Part 1
The Monitoring Framework

Introduction

Overview

Coastal environments are rich in natural and cultural resources and are the focus of economic, social, tourist and recreational activities. These demands, however, pose unique challenges for the sustainable management of our coasts.

Coastal and foreshore development, sewage treatment plant discharges, overflows from the sewerage system, septic tanks, stormwater discharges, disposal of human waste from boats, and even bathers themselves can all contribute to the faecal contamination of waterways. This pollution places swimmers and other users of recreational water at risk of contracting gastrointestinal disease; skin, eye and ear infections; hepatitis (Rose *et al*. 1999) and respiratory conditions.

The provision of safe recreational waters is the shared responsibility of Federal, State and local government, regional bodies and sewage and water service providers, as well as the community.

At the Federal level, the framework for protecting uses or environmental values of water resources is set out in the National Water Quality Management Strategy and the national guidelines for water quality. The national guidelines include the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000) and the *Australian Guidelines for Recreational Use of Water* (NHMRC 1990).

The NSW Coastal Council oversees the implementation of the NSW Coastal Policy and the delivery of the government's comprehensive Coastal Protection Package.

State agencies, such as the Department of Environment and Conservation (NSW) and the Department of Infrastructure, Planning and Natural Resources have a role in providing advice to stakeholders, preparing guidelines and protocols for water monitoring in NSW, and reporting on trends in water quality on a broad scale.

At a regional or catchment level, regional catchment management and water management bodies play an important role in identifying the actions required to improve water quality and address problems and thus achieve the agreed environmental objectives. Local councils often implement water quality monitoring programs on the ground. In this role, they work with the community to raise awareness and reduce the risk of potential threats to ecological and human health.

The NSW Government commissioned the Environment Protection Authority (EPA)[1] to undertake a pilot program in partnership with coastal councils to build capacity and provide support for improved monitoring of coastal recreational water quality.

This document gives local government and other water resource managers the practical information necessary to design and implement programs for monitoring and reporting on recreational water quality and devise effective management solutions.

[1]Since September 2003 the Department of Environment and Conservation (NSW) incorporates the EPA.

Its three key objectives are:

1. to raise awareness and understanding of water quality impacts associated with recreational water use
2. to improve the consistency and quality of monitoring of recreational water quality by local government and other water resource managers in NSW
3. to increase community access to information on recreational water quality.

Classification of recreational water use

The waters of NSW are used for a variety of leisure and recreational activities. These activities are classified into the following types of recreational use (ANZECC & ARMCANZ 2000, NHMRC 1990):

- **primary contact recreation**, characterised by full body immersion or submersion where there is direct contact with the water, including activities such as swimming, diving, water skiing and surfing
- **secondary contact recreation**, including activities such as paddling, wading, boating and fishing, where there is some contact with the water but the probability of swallowing water is unlikely
- **passive recreation**, which includes use of water bodies as pleasant places to be near or to look at, but no body contact with the water.

Primary and secondary contact recreation activities may expose individuals to health risks resulting from the presence of a variety of contaminants, including pathogenic organisms associated with faecal contamination. The visual amenity of waterways may be compromised by the presence of litter, surface scum and murky waters. However, there may be no direct health risk to the observer.

Primary contact activities expose individuals to the greatest health risk and for this reason are the focus of this document. Note that the term 'primary contact' is generally referred to as 'swimming' throughout this document.

Pilot recreational water quality monitoring programs

A draft version of this document was released in June 2002. Fifteen coastal local councils piloted 14 recreational water quality monitoring and reporting programs between October 2002 and April 2003. Ten councils extended their programs to July 2003, primarily to undertake monitoring in response to wet weather.

The pilot programs were designed to test all aspects of the draft protocol and identify any practical difficulties faced by local councils in using the protocol. The results of the pilot programs have been used to develop this final document and, in particular, to make it more user-friendly for local councils.

Benefits of using this protocol

Local councils and other water managers who use this document for recreational water quality monitoring and reporting will receive a number of benefits, including:

- quality assured water quality data for present and future use

- the ability to compare data collected between different regions
- community confidence because a scientifically rigorous and credible monitoring and reporting protocol is being used.

The Department of Environment and Conservation (DEC) will be able to provide quality assurance services to the organisations using the protocol including:

- field sampling audits to ensure appropriate monitoring methods are adhered to
- verification and storage of bacterial data in a centralised water quality database managed by DEC
- uploading of water quality data to the website, www.soedirect.nsw.gov.au, on a monthly basis, giving the general public easy access to water quality data
- help in designing water quality monitoring programs and reporting this information to the community.

Monitoring programs

Monitoring water quality over a large geographic area or over a long time frame can be prohibitively expensive. The key to minimising cost is to develop a targeted monitoring program that meets specific regional priorities and can be easily integrated with existing council activities.

This document provides a step-by-step approach to implementing a targeted water quality monitoring program. The necessary background information required for each step is also provided.

Figure 1 outlines the step-by-step framework for water quality monitoring of recreational waters.

