken into account in the analysis of blanks.

The preservation time expected before the samples can be analysed needs to be determined before samples are collected, and protocols must be designed to ensure that samples are analysed before a significant change in composition occurs.

Have blanks, duplicates and replicates been incorporated into protocols?

If it is possible that contamination could occur during the sampling process, an appropriate procedure for taking blank samples should be devised to detect and measure the contaminant. Field blanks involve taking extra containers with suitable contents to the site. There, the container is opened and closed and the contents are handled just as if this were a real sample during transfer and storage. Other types of blanks are filter blanks which are filtered in the field, container blanks which determine the contamination from the container, equipment blanks which measure contamination introduced through contact with sampling equipment or sampler, trip blanks that assess gross cross-contamination of samples during transport and storage.

Besides blanks, duplicate samples in the form of sub-samples and replicates are useful for comparative analyses to check methods or practices. Another alternative is to 'spike' sub-samples in the field to detect change. Samples to check the quality of data should be labelled in such a way that they are not distinguishable from other samples in the batch.

How are data to be stored and accessed?

Transfer of results from the field to a database should be automated where possible, and the printout of the entry should be checked against the field sampling sheet and the laboratory register. Entries can be validated by electronic screening against the expected range and against other analytes for the same site and sampling date, and field measurements. Are there agreed procedures for handling and tracking updates and corrections to data? Is there provision for handling censored data and all necessary identifiers, for traceability purposes, e.g. sample and laboratory numbers.

Quality control also relates to data security and backup. With respect to security, those personnel who have read or write access to the data must be specified. Data backup is always essential in case of system or file failures.

Consider Occupational Health & Safety Issues re Field Program (see MG 4.7)

Have all reasonable steps been taken to protect health and safety of employees? Have hazards been identified and documented? Have sampling staff been trained to ensure that sampling is done safely? Have risk minimisation plans been developed? Will staff be appropriately supervised?

All staff must be appropriately trained as part of the formal risk minimisation strategy. Training will include familiarisation with environmental hazards that may be encountered, sampling protocols (sampling procedures, chain of custody considerations, etc.), use of sampling equipment, and safety procedures. Staff must be qualified to drive appropriate vehicles, e.g. off-road 4-wheel-drive vehicles or boats, and to administer first aid.

The main Monitoring Guidelines document describes these seven directives that should reduce risks during sampling operations:

- limit continuous driving;
- choose safe sites with safe access;
- wear appropriate clothing, e.g. for the expected weather;

- take appropriate safety gear and a first aid kit;
- maintain contact with help and never sample alone;
- never go into deep water;
- avoid contact with contaminated water.

Professional practice requires sampling staff to obtain approval and permits as required. Also, individual sampling staff have a duty of care to other field personnel (helping each other where necessary, not discriminating, respecting privacy) and to the environment with regard to such matters as littering, fire, removal of human wastes, keeping to tracks, etc. Staff should never work alone, and junior staff will need appropriate supervision. For some procedures, such as in sampling of groundwaters and sediments, it is important that experienced staff are involved.

Example: the sampling stage of the GBRMPA Case Study

In the monitoring of the Great Barrier Reef Marine Park (see MG section A4.4), the design of the monitoring sites, sampling frequency and selection of analytes were guided by the following principles:

- the need to monitor concentration and loads at near-shore locations (<20 km) and offshore locations, with sampling areas being determined by the availability of personnel equipped to collect samples and make measurements;
- the need for event-based monitoring in conjunction with routine monthly sampling;
- the need to quantify regional and cross-shelf patterns of phytoplankton biomass within the Great Barrier Reef lagoon which may be related to regional differences in nutrient inputs;
- the need to determine how much temporal variability (seasonal, event-related) in phytoplankton biomass might reflect changing nutrient inputs to Great Barrier Reef waters;
- the need to monitor ambient concentrations of chlorophyll which would represent relative nutrient concentrations, i.e. the use of chlorophyll as a bioindicator of ambient nutrient concentrations;
- the need to monitor salinity because this is a function of the proximity of the river plume;
- the need for Secchi disc measurements that determine water clarity because this also relates to the proximity and intensity of the plume;
- the need for special studies to better describe in-reef physical, chemical and biological processes.

Sampling at monthly intervals would be sufficient, giving results that represented seasonal variation. The Great Barrier Reef is spatially immense, so the sampling locations were dictated by the proximity of available personnel. There was some coordination of the program with other monitoring occurring in the area.

Among other steps taken for quality assurance, the fluorimeter for chlorophyll-*a* analysis was calibrated regularly against diluted chlorophyll extracts prepared from log-phase diatom cultures.

There was early recognition of the importance of establishing a water quality data archive, including checking and validation protocols, for the entry and management of data, and documentation of sampling and analytical techniques and methods. In view of the volume of the data and the range of groups participating in sampling and analysis, only by this means could there be systematic logging, validation and entry of data; secure storage; consistent nomenclature, procedures and analytical methods; and ease of data access.

Entries into the data archive comprised information on the sample data, field observations or comments, sampling method, and site descriptions of reef condition at the time of sampling. User-specified reports were based on site description (number), date and determinands required.

An Example of a Field Record Sheet (reduced from usual size)

Officer/s………………………….………………………...……. **Date**………………………

Sampling run number:…...............……................................ **Site code**:…………………...…

Site name...

Time: start...**finish**...

Field measurements:

Parameter	Result
Depth (m)	
Secchi depth (m)	
Altitude (m)	
Temperature (^{o}C)	
Turbidity (NTU)	
Dissolved oxygen (mg/L) (% saturation)	
Electrical conductivity (mS/cm)	
pH	
Salinity ( )	
Eh (mV)	
Others	

Field observations:

Station no.………………………………...

Description...

....

Observation	Details
Weather: e.g. wind, wind direction, cloud cover	
Colour and appearance of water	
Water surface condition	
Water flow, level, tide:	
Presence of nuisance organisms (e.g. macrophytes, phytoplankton scums, algal mats)?	
Presence of oily films on surface or on shoreline?	
Presence of floating debris or grease?	
Presence of odour or frothing?	
Other observations	

Signature.. (when sample collected and entries completed)

Water quantity measurement data:

Location description..

Description of gauge...

Stage height...

Time...

Sample details:

Analyte	**Container material**	**Volume collected**	**Preservation**	**Quality control**
Major ions				
Metals				
Organic compounds				
Pesticides and herbicides				
Mercury				
Phenols				
Nutrients				
BOD and COD				
Others				

Quality Control Remarks:...

....

....

