# Chapter Two
# Setting Monitoring Program Objectives

## 2.1. Introductory Overview

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. Good monitoring programs are not just exercises in data collection.

Before defining the objectives and information requirements, the first step is to identify the issues that are to be addressed. After a comprehensive analysis of the issues, the monitoring team should understand what information is needed, and be able to formulate the specific objectives for the monitoring program.

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 reflect the uses that can be made of the water body, perhaps by aquatic ecosystems, or as water supply for primary industries (irrigation, stock drinking water, agriculture and aquaculture), or for recreational use and aesthetics, or for drinking water. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, from now on termed the Water Quality Guidelines (ANZECC & ARMCANZ 2000) has been developed so that these values can be protected.

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.

This chapter outlines the process for translating issues into monitoring program objectives, as illustrated in Figure 2.1 and Table 2.1.

As part of the objective-setting exercise, it is instructive to make a preliminary assessment of the issue and then develop a conceptual model that can form the basis of the proposed monitoring study.

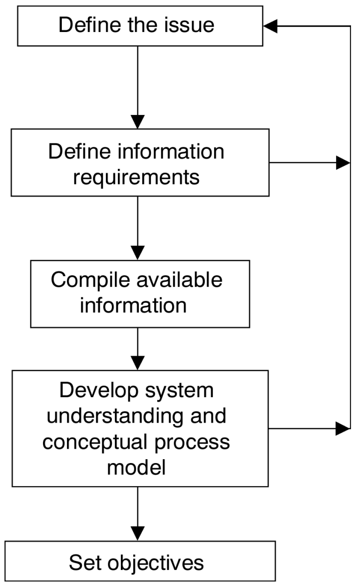


**Figure 2.1.** Framework for setting monitoring program objectives

**Table 2.1.** Checklist for determining information needs and monitoring program objectives

| | |
|---|---|
| 1. | Has the issue or question been defined? |
| 2. | Have the identities of all the information users been ascertained, so that information is obtained that will address all the stakeholders' needs? |
| 3. | Has all the available information relating to the issue or problem been collected, checked, and put into a common form? |
| 4. | Have knowledge gaps been identified and the information obtained, or have the limitations and restrictions of not having that information been evaluated? |
| 5. | Has a shared conceptual process model of the system been developed and made explicit? |
| 6. | Have the assumptions underlying the model been made explicit? |
| 7. | Has an analysis been undertaken to identify the essential information required? |
| 8. | Are specific objectives<br>(a) clear and concisely defined?<br>(b) sufficient to specify what is to be achieved?<br>(c) specific enough to indicate when each stage is complete? |

## 2.2. Defining the Issue

To define the issue, problem or question to be answered by the monitoring program, its monitoring team must interact with the end-users of the information and the stakeholders for that area. The stakeholders may be individual residents, a community group, an industry group, a government jurisdiction, and they may be found in the local area or downstream or upstream.

The definition of the issue or problem will emerge during or after discussions between the stakeholders and the monitoring team. It will be a result of the values they hold to be important, their previous knowledge and their experience. The manner in which the problem is viewed may be a major factor in determining its outcome (Miller et al. 1960), but the initial statement of the problem or question may be the most crucial single factor in determining whether a solution can be found. Bardwell (1991) identified some pitfalls to be avoided when specifying a problem:

- solving the wrong problem through not understanding the underlying issues;
- stating the problem in a way that no solution will be possible;
- premature acceptance of a possible solution before the problem is properly understood;
- use of information that is incorrect or irrelevant.

If a problem can be redefined or reframed, and conceptually explored, the monitoring team may see a larger range of alternatives and solutions to be examined or information to be obtained, and the ultimate monitoring program may benefit.

Some typical issues for new monitoring programs could include:

- excess nutrients, leading to algal blooms;
- salinity, leading to water being unacceptable for drinking or agricultural use, and having effects on aquatic ecology;
- contaminants, having acute or chronic effects on aquatic organisms or limiting water use;
- contaminants, being accumulated by biota with potential later effects on the health of human consumers;
- microbial contamination, from human or animal wastes, making water unsuitable for drinking or recreational use;
- maintenance of dissolved oxygen;
- effects of suspended particulate matter;
- effects of temperature changes;
- effects of pH changes.