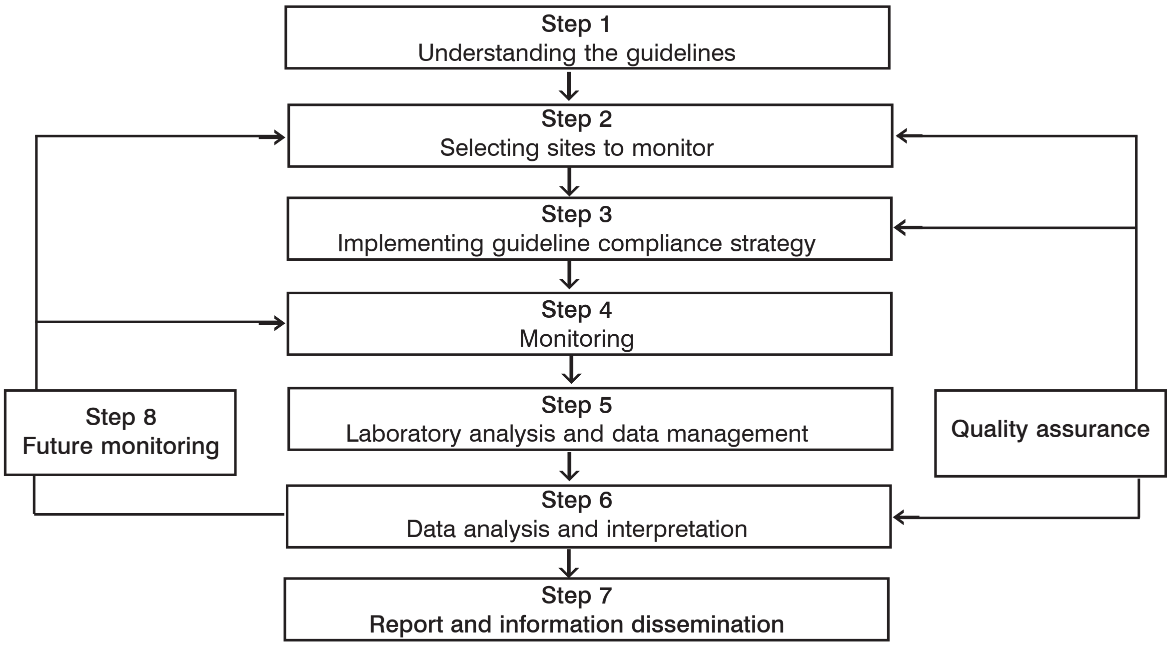


Figure 1: Water quality monitoring framework for recreational waters

Step 1 – Understanding the recreational water quality guidelines

A thorough understanding of the current recreational water quality guidelines is required before undertaking any recreational water quality monitoring and reporting program. This section contains information on the NHMRC (1990) guidelines. Appendix A presents details of human health issues related to recreational water quality.

Step 2 – Selecting monitoring sites

A risk-based process for evaluating and classifying beaches is presented. A range of readily available information is used to determine monitoring needs. The conceptual model of the beach that is developed during the evaluation process provides the preliminary understanding needed to evaluate and prioritise sites for specific local needs and available resources.

Step 3 – Implementing a guideline compliance monitoring strategy

This section provides details on the design of a monitoring program in accordance with the requirements of the NHMRC (1990) guidelines. It provides guidance on setting the scope of the study, sampling frequencies and measurement parameters.

The guideline compliance monitoring strategy is recommended to be used at selected sites until sufficient water quality data have been collected to adequately assess site performance. In most cases this may be for at least three swimming seasons or 100 samples. You can make an adequate assessment from only one season if a range of weather conditions is represented during the compliance monitoring period.

The guideline compliance strategy is the primary focus of this document, and monitoring results can be directly referenced to the national guidelines.

Step 4 – Monitoring

Once the monitoring strategy has been developed, the next step is to fill in all the details needed to implement the strategy in the field. This section gives details of sampling procedures, occupational health and safety considerations, and quality assurance and quality control requirements. Technical information and an example field manual are provided in Parts 2 and 3.

Step 5 – Laboratory analysis and data management

This section provides information on laboratory requirements, analytical methodologies, quality assurance and data handling issues.

Step 6 – Data analysis and interpretation

This section provides detailed advice on methods of data analysis, quality assurance and presentation of water quality results.

Step 7 – Reporting and dissemination of information

This section describes the development of a communication plan and the range of media that can be used to disseminate information to the public on recreational water quality.

Step 8 – Future monitoring

Water quality data derived from the compliance monitoring strategy may highlight areas of poor water quality. Depending on needs and available resources, it may be prudent to adopt other monitoring strategies that investigate the effects of rainfall on particular swimming locations or monitor potential pollution sources. Three monitoring designs that can be used for this purpose are presented, together with technical details in the appendixes.

Step 1 Understanding the recreational water quality guidelines

The National Water Quality Guidelines (ANZECC & ARMCANZ 2000) show how to establish the environmental values or uses for a waterway – such as primary contact recreation – and nominate a range of indicators that can be used to measure water quality and the associated criteria to achieve that use. The guidelines have been derived to provide guidance on the ambient water quality needed to protect these environmental values or uses in the future. Exceeding the recommended levels is a warning that management action may be needed or that there is a risk, but it does not necessarily indicate that a particular impact has occurred. In the case of recreational water quality, guidelines are based on potential human health impacts. Health issues relating to recreational water quality are presented in Appendix A.

The NSW Government has agreed on Water Quality Objectives (WQOs) – developed using the framework outlined in the National Water Quality Management Strategy and incorporating environmental values and associated criteria – for all the State's waterways, including estuaries and coastal lagoons. The government is also developing Marine Water Quality Objectives for NSW coastal waters.

The results of monitoring should be used to determine whether WQOs are being met. If they are, all relevant management bodies should be aiming to protect these WQOs. Where the WQOs are not being met, the relevant management agencies should formulate plans and undertake activities that will improve water quality.

New Australian recreational water quality guidelines are currently being drafted under the National Water Quality Monitoring Strategy, and these may result in changes in the future.

For bacteriological monitoring, the *Australian Guidelines for Recreational Use of Water* (NHMRC 1990) can be used until the new national guidelines are available.

The NHMRC (1990) microbiological guidelines are presented below.

It is considered that marine or estuarine waters are unsuitable for swimming if, for five samples taken at regular intervals not exceeding one month:

- *the median faecal coliform density exceeds 150 colony forming units/100 mL, or*
- *the second-highest faecal coliform density is equal to or greater than 600 colony forming units/100 mL, or*
- *the geometrical mean enterococci density exceeds 33 colony forming units/100 mL.*

In addition to the NHMRC guidelines, the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000) has a chapter on recreational water quality and aesthetics. Both NHMRC (1990) and ANZECC & ARMCANZ (2000) include criteria for a range of microbiological, physical and chemical parameters.

The use of this protocol does not require you to monitor additional physical and chemical parameters, but you should consider these, depending on your monitoring objectives. Appendix B provides a summary of the NHMRC (1990) and ANZECC & ARMCANZ (2000) guidelines, as well as other international guidelines.

Selecting monitoring sites

Step 2

Overview

The resources you need for comprehensive monitoring may not always be available. This does not mean that you should neglect monitoring and reporting of recreational water quality altogether. Monitoring and reporting programs can be tailored to meet specific local needs and available resources. The key to achieving this is to identify and prioritise swimming locations on the basis of their use, importance to the local community, and the potential for pollution to affect the site.

This section describes a priority evaluation and classification system that can greatly help local councils and other water resource managers to determine their monitoring needs. The approach is based on a qualitative risk assessment that uses readily available information on pollution sources and beach use. Swimming locations are then classified according to priority (i.e. high, medium or low).

The classification of beaches according to priority provides a basis for determining the allocation of resources. Swimming locations classified as high priority should attract more monitoring and reporting resources to ensure that the greatest benefit is obtained.

The priority evaluation process generates a conceptual model of the site that includes pollution sources, their potential impact, and the importance of the site to the local community. The model is developed in tandem with the priority evaluation using the accumulated wisdom and knowledge of an area.