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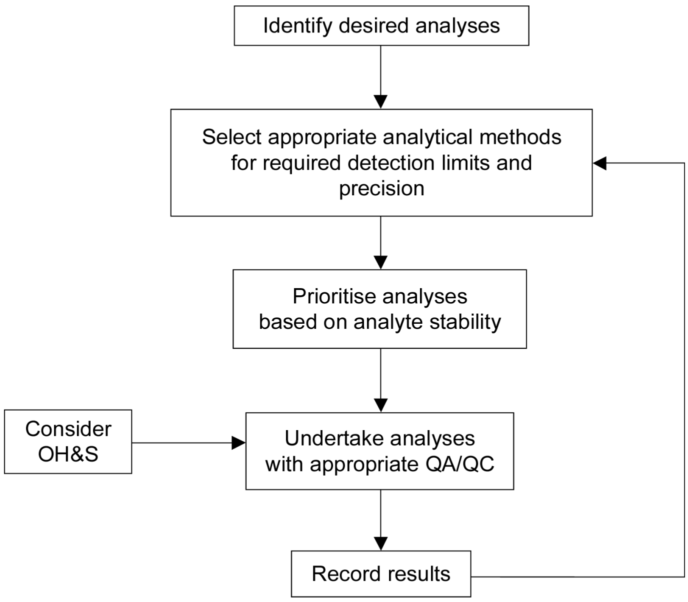
....

....

5. Laboratory Analysis

The aim of laboratory analysis is to obtain accurate and precise data in a safe environment. A framework for designing an analysis program is given in Figure 5.1. A typical laboratory request form is illustrated at the end of this chapter.

Figure 5. Framework for designing a laboratory analysis program



Checklist and Framework for Undertaking Laboratory Analyses

Identify Desired Analyses

Have the analytes been clearly stated?

The particular substances to be analysed for (analytes) may have been identified in generic terms during the study design. Now, when planning the laboratory program, the individual compounds and how they might be determined need to be considered. Their selection decides, for example, the method and equipment to be used in the laboratory, the risks to the health and safety of workers, and the cost.

Select Appropriate Analytical Methods for Required Detection Limits and Precision

Have appropriate analytical methods been identified? (see MG 5.3)

The selection of analytical methods for analytes in water, sediments and biota will largely depend on the information and management needs of the stakeholders and on the analytes themselves. However, limitations such as the financial resources available, laboratory resources, speed of analyses required, matrix type and contamination potential, are also important factors.

The choice of an appropriate analytical method is based on four considerations:

- the range of concentrations of the analyte that need to be determined. Detection limits are method-specific and the lowest concentration of interest will need to be specified.

- the accuracy and precision required. All results are only estimates of the true value and the greater the accuracy and precision required the greater the analytical complexity and cost.
- the maximum period between sampling and analysis. On-the-spot field analysis may be required, depending on the use to be made of the data.
- Where several methods can achieve the above requirements, the ultimate choice may be dictated by familiarity with the method and/or the availability of necessary analytical instrumentation.

Appropriate procedures for both chemical and biological analyses can be found by reference to standard methods (e.g. AS/NZS series), standard text books (e.g. see MG Table 5.2), or the USEPA web site. Standard methods are updated regularly, but many good non-standard methods are available that have not yet been included. Their use is acceptable, provided that justification for their choice is given and that their performance can be demonstrated through the analysis of standard reference materials or other quality control procedures. Aspects or details of both standard and non-standard procedures may require evaluation or modification for use in Australian or New Zealand conditions. Units of measurement should be chosen so that the data can be shared with other monitoring teams.

Does the laboratory have the appropriate equipment, facilities and staff competence to undertake the analytical method chosen?

Before analyses are undertaken, the monitoring team and the end-users of the data should confirm that the chosen laboratory has the appropriate equipment, facilities (water supply, air supply, environment), expertise and experience to undertake the analytical method chosen, as well as an adequate quality assurance program. If the monitoring team plans to send samples to external laboratories, it is recommended that those accredited by the National Association of Testing Authorities (NATA) be used wherever possible. Accreditation guarantees appropriate standards of laboratory organisation and of QA/QC, but not necessarily accurate results.

Has a laboratory data management system been established, and are procedures in place to ensure the data reaches the user?

It is important that data are managed systematically and are easily accessible. The sheer volume of data accumulated after just a few years of monitoring dictates the adoption of computer-based data management systems as the basis for data storage and management. The choice of a particular database depends on the types and intended use of the data and on compatibility, both of the computer hardware and software and with other databases.

The needs of the user are the most important feature in the design of a water quality database. Information to be considered at the design stage includes the scope of the data to be stored, the number of sources of data, analytical precision and validation procedures, linkages to other associated measurements, documentation, user access to the data including the possibility that data may be shared with several separate users, support for statistical and interpretative analyses, and retrieval possibilities.

The record system needs to provide a traceable pathway covering all activities from collection of samples to final analysis. All data and samples need unique identification codes. Chain of custody documentation ensures that any questions about the samples can be answered. Data entry protocols are needed to ensure the entry of data is accurate.

Are the analyses fully documented?

Traceability of analytical results from the laboratory report back to the original sample is an essential component of good laboratory practice, and is a prerequisite for accreditation of analytical laboratories. Apart from its chain of custody details for each *sample*, the laboratory record system must include the following information for each *analysis*:

- identity of the sample analysed;
- identity of analyst;
- name of equipment used;

- original data and calculations;
- identification of manual data transfers;
- documentation of standards preparation;
- use of certified calibration solutions.

Laboratories undertaking analyses must fully document the methods used, with sufficient detail to allow an experienced analyst unfamiliar with a method to reproduce it and obtain acceptable results.

Has a laboratory quality assurance plan been developed? Do operating procedures specify instrument optimisation and calibration?

The objective of a laboratory's quality assurance and quality control program is to minimise errors that can occur during sub-sampling and analytical measurement and to produce data that are accurate, reliable and acceptable to the data user.

The laboratory environment must be clean and regularly checked for airborne contamination. Deionised water of an appropriate standard is needed for analyses. All equipment and laboratory instruments should be kept clean and in good working order, with up-to-date records of calibrations and preventative maintenance. Records should be kept of all repairs to equipment and instruments and of any incidents that may affect the reliability of equipment

All protocols for preparing and analysing samples must be in written form and validated.

All staff undertaking analyses must have been assessed as technically competent, skilled in the particular techniques being used, having a professional attitude towards their work, and aware that it important to adhere strictly to analytical protocols.

Have analytical methods' accuracy, bias and precision been established?

