



Australian Government

National Health and Medical Research Council

Guidelines for Managing **Risks in Recreational Water**





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National Health and Medical Research Council

**GUIDELINES FOR MANAGING RISKS
IN RECREATIONAL WATER**

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EXECUTIVE SUMMARY

The primary aim of these guidelines is to protect the health of humans from threats posed by the recreational use of coastal, estuarine and fresh waters. Threats may include natural hazards such as surf, rip currents and aquatic organisms, and those with an artificial aspect, such as discharges of wastewater.

These guidelines should be used to ensure that recreational water environments are managed as safely as possible so that as many people as possible can benefit from using the water.

These guidelines are not mandatory; rather, they have been developed as a tool for state and territory governments to develop legislation and standards appropriate for local conditions and circumstances. The aim of the guidelines is to encourage the adoption of a nationally harmonised approach for the management of the quality of coastal, estuarine and fresh waters used for recreation.

The guidelines do not directly address environmental aspects of the recreational use of water, but the environmental impacts of such use should be considered, because a healthy environment has many benefits for human health.

This document is divided into two parts:

- **Part 1: The guidelines** — Chapters 1 and 2, which provide a general overview of the management of recreational water, including a table of the key recommendations included in the guidelines; and
- **Part 2: Supporting information** — Chapters 3–10, which provide detailed information on potential hazards associated with recreational waters.

Figure A gives an overview of the structure of the guidelines and the key elements of the supporting chapters. Table A summarises the guidelines, including guideline values and specific comments.

The guidelines represent a major revision of the previous National Health and Medical Research Council (NHMRC) guidelines — *Australian Guidelines for Recreational Water Use* (NHMRC 1990). In particular, these new guidelines include a preventive approach to the management of recreational water that focuses on developing an understanding of all potential influences on a recreational water body, through local assessment and management of hazards and of factors that may lead to hazards.

This approach provides information on the local influences on recreational water quality, as well as numerical information on the likely level of contaminants. The results can be used to:

- classify beaches, to support informed personal choice;
- provide on-site guidance to users on the relative safety of the water;
- assist in identifying and promoting effective management interventions; and
- provide a basis for regulatory requirements, and an assessment of compliance with such requirements.

Potential adverse impacts on the health of recreational water users must be weighed against the enormous benefits to health and wellbeing (eg rest, relaxation and exercise) and to local economies that rely on water-associated recreational activities.

A key aspect of the preventive approach is the development of monitoring programs that can provide a real-time indication of water quality. To ensure safety in recreational water environments, the responsible management authorities should establish programs for evaluating existing hazards and monitoring the area for any changes that may occur. Such programs should be based on a code of good practice for recreational water monitoring. To protect public health, it will often be necessary to develop programs for monitoring several aspects (beach safety, pollution control etc) in parallel.

These guidelines suggest a three-level monitoring system, with each of the major hazard groups being dealt with at each level of monitoring. The suggested levels are:

- **Surveillance mode (green level)** — this level involves routine sampling to measure contaminants (eg physical, microbial, cyanobacterial and algal).
- **Alert mode (amber level)** — this level requires investigation into the causes of elevated contaminant levels, and increased sampling to enable a more accurate assessment of the risks to recreational users.
- **Action mode (red level)** — this level requires the local government authority and health authorities to warn the public that the water body is considered unsuitable for recreational use.

The guidelines also introduce the concept of grading water bodies according to their suitability for recreational use, based on contamination with microorganisms, cyanobacteria or algae. For microbial quality, recreational water can be classified by combining a sanitary inspection category with the microbial water-quality assessment category. For cyanobacterial and algal quality, the water is classified by combining a measure of the water body's susceptibility to algal contamination with an assessment of historical cyanobacterial monitoring results, to produce an overall 'suitability for recreation' classification.