In most cases, the conceptual model will be built on assumptions rather than hard data and will involve a degree of personal judgment. Wherever possible, the priority evaluation should be done as a team exercise. As data and information become available, the conceptual model should also be tested to ensure that it is accurate and that the monitoring is appropriate.

As the priority evaluation is qualitative and subjective, beach classifications may not be comparable between council areas. If councils or organisations wish to pool resources and collaborate on a monitoring and reporting program, they should go through the priority evaluation process together.

At the completion of Step 2 your monitoring needs have been determined. This information is then used in Step 3 to design an appropriate compliance-based monitoring and reporting program.

Priority evaluation and beach classification

Identify swimming locations

The first requirement of the priority evaluation process is to make a list of all locations used by the community for swimming or other primary contact recreation activities such as surfing and diving. Areas where swimming is popular include surf beaches, bays, harbours, estuaries, lagoons, rivers and rock pools.

In many cases there may be more than one swimming location on a beach, bay or river. Factors to consider when identifying locations include the presence of a surf club; the presence of facilities such as toilets, showers and changing rooms; access points to the water such as parks or reserves; the presence of netted swimming enclosures; and areas that are commonly used by the public and, in particular, small children. Consider issues of public safety.

Briefly describe and map the location. The map can also be used to indicate the location of pollution sources.

All sites identified should be considered suitable for promotion as swimming locations by your organisation.

Priority rating matrix

By using a qualitative risk assessment approach, each swimming site is classified with a priority rating of high, medium or low. The classification is determined by using the priority rating matrix in Table 1 and is based on the following information:

- the *likelihood* of a contamination hazard at a swimming location, as determined by a review of the potential pollution sources
- the *consequence* of the contamination hazard, as determined by a review of beach use information.

Table 1: Priority rating matrix for determining beach classification

	Likelihood		
Consequence	Rare	Possible	Likely
Minor	Low priority	Low priority	Medium priority
Moderate	Low priority	Medium priority	High priority
Major	Medium priority	High priority	High priority

Source: Adapted from AS/NZS 1999

The methodology for determining the likelihood and consequence of the pollution occurring is described in the following sections and in Appendix C.

Likelihood of pollution

The next task is to identify and evaluate the potential sources of pollution at each site. The likelihood of pollution for the site is then rated as rare, possible or likely, in accordance with the qualitative definitions provided in Table 2. This rating is determined by considering the overall impact of all identified pollution sources, as described in Appendix C.

Table 2: Qualitative measures of likelihood of pollution

Rating	Description
Rare	May occur only in exceptional circumstances
Possible	Might occur at some time Some opportunity, reason or means to occur Infrequent or random recorded incidents Little anecdotal evidence
Likely	Expected to occur in most circumstances Considerable opportunity, reason and means to occur Regular reported incidents Good anecdotal evidence

Source: Adapted from AS/NZS 1999

The pollution sources that you should consider as part of this process include:

- sewage treatment plants (location of outfall, level of sewage treatment, history of bypasses and visible signs of sewage pollution at swimming location)
- discharges from sewer overflows
- discharges from stormwater drains, creek, rivers and lagoons (development within the catchment, volume of discharge, existing water quality data and visible signs of stormwater pollution at the swimming location)
- discharges from boats
- the use of on-site wastewater treatment facilities near a swimming site
- domestic and wild animals at the swimming location
- irrigation of sewage on dunes near the swimming site (known as ‘dune exfiltration’).

This list is not exhaustive and focuses on sources of faecal contamination. Where necessary, you will need to include additional known pollution sources in the assessment, such as the scale of urban or rural land use.

Appendix C gives details of the characteristics that you need to consider when determining the likelihood of pollution from each of the above sources. You should determine the likelihood for each individual source, and then weight it (as a percentage) according to the estimated contribution from each source. All weighted likelihoods can then be considered together to determine the overall likelihood of pollution for each site.

Evaluate the consequences

Finally, you must evaluate the consequence of the pollution hazard. The consequences of pollution are likely to be greater at a very popular beach where more people may come into contact with pathogens or at tourist beaches where reports of poor water quality may affect the local economy. The consequences may also be greater at beaches used by people with weaker immune systems, such as small children or the elderly. These factors are discussed in more detail in Appendix C.

Consequences are rated as minor, moderate or major in accordance with the qualitative definitions provided in Table 3. Not all elements of the description will necessarily match the beach-use data gathered. The goal of the exercise is to select the category that best suits the importance of the swimming location to the local community.

Table 3: Qualitative descriptions of consequences

Rating	Description
Minor	Location rarely used on weekdays
	Location occasionally used on weekends or holidays
	Few beach users enter the water
	Location not popular with children or the elderly
	Of little importance to the local economy
Moderate	Location occasionally used on weekdays
	Location frequently used on weekends or holidays
	Most beach users enter the water
	Location often used by children or the elderly
	Location of some importance to the local economy
Major	Location frequently used on weekdays, weekends and holidays
	Most beach users enter the water
	Location very popular with children or the elderly
	Location of great importance to the local economy

The conceptual model

The information compiled during the priority evaluation process also forms the basis of a conceptual model. The model can be a map-based diagram, such as that presented in Figure 2. It should include all identified pollution sources, information on the timing and extent of their impact, beach-use information and the findings of the priority evaluation. In practice, the priority evaluation and conceptual model are developed simultaneously and used to confirm outcomes.

The conceptual model highlights the important components of the system, the key processes, the cause–effect relationships, the spatial boundary, and any time or seasonal considerations. Development of the conceptual model is particularly useful in refining 'likelihood' and 'consequence' evaluations.