Quality assessment is the process of using internal and external measures to determine the accuracy and precision of data being produced. All laboratories must have a formal system of periodically reviewing the technical suitability of analytical methods. Any variation of the standard method must be technically justified and supported by a documented study on the effects of the changes.

The principal indicators of data quality are bias and precision. Bias is a measurement of systematic error, and can be attributed either to the method or to the laboratory's use of the method. Precision is the amount of agreement between multiple analyses of a given sample. When combined, bias and precision are expressed as accuracy; that is, the nearness of the mean of a set of measurements to the 'true' value. As a minimum, the precision and accuracy of data must be stated when data are presented in reports.

Undertake Analyses with Appropriate QA/QC

What QA/QC procedures does the laboratory use? (see MG 5.5.5)

The accuracy of analytical methods can be established by several procedures: the analysis of certified reference materials; inter-laboratory collaborative testing programs which compare results obtained for sub-samples of the same materials; the accurate recovery of analyte spiked into a sample; and the daily analysis of standard solutions. Similarly, inter-laboratory collaborative testing programs can assess whether the sample storage and preservation procedures are appropriate.

Blanks should be incorporated at every step of sample processing and analysis, but only those exposed to the complete sequence of steps within the laboratory will usually be analysed. Blanks incorporated at intermediate steps are retained for diagnostic purposes only.

Duplicate analyses of samples are used for assessing precision, both in chemical analysis and in taxonomic analysis. At least 5% of samples should be analysed in duplicate. In taxonomic analysis a second sub-sample equivalent in size to the original subsample should be obtained, and checks on subsampling and sorting should be carried out by an independent group.

In general all organisms should be identified against taxonomic keys by staff trained in their use. If keys are not available, preserved samples should be sent to other laboratories that regularly identify similar biological samples. (See MG 5.5.6.)

In ecotoxicity testing, any variability in the toxicity test organisms or their health is critical to the quality of the ecotoxicity results, so standard protocols specifying the life stage and health of an organism are essential. Quality control procedures in ecotoxicity tests include criteria for test acceptability, appropriate positive and negative controls, use of reference toxicants and water quality monitoring throughout the bioassays. (See MG 5.5.7.)

To ensure that the toxicity measured is due to the contaminant or test sample alone, it is also important to measure a range of water quality variables in each test treatment throughout the toxicity test. For freshwaters, measurements of alkalinity, hardness, pH, temperature and dissolved oxygen are the minimum parameters required. For marine studies, salinity is also monitored throughout the test.

In handling sediment samples, sample integrity must be maintained. In some situations it is important to maintain unchanged redox conditions (oxic vs anoxic) in the sediment samples. Samples analysed need to have similar particle sizes, organic carbon and sulfide contents. Sieving or grinding are used to homogenise samples. The main Monitoring Guidelines outlines matters to be considered when homogenising, or when sampling pore water or storing samples (see MG 5.5.8).

Control charts are used to visualise and monitor trends in the variability of data. Means charts track changes in certified reference concentrations, known additions, calibration check standards and blanks. Range charts track differences between duplicate analyses based on the standard deviation or relative standard deviation. (See MG 5.5.9.)

Consider Occupational Health & Safety (OH&S) (see MG 5.6)

The hazards or risks involved with laboratory work need to be identified and documented. The major issues are whether or not staff will be exposed to toxic or other hazardous substances; and whether or not staff will be placed in a position of potential physical danger. Personnel who are to conduct analyses should be physically and mentally able to carry out laboratory work. All staff must be appropriately trained as part of the formal risk minimisation strategy, and be familiar with protocols, use of equipment, and safety procedures, and qualified to handle chemicals and administer first aid. Proper professional practice requires that risks be reduced as much as possible, and that staff are not required to operate in unsafe conditions.

Example of QA/QC: field, laboratory, data handling

Natural resources in the Logan–Albert Catchment are being subjected to increasing pressure as a direct result of population growth in south-east Queensland. This has prompted an investigation of the aquifer that supplies this region with its groundwater. See MG section A4.2 for details.

The major objective was to establish a groundwater quality condition benchmark for use in subsequent monitoring, to identify and understand the processes degrading groundwater quality in the aquifer, and to integrate the information obtained and provide advice to the responsible natural resource managers.

The quality assurance and quality control guidelines relating to laboratory analysis were divided into three categories.

(i) Blanks were used to monitor contamination during any stage of the sampling and analytical process. Blanks were taken at the beginning of the trip, mid-way and at the end of the trip. A 'before' and 'after' blank was taken at each time, i.e. the distilled water before and after it had been through the decontaminated pump system. Separate blank samples were used for chemical, microbiological and isotopic analyses. 'Before' and 'after' blanks were taken at more frequent intervals for microbiological samples.

(ii) Duplicate samples were taken as a test of precision in sampling and analysis. They were taken every tenth sample and processed in exactly the same way as the 'normal' samples.

(iii) Standard additions were used to test the accuracy of the analytical instruments. In this project the samples were spiked in the field to determine degradation between collection and analysis. A spiked sample was prepared every time a duplicate sample was taken. Spiked samples were prepared for major and minor ions, metals and nutrient analyses.

Pesticide analysis involved specific QA/QC procedures.

(i) Blanks were collected on three occasions throughout the sampling period. These ensured that the rinsing procedure between sampling was efficient and that there was no contamination. 'Before' blanks were performed by extracting pesticide-free water. 'After' blanks were performed on pesticide-free water which had passed through the pump equipment after the routine cleaning of the equipment with detergent, pesticide-free water and analytical methanol.

(ii) Duplicate samples were taken on three occasions for the normal extractions. The duplicate results monitored precision of sampling, extraction and analytical methods.

(iii) Triplicate samples were spiked with a range of compounds, representing those pesticides of interest. These recoveries indicated the extraction efficiency of a range of compounds, matrix effects and degradation of analytes with storage. Acidified cartridges were also spiked on three occasions with a mixture of acid herbicides.

(iv) Each sample was spiked with a known quantity of surrogate solution before extraction. The recovery of these compounds indicates the efficiency of the individual cartridge extraction.

One grab sample was taken at the Logan River to detect possible surface–groundwater interactions with the closest bore sample.

A water quality data archive was established, including checking and validation protocols for the entry and management of data, and documentation of sampling and analytical techniques and methods. Entries into the archive comprised information on the sample data, field observations or comments, sampling method, site description and condition at the time of sampling. User-specified reports were based on site description (number), date and determinands required, and the laboratory undertaking the analysis.