Some of these are discussed in more detail in the Water Quality Guidelines (ANZECC & ARMCANZ 2000).

## 2.3. Compilation of Available Information

The next step in this preliminary stage of designing a monitoring program is to collect the available information relating to the issue at hand. Depending on the issue this step could entail a comprehensive literature review of current international understanding, or a review of relevant previous monitoring information collected either for the site of interest or for other locations, or interviews and recording of observations and evidence gathered by members of the local community. It is important that scarce funds are not spent merely to repeat studies on the issue or at the site of interest. However, information gained in previous investigations will help refine the information requirements and objectives of the present monitoring program.

The monitoring team will need to identify gaps in the assembled knowledge, and fill them if possible. If they cannot find the information, they must assess the limitations and restrictions caused by not having that information.

Existing data will probably consist of water quality measurements, stream-flow records and some biological data. Some of these data may have been published; others may be in the records of various agencies or research providers. They will need collection, checking and standardising into a common form using suitable data storage practices (see section 5.4.1).

## 2.4. Understanding the System and Formulating Conceptual Process Models

Once the issue for monitoring has been defined and the available information about it has been assembled, it is time to decide upon the questions that the monitoring program must tackle — its objectives. This is only really possible if the monitoring team has some preliminary understanding of the ecosystem for which the monitoring program is being designed. 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. The model need only be a simple box diagram that illustrates the components and linkages in the system to be monitored. It presents the factors that are perceived to be driving the changes in the system and the consequences of changes to these factors. For instance, in eutrophication studies, nutrients are commonly shown as the driving factors, while chlorophyll or algal cells are the consequences. Examples of conceptual models are shown in Figures 2.2–2.5.

Conceptual process models are important in defining the ‘why’ questions. After they have been shared with colleagues and argued about, conceptual process models set out the monitoring team’s collective knowledge, experience and perspectives of the ecosystem that is the basis of the study. The final model illustrates the team’s assumptions about how the system functions and what it believes to be the important or dominant processes. It is desirable for all team members to develop their own concepts of the system, and then to discuss and integrate these conceptual models. It should not be left to one team member, however experienced, because the differences between individual models can be important in clarifying the real issues and questions and in setting objectives.

Often the conceptual model will be based on accumulated wisdom as opposed to hard data. The monitoring team needs to articulate the assumptions underlying the model and to identify the gaps in information supporting these assumptions. The assumptions need to be critically reviewed because incorrect assumptions may lead to incorrect conclusions being drawn about information needs. One objective of the monitoring program will then be to collect data to validate these assumptions. However, all models are a simplification of reality and involve personal judgment. The models do not need to be comprehensive and embrace all components of the system; they only need to be adequate for the problem or question being investigated.

During the formulation of a model, several decisions must be made or the model will be too complex:

- what is the problem or issue of concern (e.g. nutrients, metal loads, bioavailable metals)?
- what subsystem (including ecosystem type) should the model describe (e.g. freshwater, marine waters, estuarine waters, wetland, seagrass bed, mangroves)?
- which state should the model describe (e.g. base flow, flood event)?

Once formulated, the process model can be used to help define:

- the important components of the system and the important linkages;
- the key processes;
- the cause–effect relationships;
- the important questions to be addressed;
- the spatial boundaries;
- valid measurement parameters for the processes of concern; what to measure, and with what precision;
- site selection;
- the time and seasonal considerations.

### 2.4.1. Recognising the Key Processes

The monitoring team must aim to identify the key processes that define the 'cause and effect' of the system, and 'how the system works', because these are fundamental to the conceptual process model.

The major processes that affect water quality are broadly classified as hydrodynamic, physical, chemical and biological, and include:

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

On the broadest scale, the monitoring team might be concerned with the sources and transport of contaminants, from a catchment to streams, rivers and estuaries. These form the basis of transport models, as shown for nutrients and metals in Figures 2.2 and 2.3.