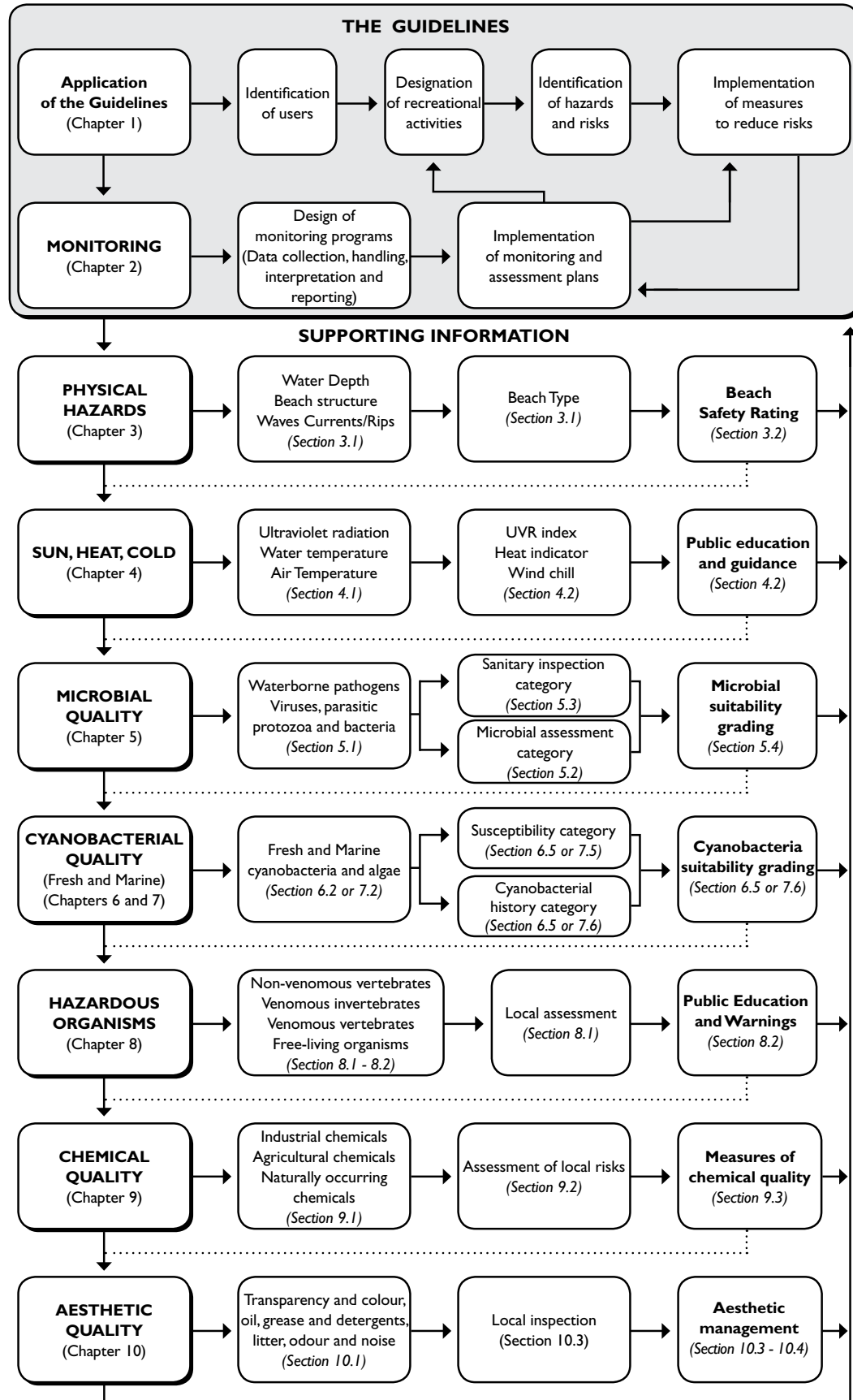
Figure A Structure of the guidelines for managing risks in recreational water