For quality assurance/quality control:

- validation checks were standard for various fields in the database to minimise data entry errors;
- data analysis and interpretation were peer reviewed.

A Typical Laboratory Request Form

(reduced from usual size, and partially filled-in as an example)

Sample program / site description..

Sampling officer...**Title**.................**Section**.............................**Branch**.....................................

Sampling date....................................**File Reference**.......................**Payment Authority No.**..

Sample no.	Sample time	Sample location	Sample description	Parameters to be analysed	Sample size (mL or g)	Reference criteria*
MB1	09.00	Monitor bore (north-east)	Groundwater	pH, EC, TP, TN	1000 mL	SW, IP
SP2	09.45	Creek upstream of site	Creek water	Colour, NFR, EC, TP, TN	1000 mL	A, AE

***Codes:** AE = aquatic ecosystems, DW = drinking water, IP = irrigation of plants, SW = stock water supplies, IW = industrial water supplies, A = aesthetic values; R = Recreational waters (reference: *Australian & NZ Water Quality Guidelines for Fresh and Marine Waters* (1992))

Site conditions during sampling..

(e.g. Cool 12^{o}C, raining, creek flowing at estimated 10–15 L/sec)

Sample preservation details...(e.g. On ice)

Analytical laboratory..**Accepted by**..**Title**............

Date.............................**Time**.......................................

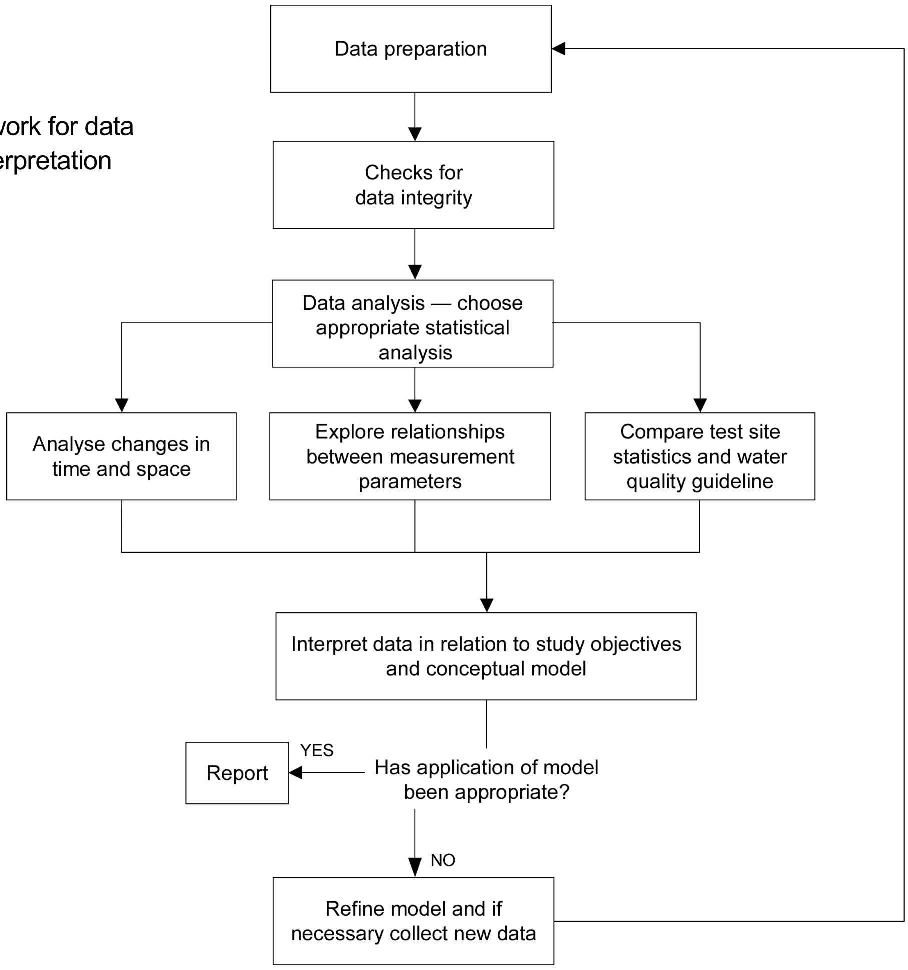
Comments:

Analysis request notes (tick requirement):	Return analysis results to:...................
Routine.............. (.......) — mail results when ready	Entity..
Urgent................ (.......) — fax results to ...., as soon as possible	Address...
	....
Legal action........ (.......) — ensure chain of custody and data validation	....

6. Data Analysis and Interpretation

Data analysis should be viewed as an integral component of the water quality management process. As discussed in Chapter 3, particular consideration needs to be given to the statistical design associated with any data gathering activity because the *way* in which data are collected influences the form of analysis and vice-versa. Data types, quantities, and methods of statistical analysis need to be decided upon collectively, at the early planning stages of any monitoring program. A framework for data analysis and interpretation is shown in Figure 6. See MG Chapter 6, and MG Appendix 5 for details and worked examples.

Figure 6. Framework for data analysis and interpretation



Checklist and Framework for Data Analysis

Have preliminary issues been dealt with, and the data been prepared ready for data analysis?

The overriding objective of the data analysis exercise should be to increase the understanding of the aquatic system under investigation. One of the main challenges for the data analyst is to extract a 'signal' from an inherently noisy environment.

This preliminary data analysis stage depends on decisions made earlier in the program design. While setting objectives and designing the study and sampling program, the monitoring team will have decided on the measurement parameters. Decisions will have been made about preliminary hypotheses to be tested, and situations and/or processes to be described, to focus the data analysis more on discovering and understanding the dynamics of an environmental effect. While designing the sampling program, the monitoring team will have planned the data collection to allow for comparison of data from different sources. For example, to calculate nutrient loads the team will have collected concentration data and flow data at the same location at the same time. If the team plans to compare its data with data sets from other places or years it will have chosen to use appropriate units of measurement and time frames. The data storage systems, usually databases, will have been organised.

Before collecting any data, the monitoring team will also have chosen a sequence of suitable statistical analyses. The team should be careful to distinguish between the legitimate activities of exploratory data analysis (EDA) and data mining, and the unstructured and undisciplined application of statistical techniques that are applied because they 'seem to work' or produce a predetermined outcome.

Checks for Data Integrity

Have data reduction methods (graphical, numerical, and tabular summaries) been applied? Have 'aberrant' observations been identified and remedial action taken?