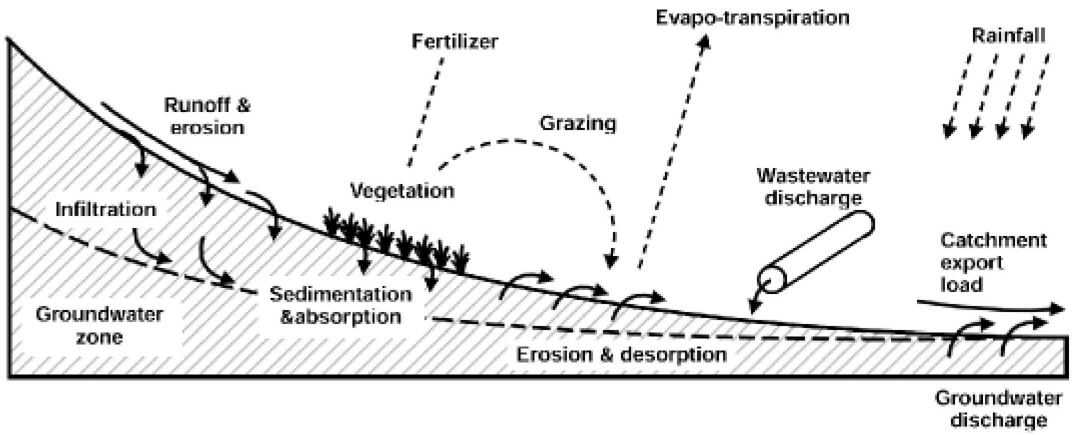


**Figure 2.2.** Model of sources and transport of nutrients through a landscape

The model in Figure 2.2 shows potential sources and transport of nutrients in the landscape. A more specific model might focus on a single water body, and the issue of concern in that water. Figure 2.4 illustrates a simplified model for phosphorus cycling in a stratified lake in relation to algal growth. The question that immediately arises is this: if you want to determine the extent of an algal bloom do you measure chlorophyll-*a*, algal cell counts in the water column, or some aspect of the scum? Further, if you wish to measure phosphorus concentrations in the water column, do you take the samples from the epilimnion or hypolimnion or both? (For this example, chlorophyll-*a* would probably be measured because it is a more reliable measure of algal biomass, and the samples would be taken from the epilimnion because this is where algal growth occurs.)