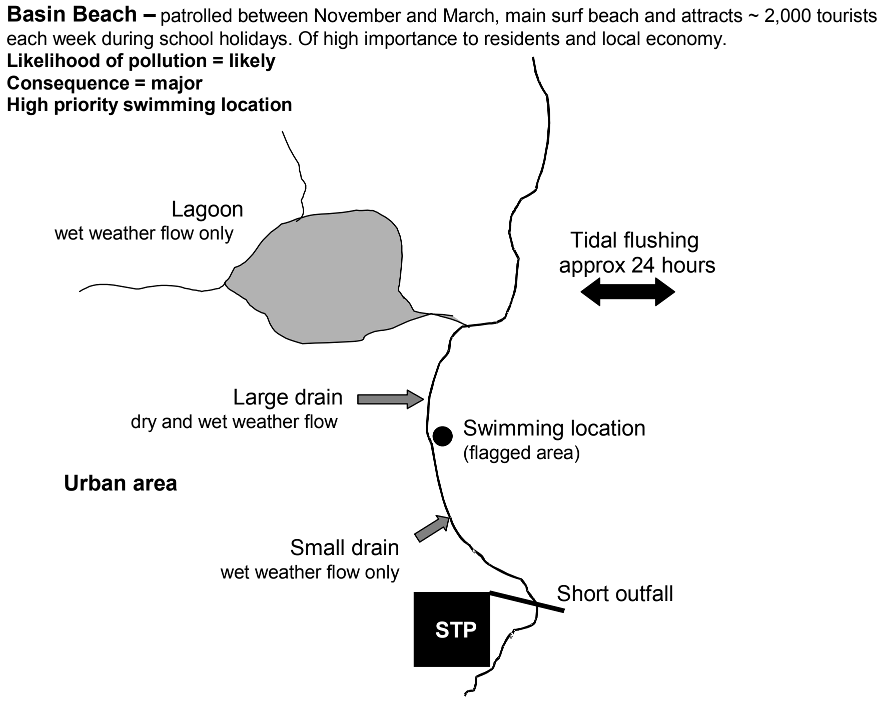


Figure 2: Map-based conceptual model for a hypothetical beach

Determine priority rating and monitoring need

Once the conceptual model has been developed and the likelihood and consequence ratings have been determined for each swimming location, you can select a priority rating by using the priority-rating matrix in Table 1.

The priority rating provides a valuable insight into the monitoring needs of a swimming site. A beach that has been classified as high priority is either of high importance to the community or is likely to be contaminated, or both. In any case, the high priority rating indicates that resources should be focused on the swimming site. The need for monitoring at beaches that have been classified as medium or low priority is less than for those classified as high priority. Where resources are available after the needs of high priority beaches have been met, the needs of medium and then low priority beaches can be addressed. It is recommended that you use compliance monitoring for high priority beaches. This monitoring strategy is discussed in detail in Step 3.

Step 3

Implementing a guideline compliance monitoring strategy

Overview

The primary strategy recommended for monitoring high-priority swimming sites is guideline compliance. This strategy is used to determine whether the swimming sites comply with the NHMRC 1990 guidelines. You should implement this monitoring strategy until sufficient water quality data have been collected to adequately assess site performance. In most cases this may be for at least three swimming seasons or 100 samples. You can make an adequate assessment with fewer data – say for one season – if a range of weather conditions is represented during the compliance monitoring period.

The objective of the guideline compliance monitoring strategy is to provide the community with information on the suitability of water quality for swimming over a swimming season. Guideline compliances can be compared between sites to determine which are the most suitable for swimming. Compliances can also be compared over time to assess long-term changes in water quality.

Guideline compliance monitoring will not, however, give beach users timely or accurate daily information on the suitability of a site for swimming.

To implement the guideline compliance strategy you need to consider the following issues.

Sample design

Sampling location

Always take samples for guideline compliance monitoring at locations where primary contact occurs (Note 2, NHMRC 1990). At patrolled beaches, this is likely to be between the flags, so the actual sampling location will move from day to day according to surf conditions. The swimming zone may therefore be several hundred metres wide. Therefore, consider any pollution sources that could affect one area of the zone more than others, for example a stormwater drain.

For unpatrolled beaches and other waterways, select the location where the majority of people swim. Also identify preferred swimming locations for small children, as these may coincide with ponded stormwater that may be contaminated, or areas where there is minimal flushing. Small children, as a group, are most at risk. Consider access points to the water and the presence of facilities when selecting the location.

Collect samples at knee depth within the ‘swash zone’ (the area of low waves near the shore). This has two distinct advantages. First, this is the area used by small children. Secondly, sampling near the shore reduces the risk to field samplers, who may have to sample on days when the beach or swimming location is closed because of dangerous conditions.

Sampling frequency

To assess compliance in accordance with the 1990 NHMRC water quality guidelines for primary contact recreation, a minimum of five bacterial samples must be collected each month. We recommend sampling on a six-day roster (although this is not mandatory), as this will ensure that all days of the week are sampled. The popularity of sites on weekends, the additional cost of weekend sampling, and the availability of laboratories for weekend sample analysis are important factors that you need to consider.

The 1990 NHMRC and 2000 ANZECC & ARMCANZ guidelines do not specify the frequency of sampling or the minimum number of observations required for measuring non-bacterial parameters, such as algae, pH and temperature. If your council chooses to monitor non-bacterial parameters, these measurements should coincide with bacterial sampling.

The time of day at which samples are collected must also be taken into consideration. Factors such as tides, winds, waves, pollution inputs and the number of swimmers present can all affect bacterial levels. There is also evidence that diurnal UV exposure affects bacterial levels. Where possible, the time of sampling should coincide with the time of highest risk. For example, if you know that a pollution source operates only in the morning, take samples in the morning; if afternoon winds are likely to drive pollution on shore, collect samples in the afternoon. Where there is unlikely to be a daily pattern in bacterial levels, sampling times should be randomised. Do this by beginning your sampling at different times of the day or by varying the order in which you sample swimming locations.

The duration of sampling during the year is defined typically by the length of the swimming season, which varies considerably according to climate. In the Sydney area the season is usually classified as the period from the beginning of October to the end of April.

Measurement parameters

The primary water quality parameters that are mandatory in this protocol are faecal coliforms and enterococci, as specified in NHMRC (1990). Depending on your council's needs, it may also be prudent to measure other parameters that are specified in ANZECC & ARMCANZ (2000).

Table 4 presents a range of parameters that can be measured for recreational water quality monitoring purposes. The methods for collecting the data are also specified.

Resource and planning issues

Experience shows that resource requirements are often underestimated. When planning the monitoring program, consider the duration of sampling; the frequency, number and type of samples collected; and data entry, analysis and reporting. Resourcing and planning issues highlighted by councils participating in the pilot program are discussed in Steps 4, 6 and 8.