The monitoring data are now subjected to standard methods of data summary, presentation, and checking (see MG 6.3.1). For summarising data, the monitoring team can use graphs (e.g. histograms, box-plots, dot-plots, scatterplots), and tables (e.g. frequency distributions, cross-tabulations), and numerical measures (e.g. means, medians, standard deviations, percentiles). Summary statistics should convey the essential information contained in a set of data as concisely and as clearly as possible.

The choice of which summary statistics to use, and the types of statistical analysis and modelling appropriate to the data, will partly depend on the level of measurement employed. The data may consist of counts, or ranks (absent, sparse, common, abundant, or very abundant). Most commonly they will be numerical measurements with respect to an arbitrary zero ('interval data'; e.g. temperature measured in relation to 0°C), or with respect to a true zero ('ratio data'; e.g. phosphorus concentration for which 0 indicates there are no phosphorus molecules present). Note that not all summary statistics are appropriate to all types of measurement (see MG section A5.1.1).

In a set of data, measurements are often below the detection-limit for a parameter (i.e. they are 'censored' data). If many of the measurements are affected, the monitoring team will need to use advanced statistical skills to draw unbiased inferences from the data. A data set also often contains erroneous values or lost data or aberrant values that will be revealed by the summarising tools and that must be dealt with appropriately (see MG 6.2.2). Outliers need to be checked; they can have strong influence on the statistical analyses of the data, but it may be better not to discard them. They can indicate a need for more thorough investigation, and might hold the key to new information!

The monitoring team will consign most computation to statistical software packages such as SAS® (for large data sets and complex analyses), MINITAB®, STATISTICA® or SYSTAT® (for medium–large sized data sets; they are easy to use, with a comprehensive set of procedures), S-PLUS® (which offers many contemporary and robust statistical procedures that are not readily available elsewhere) or Microsoft EXCEL® (which is useful for data screening and manipulation).

Has there been a check for potential violations of statistical assumptions (e.g. non-normality, non-constant variance, autocorrelation)? Suitably transform data if necessary (see MG section A5.1.2).

If classical statistical techniques are to be used, do the collected data fit the assumption that they are, say, normally distributed and have constant variance in space and time? Are the observations truly independent (uncorrelated)? Water quality data rarely satisfy these assumptions. Statistical software can do the computations associated with checking assumptions about statistical distributions, but the monitoring team should include members who are competent in applying and interpreting the results.

When one or more assumptions of a proposed statistical test appear to have been violated, it is common practice to mathematically transform data (e.g. by conversion to logarithms or square roots). In many instances this is unnecessary because a number of standard statistical procedures (such as

ANOVA, t-tests, etc.) are relatively robust in the presence of slight to moderate departures from normality.

Rather than attempting to achieve normality, the practitioner should ensure that the distribution of the data has a reasonable degree of symmetry. The only time significant distortions in the test results are likely to occur are in cases of high skewness and/or high kurtosis (peakedness). It is far more important to check the data for homogeneity of variances (i.e. the variance of the variable of interest remains constant over different groups, times, or space) and independence. Data that are correlated either spatially or temporally (or both) are not amenable to the statistical test procedures in the Monitoring Guidelines.

Data Analysis: analyse changes in time and space; explore relationships between measurement parameters

Have data been analysed using previously identified methods; have alternative procedures been identified for data not amenable to particular techniques?

While data analysis — summarising, presenting, and describing the information — is an important activity in its own right, most statistical analyses are concerned with inference. Inference is the use of methods to infer something about some characteristic of a population of values based on the limited information contained in a sample drawn from that population (see MG 6.4, A5.1.5).

'Classical' methods of statistical inference are established on the notion of repeated sampling from the population[3]. By examining the variation in the values obtained by repeated sampling, it is possible to develop tests to make judgements about the likelihood of a particular result being attributable to chance variation or to some real effect. Examples are t-tests, F-tests, χ^2-tests, analysis of variance, analysis of covariance, etc. (see MG A5.1.6, A5.1.7, A5.1.8).

Confidence limits (or intervals) for the true value give the range within which it is highly (say 95%) probable that the true population value lies (see MG 6.4.1, A5.1.5.1).

Two classes of statistical models that deserve greater attention in water quality studies are generalised linear models and generalised additive models (GAMs). See MG 6.4.2, A5.1.9 and A5.1.12.

Relationships between pairs of water quality variables can be conveniently handled using the standard statistical tools of correlation and regression analyses (see MG 6.5 and A5.1.11), or GAMs. A correlation analysis generally precedes a regression analysis in which relationships between the variables are tested and inferences are made about the likely values of true parameter values.

An important assumption of regression analyses is that the errors are independent. However, samples collected serially in time often display a degree of autocorrelation. For example, the concentration of phosphorus in a water-storage at a particular time has a great bearing on the concentration an hour later, and probably a day later. If one measurement is well above the general trend, the other is likely to be also. This can affect the assumed Type I error rate (the risk of raising a false alarm that a disturbance has occurred), though the estimated parameters of the regression tend to be little affected. One way to overcome temporal dependence (i.e. dependence on time) is to select a sampling interval that is large enough to ensure no dependence between consecutive measurements.

Water quality monitoring programs often generate multivariate data sets that pose considerable challenges for the data analyst (see MG 6.5.4). For each sample there is often a group of observations rather than a single value. These values (variables) tend to be correlated among themselves to some extent, indicating that they co-vary. If the co-dependence between variables is ignored and the aberrant observations are examined one variable at a time, unusual observations may be missed, and the whole procedure will be inefficient. All the statistical software packages mentioned above have multivariate statistical analysis capabilities. Before applying these tools, though, the analyst should

[3] Bayesian methods, based on a different paradigm of statistical inference, are becoming increasingly popular.

explore the data at hand and attempt to identify relationships between pairs and groups of parameters. Two useful techniques are principal component analysis and multidimensional scaling.

Principal component analysis (PCA) constructs linear combinations of the original variables in such a way that the resulting combinations account for the maximal amount of variation in the original data using considerably fewer constructed variables. The drawback is that the constructed variables (the 'components') generally have no real or physical meaning and have no recognisable units of measurement.

Multidimensional scaling (MDS) attempts to reveal relationships or patterns among a large number of variables by reconstructing 'similarities' between pairs of these variables in a 'reduced' space (i.e. one of fewer dimensions). Biologists and ecologists have found MDS analysis particularly useful in teasing out complex space–time interactions among biological variables (see MG 6.6.3 and A5.1.14).

A number of statistical methods are available to assist with trend analysis (see MG 6.6, MG 6.3.6 and A5.1.4); these range from simple descriptive tools, such as time series plots, to more sophisticated modelling techniques that attempt to separate out a signal from 'noise'. The variability of a constituent or process is equally as important as, and sometimes more important than real changes in level.