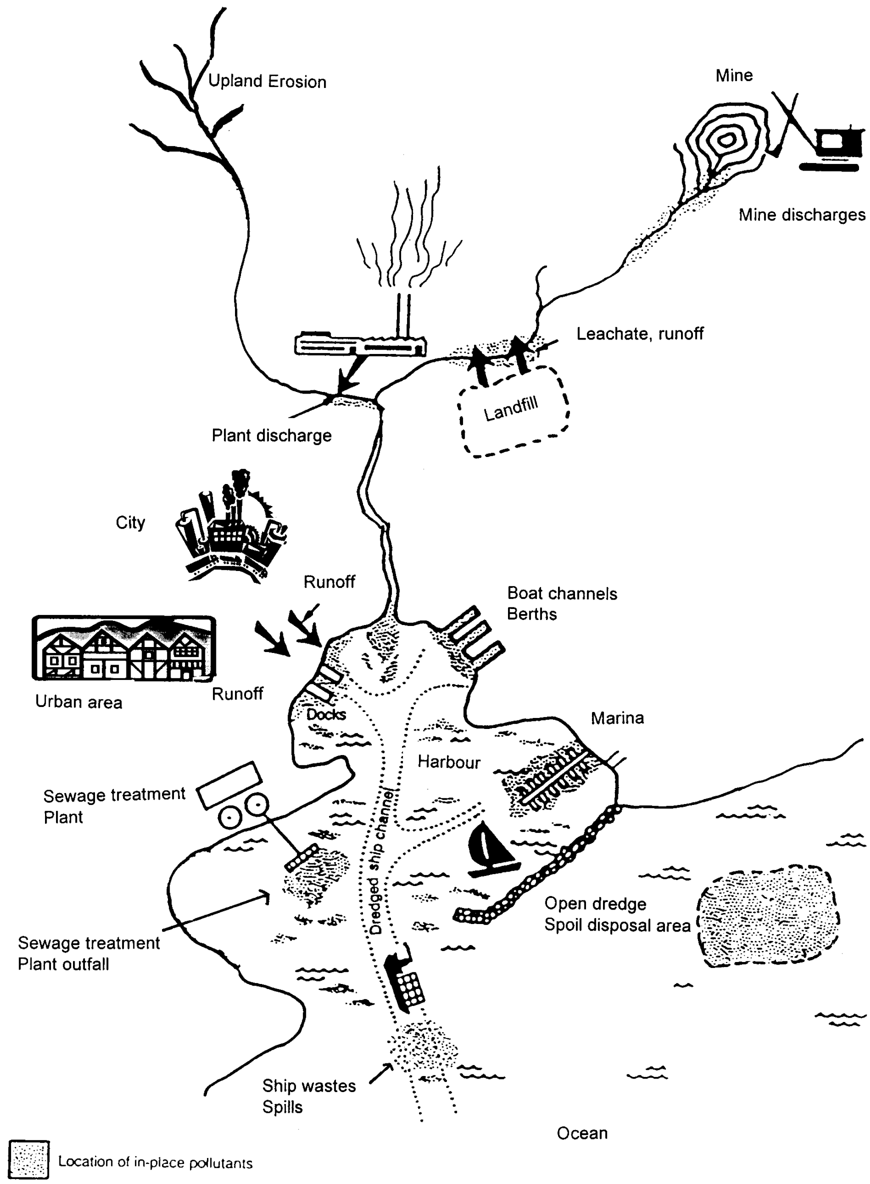


**Figure 2.3.** Model of sources of metal contaminants to the aquatic environment

Models can also include transformation processes — chemical, physical or biological. For example, Figure 2.5 illustrates the transformation processes that are associated with copper in a water body. Such models usually describe the chemical concentrations at thermodynamic equilibrium, and do not consider kinetics.

Kinetic models are based on the kinetics of reactions or growth, and are applicable when it is the rate of chemical reactions or biological growth that is important, rather than the thermodynamic equilibrium. These models can be used in describing the reactions of metals with particles, or biological growth processes such as the growth of algae or other organisms. The models are typically used for understanding oxygen utilisation, organism death and respiration, decay of pathogen populations, chemical and biological degradation of toxic substances, biodegradation of organic material, oxidation of organic and inorganic compounds, and excretion of toxic and non-toxic compounds by organisms.