Table 4: Measurement parameters for compliance monitoring

Parameter	Guideline	Method
Faecal coliforms*	Median of 5 samples not to exceed 150 faecal coliforms/100 mL and 4 out of 5 not to exceed 600 faecal coliforms/100 mL	Grab sample
Enterococci*	Geometric mean of 5 samples not to exceed 33 faecal coliforms/100 mL	Grab sample
Nuisance organisms**	Macrophytes, phytoplankton scums, filamentous algal mats, blue-green algae, sewage fungus and leeches should not be present in excessive amounts Primary contact discouraged if algal levels of 15 000 to 20 000 cells/mL are present (depending on algal species) Large numbers of midges or aquatic worms should be avoided	Observation + sample of algal blooms
Visual clarity and colour**	The horizontal sighting of a black Secchi disk should exceed 1.6 metres	Observation
pH**	Should be within the range of 5.0 to 9.0, assuming that the buffering capacity of the water is low, near the extremes of the pH limits (ideally around pH 7.4)	Field measurement
Temperature**	For prolonged exposure, temperature should be within the range of 15°C to 35°C	Field measurement
Surface films**	Oil and petrochemicals should not be noticeable as a visible film on the water, nor should they be detectable by odour	Observation
Toxic chemicals**	Refer to Appendix C for details	Sample***

* From NHMRC (1990)
** From ANZECC & ARMCANZ (2000)
*** Where the conceptual model indicates that toxic chemicals are likely to be present.

Monitoring

Step 4

Overview

The compliance monitoring strategy described in the previous step provides the basic outline of the program. The next stage is to implement this strategy in the field.

This section provides an overview of field sampling procedures, including field measurements, sample container requirements, sample collection methods and sample storage requirements, and is supported by the detailed information provided in Part 2: Field Manual. Occupational health and safety considerations, and quality assurance and quality control needs are also described.

Documentation

Field manual

Comprehensive and accurate documentation of sampling protocols is an essential component of any monitoring program. Use a field manual that you can take into the field for reference to document the procedures used for collecting, labelling, transporting and storing samples; taking field measurements; taking field notes; and recording the types and numbers of quality assurance samples required. The field manual should also contain detailed information on site location; access issues; occupational health and safety (OH&S) considerations; contact numbers for office, laboratory and any other relevant personnel; and copies of field sheets.

An example of a field manual is provided in Part 2. It can be modified to meet the individual requirements of monitoring programs.

Chain of custody

It is important to be able to track all samples from collection through to the laboratory. Chain-of-custody documentation serves this purpose and is recommended. An example of a chain-of-custody form is included in Part 2: Field Manual.

Sampling procedure

Sampling equipment

Sample containers for bacterial analyses. The sample bottles used to collect water samples for bacterial analyses must be sterile. Reuseable bottles are suitable for collecting large numbers of samples, but they must be sterilised before each use. Bottles must therefore be able to withstand the sterilising conditions and the solvent actions of water. Wide-mouthed glass bottles with screw caps are frequently used, but they can break, causing loss of samples and injury to the sampler. Heat-resistant polycarbonate bottles are a practical substitute, although care must be taken when sterilising these.

Sample bottles should have a capacity of at least 250 mL. Consult the laboratory doing the analyses to determine their exact requirements.

Sample containers for algal analyses. It may be prudent to collect algal samples from sites that have a history of algal blooms. Sample bottles for algal samples should be dark-coloured and have a volume of at least 125 mL.

Sample containers for toxicant analyses. A wide range of toxicants is included in the ANZECC & ARMCANZ (2000) guidelines. If a toxic chemical is likely to be present, contact the analytical laboratory for advice on what sampling containers you need for the chemical of interest. Alternatively, the American Public Health Association's Standard Methods document can provide guidance (APHA 1998).

Sample collection, storage and transport

At each site, note the location, time of sample collection, condition of the water body and weather conditions on the field sheet and on the sample container. Waterproof, non-smearing labels are recommended for sample containers. An example of a field sheet is provided in Part 2: Field Manual.

There are specific sampling protocols for bacterial, algal and toxicant analysis. This is to ensure that a representative sample is taken and that results can be relied upon for further analysis and comparison with past and future sampling. For more detail on sampling procedure, storage and transport refer to Part 2: Field Manual.

Quality assurance and quality control

'Quality control' refers to the devising and implementing of safeguards to minimise corruption of data. These safeguards are required at every step of the process to ensure that the data collected are valid. 'Quality assurance' means testing the effectiveness of these safeguards.

Points at which data may be corrupted during the monitoring phase include:

- equipment preparation
- sample collection
- field notes
- storage and transport.

Equipment preparation

Quality control procedures. Make sure that sampling containers are cleaned in accordance with laboratory and standard procedures. Discard any sample container that is cracked, discoloured or damaged in any way, and store sample containers in a clean, dry environment.

Quality assurance procedures. Collect a *container blank* for one in every 10 containers. Containers are randomly selected and filled with sterilised water. Analysis of this water detects contamination from the container.

Sample collection

Quality control procedures. Provide training in sampling techniques. Provide a field manual that clearly marks site locations and sampling procedures.

Quality assurance procedures. Collect a *field blank* for one in every 10 samples collected. A field blank is prepared in the field. Sterilised water is taken into the field and the container is filled, handled and stored as if it were a real sample. A field blank will detect contamination by the sampler. Field sampling procedures should also be audited regularly.

Field notes

Quality control procedures. Include a sign-off point on each field sheet to promote double-checking of completeness and accuracy.

Quality assurance procedures. Do a regular audit of field sampling procedures.

Storage and transport

Quality control procedures. Include methods of sample preservation in the field manual. Ensure that samples stored on ice are not immersed in water. Samples generally need to be kept at 4°C after collection, but sample storage temperature requirements may vary, depending on what you are analysing the sample for.

Transport samples to the laboratory for analysis within 24 hours, and preferably within 6 hours.

Quality assurance procedures. Collect a *trip blank* on each sampling run. A trip blank can be used to assess cross-contamination of samples during storage and transport. Containers are filled with sterilised water, taken into the field, and stored and transported as if they were real samples.

Audit field-sampling procedures regularly.

Occupational health and safety

OH&S is a major issue that needs to be carefully considered when you are implementing any water quality monitoring program. OH&S issues are discussed in detail in Appendix F.

Resource and planning issues

Sampling twice in one week

The five-day-a-month compliance monitoring regime occasionally requires samples to be collected twice in one week. Results from the pilot monitoring program have shown that this interfered markedly with council officers' other duties, and in some instances the extra sampling was missed because of conflicting priorities. Careful planning is therefore required to accommodate this extra sampling.

Distance between sampling sites

You need to consider not only the number of sites, but also the distance between sites. Make conservative estimates of distances able to be travelled, as this may have OH&S implications for drivers and for the timely delivery of samples to the laboratory. Some councils in the pilot program had to reduce their numbers of sampling sites because the distances travelled were too great.

Step 5

Laboratory analysis and data management

Overview

This section contains information on selecting a laboratory, methods of analysis, quality assurance considerations, and data handling issues.