Given the high variability of most natural ecosystem processes (or of indirect processes that influence them), it is not surprising that water quality data also tend to exhibit a high degree of variation over both space and time. This high natural 'background' variation tends to mask trends in water quality parameters and hence reduce our ability to extract a signal from the 'noise'. Simple graphical tools such as scatterplots and time series plots provide a combined view of both the trend and the noise. However, 'robust smoothers' are remarkably effective in teasing out a signal from very noisy data. They 'window' a portion of the data, computing some numerical quantity such as mean or median and then 'stepping' the window across the data and repeating the process. The collection of statistics obtained in this way can be plotted at the mid-points of the intervals to obtain a smooth representation of the underlying process.

Formal statistical analysis of time series data can be rather complex and requires a good degree of skill in identifying suitable models. Time series data tend to exhibit varying degrees of serial dependence or autocorrelation.

Data Analysis: compare test site statistics and a water quality guideline (see MG 6.4.3)

The revised Water Quality Guidelines (NWQMS paper no. 4; see Table 1) describes how stakeholders for a waterbody can assess change in its quality by collecting monitoring data at test site(s) and comparing the median from the test site with guideline trigger values derived from reference sites. Where non-biological indicators are concerned, the 80th percentile of the reference site data is recommended as the trigger value (20th percentile for parameters where low values such as dissolved oxygen are a problem).

Control charts or time series plots are useful for graphing data values in comparison to guideline or reference values over time. The advantages of these graphs are that minimal processing of data is required and that they make it easy to see trends — the need for remedial action can be identified at an early stage. Confidence limits can be added to each of the plotted points when sample means are used, but this is not straightforward when dealing with percentiles (particularly a 'rolling' percentile at a reference site).

Confidence intervals themselves provide another good way of comparing observations of a water quality variable to a guideline value: if a confidence limit overlaps the guideline, it shows that the guideline may have been exceeded.

The main Monitoring Guidelines also outlines two probability-based methods of comparing water quality with guideline values (see MG 6.4.3.4, MG 6.4.3.5).

Interpret Data in Relation to Study Objectives and Conceptual Model

Have results been collated into a concise (statistical) summary and have statistical diagnostics (e.g. residual checking) been used to confirm the utility of the approach? Has the statistical output been carefully assessed and given a non-technical interpretation?

After the data analysis, the monitoring team collates the results into a concise statistical summary, and assesses these results by use of residual diagnostics (see MG A5.2 Worked Examples). This is the stage at which the team interprets the information the results provide, in the context of the objectives or questions the program was originally set up to answer. Interpretations might be, for example, that the values of a contaminant exceed the guidelines for ambient water quality because of the release of effluent by a sewerage system; or that the values of important measurement parameters before and after the building of a coastal recreation development differ significantly; or that two tested factors are not significantly reducing groundwater quality.

Refine Model and If Necessary Collect New Data

Have the objectives been addressed? If not, has the study been redesigned, have new or additional data been collected, has the conceptual model been refined and have the data been re-analysed?

Once the monitoring team has expressed the interpretation concisely in non-technical terms, it can decide whether or not the program objectives have been satisfied, and whether it is appropriate to report to stakeholders.

If the interpretation does not support the conceptual model or the objectives have not been met, the model needs to be refined, the study needs to be redesigned, and new or additional data need to be collected and the analysis restarted.

To assist in the evaluation of detailed monitoring programs, the study team may consider seeking an independent peer review that can assess the program design and outcomes against the monitoring program objectives.

Examples

(a) In the study of the Murrumbidgee River and Burrinjuck Dam, NSW (see MG section A4.1), the initial data analysis comprised statistical analysis of the medians, ranges and trends (time and distance downstream), and correlation analysis of the parameters.

The explanatory power (validation) of a range of conceptual models was tested.

A range of restoration measures was adopted as part of an integrated catchment management strategy. (They included the tertiary treatment of Canberra sewage, urban stormwater pollution control ponds, gross pollutant traps and 'at-source' controls.) After the restoration measures had been set up, the data analysis phase of the monitoring program included time-based trend analysis, comparison of average summer algal levels, normalised for varying streamflow or water loading conditions (modified loading-based model), and assessment of changes in biological indices of river health (with AUSRIVAS).

(b) In the Great Barrier Reef Marine Park case study (see MG section A4.4), the concentrations of chlorophyll recorded at the reef stations were often skewed and it was necessary to transform the data. Extreme values made the choice of summary statistics important. The means were greatly influenced by the outliers, whereas median values were more conservative but used only 50% of the data.

The analyses of long-term temporal trends in chlorophyll concentrations predominantly used non-parametric[4] techniques.

[4] For discussion of non-parametric techniques see MG section A5.1.13.

7. Reporting

Effective monitoring programs include a reporting system that efficiently and accurately transmits the information required. Figure 7 is a framework for designing reporting and information dissemination systems.

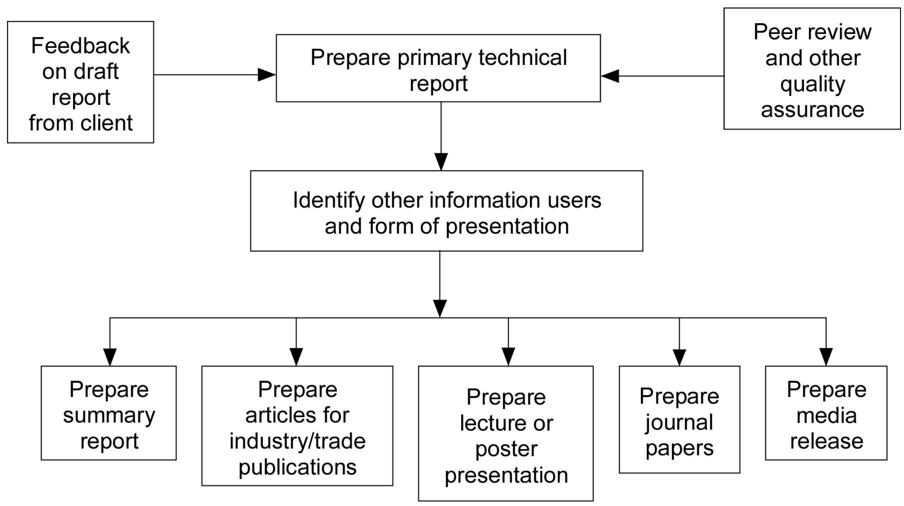


Figure 7. Framework for reporting the monitoring program results

Checklist and Framework for Designing a Reporting System

Has all the information required been obtained? Have the identities of all those who want the information ascertained?