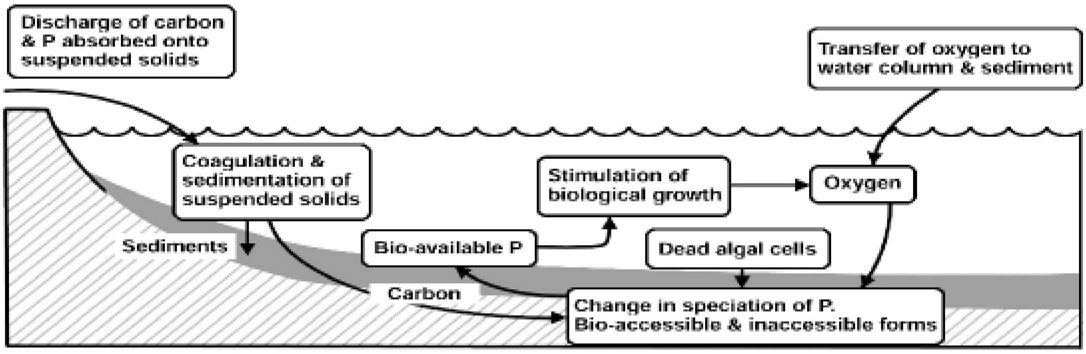


**Figure 2.4.** Model of in-lake or in-stream nutrient pathways

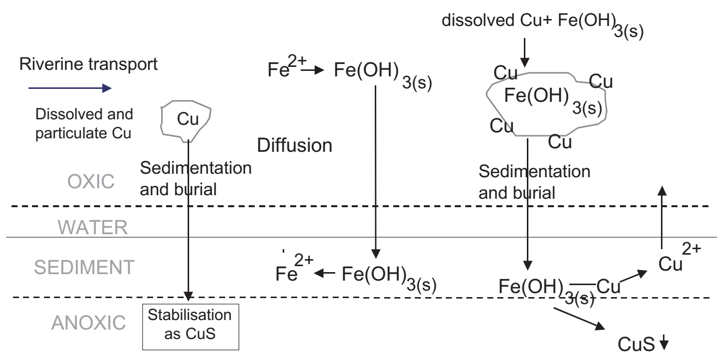


**Figure 2.5.** Model of pathways for copper in a water body

Models in the various climatic and geographic regions of Australia may differ. For example, conceptual process models will differ significantly between the wet tropics, the seasonally-dry monsoonal tropics, the arid interior, the temperate wet and the temperate Mediterranean regions. These factors can significantly affect study design, especially sampling strategies.

One of the limitations of using models is the assumption of continuity. In practice, the dominant processes may change as the previous state reaches some limiting condition. Different flow, mixing, chemical and redox regimes will turn alternate processes on and off.

It is important to be aware that the conceptual model being used might be wrong. Data that seem inconsistent can be important, leading to significant scientific breakthroughs from which new and more powerful conceptual models can evolve. 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.

### 2.4.2. Testable Hypotheses and Conceptual Models

A monitoring objective is often framed as a testable hypothesis and based on a conceptual process model. 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, such as these:

- variable A in a specified area or over a given time does not differ from a given baseline by more than some pre-defined difference;
- variable A in a specified area is not changed by more than some pre-defined amount per unit time;
- variable A (cause) is controlling variable B (effect).

Some hypotheses relevant to nutrient sampling might include these:

- phosphorus concentration is below (or above) the specified water quality guideline;
- phosphorus loading is controlling algal biomass;
- bioavailable phosphorus and nitrogen are limiting algal growth;
- phosphorus and nitrogen are being released from benthic sediments into the water column;
- in-flowing phosphorus is adsorbed by particles which settle to the bed of the lake;
- catchment activities have led to an increase in the annual phosphorus load to a lake.

A statistical hypothesis is a supposition based on available facts that can be subjected to a statistical evaluation, after further data have been obtained, to determine whether it can be accepted (or rejected). This sort of hypothesis is written in such a way that two outcomes are possible: either rejection or acceptance. The null hypothesis (that there is not a significant difference) can never be proved to be correct, but can be rejected, with known risks of doing so, by using statistical power analysis (Fairweather 1991). Any assumptions made when establishing hypotheses must be stated because their validity must be examined as part of the sampling design. If the hypothesis is rejected, the conceptual model should be refined.

There is some debate about the need to formulate a hypothesis. Monitoring is not always undertaken to overtly test some statistical hypothesis, although it almost always has a stated objective. Often, as Pratt (1976) noted,

> which hypothesis you are in is treated as overridingly more important than where you are in it. This is often an inappropriate view.

The requirement that monitoring be reduced to a null hypothesis and an alternative hypothesis is an artefact of classical statistical inference. Thus, hypothesis testing often forces the researcher to try to establish a significant difference between locations, say, instead of attempting to *describe* interesting spatial trends over a river reach.

The monitoring team must decide which of these approaches it will adopt in such cases because this will affect the data that need to be collected.

## 2.5. Setting Objectives

Once the monitoring team has defined the issue for monitoring, and has specified in general terms the information required from the monitoring program, and has 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.

Good monitoring objectives should be specific and precise, measurable, result-oriented, realistic and attainable, meaningful, concise and clear, and understandable. Clear objectives make it possible to design a sampling program to obtain the information required, but reviews of water quality monitoring programs in Australia show that inadequate objectives are a common problem. 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 the ANZECC & ARMCANZ water quality guideline trigger values for the protection of aquatic ecosystems in the receiving waters beyond the mixing zone.

Note that the objectives do not specify details such as sampling season or sampling frequency. Those are matters for the next stage, study design, described in Chapter 3.

Some examples of actual issues and resulting objectives are given in the four case studies in Appendix 4. For instance, 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 (see section A4.2.1). As another example, 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. 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 (see section A4.4.1).

The setting of objectives will commonly go beyond scientific issues by addressing 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.