The laboratory

Accreditation

The analytical laboratory must be of a suitable standard. A good indication whether a laboratory has met a suitable minimum standard is its compliance with Australian Standards 3901, 3902, 3903, 3904, ISO 9000 accreditation or NATA (National Association of Testing Authorities) accreditation for the relevant analyses performed. Such laboratories have proved their performance to independent assessors and can ensure quality performance for their clients. Carefully assess any variation from recognised standard analysis procedures.

Other considerations

For analyses that must be undertaken within a short time frame, such as analysis of faecal coliforms and enterococci, the location of the laboratory is an important factor in the selection process. Ideally, the laboratory should be within two hours' drive of the last sample collection point. If the laboratory is outside this range, consider employing a courier to deliver samples to prevent driver fatigue in samplers.

The working hours of the laboratory must also be considered. As bacterial samples must be processed immediately, many laboratories will require delivery of samples by 4 pm or earlier. This may not be practical if there are a large number of sites to be sampled or if the distance from the study area to the laboratory is great. Where later sample delivery times are required, these will need to be negotiated with the laboratory and may incur additional cost.

Consider the laboratory's opening times. This will affect not only whether samples can be collected and submitted on the weekend, but also whether they can be collected later in the week. As bacterial analysis takes several days, samples collected on Thursday or Friday will need to be analysed on the weekend. If a laboratory does not work on weekends, sampling will need to be restricted to Monday, Tuesday or Wednesday.

Methods

Bacterial analysis

Ideally, a laboratory should use the standard methods listed below. However, if the standard methods are modified or another standard used, then evidence is needed that similar results can be obtained.

Faecal coliforms. Faecal coliform density should be analysed by using method 9222D of *Standard Methods for the Examination of Water and Wastewater* (APHA 1998).

Enterococci. Enterococcal density should be analysed by using method 9230C (a) mE Method (using either mE agar or Slanetz and Bartley medium) of *Standard Methods for the Examination of Water and Wastewater* (APHA 1998).

Detection limits. Detection limits for samples submitted for bacterial analysis will vary, and appropriate limits will need to be decided on. As a guide, the Department of Environment and Conservation's Beachwatch program requires that original analyses are able to detect between 1 and 10,000 cfu/100 mL, and that retest analyses are able to detect between 1 and 1,000,000 cfu/100 mL.

Confirmation of results. Microbiological laboratories offer two sets of results: presumptive and confirmed. For faecal coliforms and enterococci, presumptive results can be obtained within 24 and 48 hours, respectively. Confirmation tests require up to a further 48 hours of analysis. Thus, confirmed results can take up to five days. If presumptive results are used, a certain number of samples (e.g. 10 a month) should include the confirmation steps as a check on the accuracy of presumptive results.

Algal analysis

For details of the identification and toxicity testing of algal samples, refer to method 8080D of *Standard Methods for the Examination of Water and Wastewater* (APHA 1998).

Toxicant analysis

For details on analytical procedures for toxicants, refer to *Standard Methods for the Examination of Water and Wastewater* (APHA 1998).

Quality assurance

Errors in analysis

The objective of quality assurance and quality control in a laboratory is to minimise errors that may occur during analysis and reporting and thus ensure that data are accurate and reliable.

A system of tracing results is part of good laboratory practice and an essential requirement for accreditation. For each analysis, the laboratory should keep records of the samples analysed, the person doing the analysis, the equipment used, original data and calculations, any manual data transfers, and standards preparation.

Quality assurance of laboratory results can be achieved through a range of measures. For bacterial analyses, laboratories commonly use interlaboratory comparisons and duplicate samples.

Interlaboratory comparisons. Interlaboratory comparisons are a form of proficiency testing. Replicated samples are sent to the regularly used laboratory and to two or more additional laboratories. The results from all laboratories are combined to generate a consensus mean. The results from the regularly used laboratory are then compared against this value to determine the accuracy of its results. Although the consensus mean is not necessarily the true value, the more laboratories that are included in the program, the less the consensus mean will be affected by outlying values. All laboratories participating in a Beachwatch program should participate in an interlaboratory program coordinated by the Department of Environment and Conservation.

Duplicate samples. Duplicate samples are used for assessing precision. At least 5% of samples should be analysed in duplicate. Duplicate samples are obtained by collecting a sample in a sterilised 1-litre container, shaking vigorously for one minute to homogenise the sample, and then decanting this into two sterile sampling containers. The analysis of duplicate samples is standard procedure in laboratories.

Data handling considerations

Laboratory reports

Reports from the laboratory should include the name and address of the laboratory, tabulated samples and analysis data, identification of analytical methods used, date of analysis, name of the technician, and a quality assurance statement.

When you receive the laboratory report, check it and identify any anomalous data – such as unexpectedly high or low results. Cross-check the field sheets to identify any reason for the result: for example, discharges to the beach or pollution evident in the water. If the result cannot be explained, ask for a retest of the sample in the case of algal or toxicant samples. (This is not possible for bacteriological samples after 24 hours.)

So that retests can be done, the laboratory should store residual sample waters at 4°C for seven days after results have been provided. For bacterial analyses, test membranes and plates should also be stored at 4°C for one or two days after the results have been provided.

Data management

Develop clear and detailed written procedures for managing data. The procedures should include electronic file locations, location of stored hard-copy reports, step-by-step instructions for data screening, importing and archiving, and the mandatory quality assurance checks. Develop procedures for dealing with data that are below the detection limit or are considered not to be of high quality.

Regularly review the quality assurance results to quickly identify and rectify problems. Store these results in a database.

Step 6

Data analysis and interpretation

Overview

Data analysis is a major component of the investigation and monitoring of recreational water quality. Appropriate data analysis is needed so that pollution events and the health risks associated with recreational water use can be easily identified.

This section provides detailed advice on methods of data analysis and interpretation and presentation of results for your guideline compliance strategy.

Technical information and worked examples are provided in Appendix E.

Guideline compliance strategy

The national guidelines for recreational water quality (NHMRC 1990 and ANZECC & ARMCANZ 2000) recommend that the sample data for bacterial indicators are assessed monthly or seasonally. Both methods are outlined below.

Monthly compliance

Monthly compliance of bacteria is assessed as a pass or fail. A worked example of how to determine monthly compliance is presented in Appendix E.

Monthly assessment of the sample data allows more frequent reporting of compliance results to the community than a single report at the end of the bathing season. This method is also useful as an earlier indication of when and where further investigation may be required. A limitation of monthly assessments is the small number of data (a minimum of five bacterial samples) available for interpretation.