Once the results have been obtained and interpreted, the next step is to report the findings to the people who commissioned the study. Then there can be further dissemination of the findings to other stakeholders and information users. At various stages through the design and performance of the monitoring program, there will have been interaction with the end-users of the information, particularly during the setting of objectives, the detailed study design and the laboratory analyses. The monitoring team will have clearly identified the end-users' data needs and information requirements.

Has the time frame in which each information user requires information been determined?

In both short- and long-term monitoring programs, a realistic time frame in which to report the information must be developed. The monitoring team will have negotiated a reporting schedule during the initial study design. A typical schedule might include the reporting of interim results on a monthly, bimonthly, quarterly or six-monthly basis. In some instances, e.g. where there is a public health concern, it may be appropriate to transmit the findings rapidly to the end-users of the data so that remediation can be initated rapidly. It is important that pressure for results does not compromise essential quality assurance and checks of the analytical data and their analysis.

Has the best form of information presentation been chosen, appropriate to the level of understanding of each user and consistent with the style expected by each user?

The scope and format of reports depend on the client or community groups to which they are targeted. Reports range from laboratory reports on results of analysis, to data extraction reports in response to requests, reports about the actual analysis of data, and overall study reports. Interim reports provide a means for those conducting the program and those commissioning it to review progress and, if necessary, modify the study design.

Prepare Primary Technical Report

At the completion of the study, or, for on-going monitoring programs, usually on an annual basis, a primary report is produced, in a form agreed to by all parties and in the traditionally accepted style (see MG 7.2).

The primary report contains full and complete details of all aspects of the study. It is the reference or source document for subsequent publications. When a report is very large, a shorter summary report may be useful, to encapsulate the technical findings of each component of the study in an abbreviated form. Data summaries and graphical presentations of results significantly enhance the readability and utility of reports; they are excellent ways of presenting the data.

It is important that the clients receive a draft version of the document to ensure that the final product will meet their expectations and cover all the issues that they had hoped to see addressed. This is the first stage of the review process. So that the client and other stakeholders can have confidence in the output, it is desirable to organise external peer review of the report. Such a review should address data quality, data interpretation, and whether the findings are scientifically acceptable and consistent with the monitoring program objectives.

Identify Other Information Users and Form of Presentation (see MG 7.4)

The dissemination of information to other users can be organised after the delivery of the primary report, if necessary. Depending upon the commercial sensitivity of the information, the report could be made publicly available via national, regional or organisational listings of publications or other bibliographic services.

A broad range of stakeholders and others will use the information that the monitoring program provides. They may or may not have been involved in the study design, and could include:

- the resource manager at state, local government or catchment level;
- an environmental agency, reporting for State of the Waters, or State of the Environment;
- individual water users, who are usually concerned when the values of particular measurements fail to remain within safe operating limits;
- industries that use the water or discharge into it;
- community groups involved in catchment management, integrated land and water use, etc.;
- the general public (not necessarily local), who receive general media reports;
- the scientific community, concerned as part of particular environmental research.

Of the available forms of information transmission, which form is most appropriate for each information user (written, oral, electronic)?

Methods for information reporting and dissemination can be publications; industry and professional association conferences, seminars and workshops; Internet web pages; film and video presentations; press releases and media articles.

Known users of information can be reached by mailouts of factsheets, letters or newsletters which can alert them that the information is available in one or several formats. Other users can be generally alerted via media articles or by abstracting services such as Streamline.

There is a view that data collected with public funds, or data required as part of a licence, should be publicly available. Some jurisdictions are now placing such data on web sites to make them widely available with minimal data extraction costs. For example, the Victorian State Water Resources Data Warehouse is available at www.vicwaterdata.net/. It is intended to improve community access to information about Victoria's water resources, particularly the water quality and stream-flow monitoring programs, and ultimately to provide information about marine, biological, groundwater and community monitoring.

Example

The Derwent Estuary in Hobart has sustained extensive organic, heavy metal, nutrient and pathogen pollution since the 1920–30s, from paper processing, zinc processing and sewage discharges (see the main Monitoring Guidelines Appendix A4.3 for details). The Department of Environment and Land Management (now E&P/DELM) established a variety of medium- to long-term monitoring programs, covering toxicants, nutrients, algae and bacteria, with the objective of ascertaining the current environmental health of the estuary. In addition, the Department has required annual surveys of heavy metals in aquatic organisms (by Pasminco Hobart Smelter), since 1972.

Reports were prepared by the Department of Environment and Land Management, the Inland Fisheries Commission, and Pasminco EZ. Information from these studies has been presented at workshops and conferences, published in scientific journals, and incorporated in reports by Commonwealth agencies. In 1997, all available environmental monitoring data for the Derwent Estuary were reviewed, compiled and synthesised in a report that has been an important catalyst for improved management, including further monitoring.

A number of Priority Environmental Issues have been identified and briefing sheets have been prepared for each of these issues for consideration in the next stage of the Derwent Estuary Program. The briefing sheets provide a good example of the use of existing information to identify and develop objectives, and monitoring strategies that meet the information requirements for those objectives.

Glossary

Acidity
the quantitative capacity of a water to react with a strong base to a designated pH

AFFA
Agriculture, Fisheries and Forestry Australia

Algae
comparatively simple chlorophyll-bearing plants, most of which are aquatic, and microscopic in size

Alkalinity
the acid-neutralising capacity of an aqueous system; the sum of all titratable bases

Ambient
surrounding

Anion
a negatively-charged ion

ANZECC
Australian and New Zealand Environment and Conservation Council

Aquatic ecosystem
any water environment from small to large, from pond to ocean, in which plants and animals interact with the chemical and physical features of the environment

Aquifer
an underground layer of permeable rock, sand or gravel that carries water, allowing it free passage through pore spaces

ARMCANZ
Agriculture and Resource Management Council of Australia and New Zealand

AUSRIVAS
Australian River Assessment Scheme

BACI
Before–after, control–impact

Benchmark
a standard or point of reference

Benthic
referring to organisms living in or on the sediments of aquatic habitats

Bioassay
a test used to evaluate the relative potency of a chemical by measuring its effect on a living organism relative to a control

Bioavailable
able to be taken up by organisms

Biochemical oxygen demand (BOD)
the decrease in oxygen content in a sample of water that is brought about by the bacterial breakdown of organic matter in the water

Bivalve
mollusc with a shell in two parts, hinged together

Bloom
an unusually large number of organisms of one or a few species, usually algae, per unit of water

BOD
Biochemical oxygen demand

Cation
a positively-charged ion

Chemical oxygen demand (COD)
the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant

COAG
Council of Australian Governments

COD
Chemical oxygen demand

Community
assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another

Concentration
the quantifiable amount of a substance in water, food or sediment

Contaminants
biological or chemical substances or entities, not normally present in a system, capable of producing an adverse effect in a biological system, seriously injuring structure or function

Control
part of an experimental procedure that is ideally exactly like the treated part except that it is not subject to the test conditions. It is used as a standard of comparison, to check that the outcome of the experiment is a reflection of the test conditions and not of some unknown general factor.

Criteria (water quality)
scientific data evaluated to derive the recommended quality of water for different uses

CSIRO
Commonwealth Scientific and Industrial Research Organisation

Detection limit
method detection limit is the concentration of a substance which, when processed through the complete analytical method, produces a signal that has a 99% probability of being different from the blank

Duplicate samples
obtained by dividing a sample into two or more subsamples, to reveal the sizes of random and/or systematic errors due to contamination

EC (Electrical conductivity)
the ability of water or soil solution to conduct an electric current; commonly used as a measure of salinity or total dissolved salts

Environmental values
particular 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 contaminants, waste discharges and deposits. Several environmental values may be designated for a specific waterbody.

EPA
Environment Protection Authority

Eutrophication
enrichment of waters with nutrients, primarily phosphorus, causing abundant aquatic plant growth and often leading to seasonal deficiencies in dissolved oxygen

Fate
occurrence of a material in various environmental compartments (e.g. soil or sediment, water, air, biota) as a result of transport, transformation and degradation

Guideline
numerical concentration limit or narrative statement recommended to support and maintain a designated water use

Guideline trigger levels
the concentrations (or loads) for each water quality parameter, below which there exists a low risk that adverse biological (or ecological) effects will occur. They are the levels that trigger some action, either continued monitoring in the case of low risk situations or further ecosystem-specific investigations in the case of high risk situations.

Hardness
a measure of the sum of the concentrations of calcium and magnesium ions in water, both expressed as mg/L calcium carbonate equivalent

Hypothesis
supposition drawn from known facts, made as a starting point for further investigation

Index (indices)
composite value(s) that can give a quick ranking to a waterbody or other ecosystem feature, derived via a formula that combines measurements of important ecosystem characteristics; typically used to rank ‘health’ or naturalness

Indicator
measurement parameter or combination of parameters that can be used to assess the quality of water

Invertebrates
animals lacking a dorsal column of vertebrae or a notochord

Ion
an electrically charged atom

Measurement parameter
any parameter or variable that is measured to find something out about an ecoystem

NATA
National Association of Testing Authorities of Australia

NHMRC
National Health and Medical Research Council

NWQMS
National Water Quality Management Strategy

Organism
any living animal or plant; anything capable of carrying on life processes

Oxidation
the combination of oxygen with a substance, or the removal of hydrogen from it, or, more generally, any reaction in which an atom loses electrons

Parameter
a measurable or quantifiable characteristic or feature

Pathogen
an organism capable of eliciting disease symptoms in another organism

Periphyton
organisms attached to submerged plants

Pesticide
substance or mixture of substances used to kill unwanted species of plants or animals

pH
the intensity of the acidic or basic character of a solution, defined as the negative logarithm of the hydrogen ion concentration of a solution

Plankton
plants (phytoplankton) and animals (zooplankton), usually microscopic, floating in aquatic systems

Precipitation
the settling out of water from cloud, in the form of rain, hail, fog, snow, etc. (also the formation and settling out of solid particles in solution)

Protocol
a formally agreed method and procedure for measuring an indicator, including sampling, sample handling procedures and sample analysis

QA/QC
Quality assurance/quality control

Quality assurance (QA)
the implementation of checks on the success of quality control (e.g. replicate samples, analysis of samples of known concentration)

Quality control (QC)
the implementation of procedures to maximise the integrity of monitoring data (e.g. cleaning procedures, contamination avoidance, sample preservation methods)

Redox
simultaneous (chemical) reduction and oxidation: reduction is the transfer of electons to an atom or molecule; oxidation is the removal of electrons from an atom or molecule

Reference condition
an environmental quality or condition that is defined from as many similar systems as possible and used as a benchmark for determining the environmental quality or condition to be achieved and/or maintained in a particular system of equivalent type

Replicates
two or more samples collected simultaneously to establish the reproducibility of sampling

Risk
a statistical concept defined as the expected frequency or probability of undesirable effects resulting from a specified exposure to known or potential environmental concentrations of a material, organism or condition. A material is considered safe if the risks associated with its exposure are judged to be acceptable. Estimates of risk may be expressed in absolute or relative terms. Absolute risk is the excess risk due to exposure. Relative risk is the ratio of the risk in the exposed population to the risk in the unexposed population.

Salinity
the presence of soluble salts in water or soils

Sediment
unconsolidated mineral and organic particulate material that is suspended or has settled to the bottom of aquatic environments

Species
generally regarded as a group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not normally breed with members of another group. (Chemical species are differing compounds of an element.)

Stakeholder
a person or group (e.g. an industry, a government jurisdiction, a community group, the public, etc.) that has an interest or concern in something

Standard, e.g. water quality standard
an objective that is recognised in environmental control laws enforceable by a level of government

Stressors
the physical, chemical or biological factors that can cause an adverse effect on an aquatic ecosystem as measured by the condition indicators

Suspension
very small particles (solid, semi-solid, or liquid) more or less uniformly dispersed in a liquid or gaseous medium

Taxon (taxa)
any group of organisms considered to be sufficiently distinct from other such groups to be treated as a separate unit (e.g. species, genera, families)

Toxicant
a chemical capable of producing an adverse response (effect) in a biological system, seriously injuring structure or function or producing death. Examples include pesticides, heavy metals and biotoxins (i.e. domoic acid, ciguatoxin).

Toxicity
the inherent potential or capacity of a material to cause adverse effects in a living organism

Toxicity test
the means by which the toxicity of a chemical or other test material is determined. A toxicity test is used to measure the degree of response produced by exposure to a specific level of stimulus (or concentration of chemical).

True colour
the colour of water resulting from substances that are totally in solution; not to be mistaken for apparent colour which includes the effects of colloidal or suspended matter

USEPA
United States Environmental Protection Agency

Zooplankton
see plankton

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