In addition, the monthly assessment could include the range of temperature and pH levels recorded over the month, algal bloom observations and notes on water clarity, if this information has been collected.

Monthly reports provide only limited insight into trends. Consider the following information when interpreting the results of monthly data:

- Elevated faecal coliform levels in the samples, whether or not enterococcal levels are also elevated, indicate regular contamination of the bathing waters by reasonably fresh sewage.
- Low faecal coliform levels or no faecal coliforms in the samples, but elevated enterococcal levels, indicate regular contamination of the bathing waters by aged sewage.
- When neither faecal coliforms nor enterococci are elevated, regular contamination of the bathing waters by sewage is not indicated.

Seasonal assessment

The recommended seasonal assessment methodology is the calculation of compliance as the fraction of months that passed guideline levels on a monthly basis. For example, a swimming season may be seven months and a particular swimming site may have passed the compliance guidelines for, say, five months within the swimming season. Therefore the seasonal compliance for that swimming site would be 5/7.

Resource and planning issues

The majority of councils that participated in the pilot monitoring and reporting program significantly underestimated the staff time required for managing and analysing data. These processes are essential for the success of any monitoring program. Estimate staff time conservatively and review it regularly.

Data management

Consider how long it will take to set up and maintain a database, data entries and quality checks. This may be of particular concern in small councils that do not have much computing support.

Data analysis

Insufficient planning for data management affects your capability for, and the timeliness of, data analysis. Consider setting up and maintaining spreadsheets that can automatically calculate compliances.

Reporting and information dissemination

Step 7

Overview

Reporting and information dissemination are integral components of the investigation and monitoring of recreational water quality. They are essential parts of raising the community's awareness and increasing its understanding of the potential pollution sources and health risks associated with recreational water use.

Keep reports of the monitoring of recreational water quality as simple as possible, and present results in clear and easy-to-interpret formats. Take care when interpreting data on recreational water quality, and clearly state whether or not the NHMRC (1990) guidelines on recreational water quality were followed.

This section will help you to develop a communication plan.

The communication plan

In many cases, recreational water quality is monitored to give the community information on a beach's suitability for swimming. If people are given this information they can make informed decisions about where and when to swim, and risks to public health can be greatly reduced.

An effective communication plan is therefore an essential component of a monitoring and reporting program for recreational waters. The following information is presented to help you identify the audience for beach water quality data and select suitable communication media.

Audience identification

The potential target audience for information on beach water quality must be identified and characterised. The characteristics of beach users will define the mode of communication you select. For example, a sign posted at a beach entrance may be suitable if most beach users live locally, whereas an additional message on a website or telephone line may be necessary where the beach is used by those living further away.

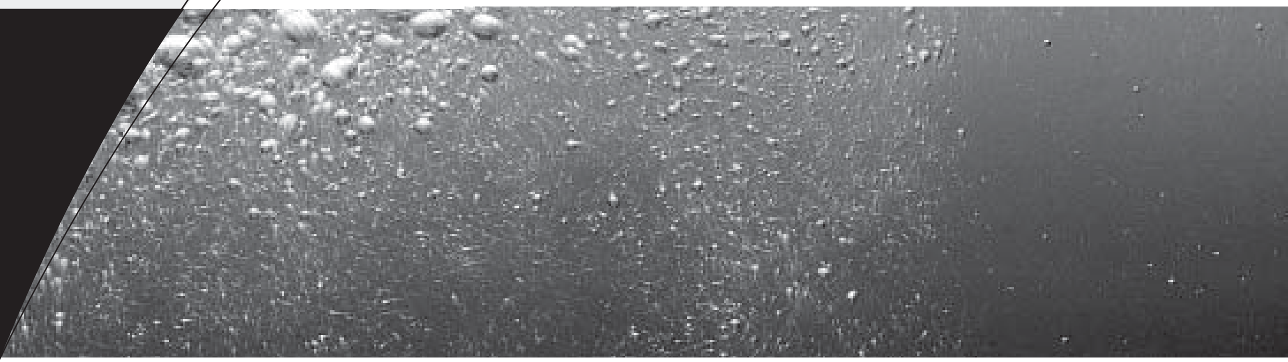
A survey of the public is a useful means of identifying the audience and gaining an understanding of public behaviour, knowledge and beliefs; and the information sources that people use to obtain information. Surveys can be mailed to residents, conducted over the telephone, or done on the beach itself. Information on undertaking a survey is given in Appendix H.

Methods of communication

The method of communication chosen will largely depend on the needs of the target audience and the objectives of the monitoring program. The methods that are most commonly used are:

- beach signs
- mass media (newspapers, television and radio)
- websites
- technical reports.

For more information on all of these methods and examples, refer to Appendix G.



Evaluation of your communication plan

Evaluate your communication plan regularly to ensure that it meets the needs of the public and the objectives of the council. Perform a summary evaluation at the end of the swimming season or holiday period.

A survey of the community and tourists could include questions on their knowledge of the health risks associated with swimming in contaminated water, recollection of advice, awareness of websites, and their level of media use and preferred media for communication. A do-it-yourself evaluation toolkit that includes survey questions and guidelines for telephone interviewing is presented in Appendix H.

Algal bloom response protocol

ANZECC & ARMCANZ (2000) recommends that people should not engage in direct contact activities if algal levels exceed 15,000 to 20,000 cells/mL, depending on the species present.

The Metropolitan and South Coast Regional Algal Coordinating Committee (2000) recommends that public health warnings for recreation should be issued when the abundance of known toxigenic species of blue-green algae exceeds 15,000 cells/mL or the total bio-volume of all blue-green algal species exceeds 2 mm^3/L.

Biotoxins produced by some algal blooms may cause gastrointestinal and neurological illness in humans and, in the most severe cases, death. In most cases, warning signs, media releases and the obvious presence of blooms should be enough to alert people to the risks of using water affected by algal blooms. However, responsible agencies may also need to close areas that pose an increased health risk. The most common estuarine and marine species are the blue-green algae *Trichodesmium* spp. and the ‘red tide’ forming non-toxic species *Noctiluca scintillans*.

In general, each council should follow the algal bloom response procedures outlined in the appropriate Regional Algal Coordinating Committee’s algal contingency plan. Each plan gives details of specific procedures for dealing with algal blooms in estuarine and marine waters.

If an algal bloom is observed in a marine or estuarine area, contact the relevant Department of Infrastructure, Planning and Natural Resources (DIPNR) office or the Department of Environment and Conservation:

- DIPNR’s Penrith office on (02) 4722 1188 (business hours) for areas between the Hawkesbury River and the NSW–Victorian border
- DIPNR’s Newcastle office on (02) 4929 9843 (business hours) for areas between the Hawkesbury River and Camden Haven
- DIPNR’s Grafton office on (02) 6640 2125 (business hours) for areas north of Camden Haven to the NSW–Queensland border
- Pollution Line on 131 555 (all hours) for all areas in NSW.

Future monitoring

Step 8

Overview

The primary monitoring strategy can be used not only to advise the community on the suitability of water quality for swimming, but also as a management tool to develop future monitoring strategies. Water managers should determine and use secondary strategies after sufficient water quality data have been collected and analysed under the compliance assessment strategy. Ideally, this equates to at least three seasons or 100 data records, but you may make a preliminary assessment with one season's data if a range of weather conditions is represented during the season.

The secondary strategies below have been provided for guidance only; where necessary and appropriate, you can devise alternative monitoring strategies.

The pilot monitoring programs indicated that planning and resourcing was a major issue for successfully undertaking secondary monitoring strategies. Most councils had difficulty rapidly responding to wet weather, a need that is central to these strategies. Planning and resourcing issues are discussed at the end of this section.

Verification of priority evaluation and conceptual model

The objective of this secondary monitoring strategy is to identify pollution sources and reassess your priority evaluation and conceptual model. If previous compliance monitoring indicates that a swimming site is affected by poor water quality, further investigation may be warranted.

Sample design

Collect samples from pollution sources such as drain, lagoon or creek outlets under the range of conditions in which they operate. For example, a stormwater drain that discharges in dry and wet weather should be sampled in both dry and wet weather.

The water quality data collected enables potential pollution sources to be identified and the conceptual model and priority evaluation to be reassessed. This information can also be used to develop remediation strategies.

Alternative sampling strategy

Your previous compliance monitoring may have indicated that the water quality in a sampling area deteriorates to unacceptable levels after rainfall. The objective of the alternative sampling strategy is to provide the community with guidance on how long to avoid swimming following rainfall.

Sample design

Collect samples during wet weather, with follow-up sampling each day after the event to establish the time it takes for bacterial levels to return to dry-weather levels. You can use this information to develop general warnings for the public, such as 'Avoid swimming for 24 hours after heavy rainfall'.

Collect additional dry-weather samples once a month during the swimming season to ensure that the baseline level of contamination does not vary significantly. The drawback of this approach is that data cannot be referenced to the national water quality guidelines, because samples will not necessarily be collected at the required frequency to determine a monthly pass or fail, or seasonal compliance.

Data analysis

The median faecal coliform criteria (150 cfu/100mL) and geometric mean enterococcal criteria (33 cfu/100mL) can be employed to estimate how long it takes for water quality to recover following rainfall. Dry-weather baseline water quality data obtained from previous compliance monitoring can also be used for the estimate. A worked example is provided in Appendix E.

Consider the following points:

- Elevated faecal coliform levels in the samples, whether or not enterococcal levels are also elevated, indicate contamination of the bathing waters by reasonably fresh sewage.
- Low faecal coliform levels or no faecal coliforms in the samples, but elevated enterococcal levels, indicate contamination of the bathing waters by aged sewage.

The advice

Advice on suitability for swimming should take the form of a general rule. The rule should reflect the findings of the monitoring, for example:

- Avoid swimming at all times.
- Avoid swimming during, and for 24 hours after, rain.
- Avoid swimming during, and for 48 hours after, heavy rain.
- Avoid swimming during, and for 72 hours after, heavy rain.
- Avoid swimming if the lagoon is open.

Communication plan

Signs are an effective way to communicate advice to the community on when not to swim. A permanent sign displaying the advice can be erected at the access points to the beach. Alternatively, lifeguards can erect temporary signs warning of pollution on particular days or can close the beach if necessary.

There may be legal implications in using some beach signs. Seek legal advice for particular signs and locations.

The information may also go out as a press release at the beginning of the swimming season or at the beginning of holiday periods. It may be useful to display the advice prominently on the council's website or on a flyer with rates notices. More information on developing a communication plan is given in Step 7 and Appendix G.

Predictive advice

For primary contact sites that are very popular, the objective of a sampling program may be to develop a predictive model for daily reporting. The aim is to overcome the time lag between sampling and obtaining results. Data from previous compliance monitoring can be used to develop the predictive model, but note that a large amount of data is required. Historical compliance data can be supplemented with data obtained from samples collected in response to a wide range of rainfall events.

One of the simplest models to develop is a rainfall-based alert curve. This model uses the statistical relationship between rainfall in the catchment and the measured bacterial indicator concentration at a specific swimming location. The methodology used to develop a predictive model is provided in Appendix D.

Communication plan

Daily advice must be provided through media that can be easily accessed. Not only does the advice need to be updated each morning, but rainfall during the day or reports of other pollution incidents may require further updates.

A website is an ideal medium for disseminating this information. It can be readily updated and include detailed information on pollution events, beach closures and beach conditions.

The daily reports can also be faxed to local radio stations, caravan parks or motels for display on public noticeboards, and to lifeguards for their information and display at the beach. More information on developing a communication plan is given in Step 7 and Appendix G.

Resource and planning issues

The secondary monitoring strategies are far less structured than the compliance monitoring strategy, and sampling is usually done in response to rainfall or pollution events. The pilot monitoring programs highlighted the need for thorough planning and commitment to adequately respond to these events.

In implementing a secondary monitoring strategy you should ask the following questions:

Are rainfall data readily accessible?

You may obtain these data from your own rain gauge or from the internet. Sampling staff need to be able to respond rapidly once rainfall triggers have been reached, particularly if this happens out of normal working hours.

Are staff available to do sampling on weekends and public holidays or beyond normal working times?

This is crucial, as rapid responses to rainfall events are generally required. The project budget might also account for out-of-hours work (overtime).

Is sampling equipment ready to be used at short notice?

Sampling containers, wet-weather gear, the field manual, Eskies and ice must be readily accessible and available at short notice. Samplers need to have a thorough understanding of monitoring requirements, which should be documented in the field manual.

Are you able to arrange transport of samples to the laboratory or on a one-off basis?

If sampling staff are unable to transport samples, will a courier be available, particularly outside normal working hours?

What are the operating hours of the laboratory?

You need to negotiate with the laboratory to accept samples for analysis seven days a week. However, this could result in significant increases in analytical costs.

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