Table A **Summary of the Guidelines**

Characteristic	Guideline	Comment	Supporting information
Physical hazards	Recreational water bodies and adjacent areas should be free of physical hazards, such as floating or submerged objects that may lead to injury. Where permanent hazards exist, for example rips and sandbars, appropriate warning signs should be clearly displayed.	Injuries related to these objects may result during activities such as swimming, diving and water skiing.	Chapter 3
Sun, heat and cold water temperature	The temperature of recreational water bodies should be in the range 16–34°C. Recreational water users should be educated to reduce exposure to ultraviolet radiation (UVR), particularly during the middle of the day.	Exposure to cold water (<16°C) can result in hypothermia (excessive heat loss) or a shock response. Prolonged exposure to waters >34°C may result in hyperthermia (heat exhaustion or heat stress). Levels of UVR vary throughout the day, with a maximum occurring during the 4 hours around noon.	Chapter 4
Microbial quality	Preventive risk management practices should be adopted to ensure that designated recreational waters are protected against direct contamination with fresh faecal material, particularly of human or domesticated animal origin.	The main health risks are from enteric viruses and protozoa.	Chapter 5
Cyanobacteria and algae in fresh waters	Fresh recreational water bodies should not contain: • $\geq 10 \mu\text{g/L}$ total microcystins; $\geq 50\,000$ cells/mL toxic <i>Microcystis aeruginosa</i>; or biovolume equivalent of $\geq 4 \text{ mm}^3/\text{L}$ for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or • $\geq 10 \text{ mm}^3/\text{L}$ for total biovolume of all cyanobacterial material where known toxins are not present; or • cyanobacterial scums consistently present.	A single guideline value is not appropriate. Instead, two guideline values have been established, based on known risks associated with known toxins and probability of health effects caused by high levels of cyanobacterial material. A situation assessment and alert levels framework for the management of algae/cyanobacteria in recreational waters has been developed that allows for a staged response to the presence and development of blooms.	Chapter 6
Cyanobacteria and algae in coastal and estuarine waters	Coastal and estuarine recreational water bodies should not contain: • ≥ 10 cells/mL <i>Karenia brevis</i> and/or have <i>Lyngbya majuscula</i> and/or <i>Pfiesteria</i> present in high numbers.	A situation assessment and alert levels framework for the management of algae/cyanobacteria in recreational waters has been developed that allows for a staged response to the presence and development of blooms.	Chapter 7
Dangerous aquatic organisms	Direct contact with venomous or dangerous aquatic organisms should be avoided. Recreational water bodies should be reasonably free of, or protected from, venomous organisms (eg box jellyfish and bluebottles). Where risks associated with dangerous aquatic organisms are known, appropriate warning signs should be clearly displayed.	Risks associated with dangerous aquatic organisms are generally of local or regional importance and vary depending on recreational activities.	Chapter 8

Characteristic	Guideline	Comment	Supporting information
Chemical hazards	Waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes.	Chemical contamination can result from point sources (eg industrial outfalls) or from run-off (eg from agricultural land). All chemical contaminants should be assessed on a local basis.	Chapter 9
pH	6.5–8.5	A wider pH range of 5–9 is acceptable for water with a very low buffering capacity.	Chapter 9
Dissolved oxygen	> 80%	When considered with colour and turbidity, dissolved oxygen is an indicator of the extent of eutrophication of the water body.	Chapter 9
Aesthetic aspects	Recreational water bodies should be aesthetically acceptable to recreational users. The water should be free from visible materials that may settle to form objectionable deposits: • floating debris; • oil, scum and other matter; • substances producing objectionable colour, odour, taste or turbidity; and • substances and conditions that produce undesirable aquatic life.	Consumer complaints are a useful guide to the suitability of water for recreational use.	Chapter 10

Physical hazards

Guideline

It is acknowledged that recreational water and adjacent areas should be free of physical hazards, such as floating or submerged objects that may lead to injury, as much as a reasonable person would deem realistic. Where permanent hazards exist (eg rips and sandbars), appropriate warning signs should be clearly displayed.

Drowning, impact injuries and puncture injuries represent the highest priority for recreational water-quality management programs because these injuries can cause death or lead to permanent or temporary incapacitation. Most injuries can be prevented by appropriate measures, especially at the local level.

Physical hazards in or around a recreational water body should be removed. If removal is not possible, the hazards should be mitigated, or measures should be taken to prevent or reduce human exposure. Physical hazards that cannot be dealt with in these ways should be subject to additional preventive or remedial measures — for example, general warning notices or special warnings, especially at times of increased risk.

A regular assessment plan should be implemented to monitor for variations in local hazards. The assessment of hazards in a beach or water environment is critical to ensuring public safety. An assessment of physical hazards of a recreational water body should catalogue those characteristics that may affect public health. These can be identified from local knowledge, risk management audits and records of health effects.

Monitoring and assessment programs should also take into consideration those hazards and preventive measures that are subject to gradual or rapid change. For example, this might include assigning a beach-safety rating that takes into consideration the beach state and varying wave height.

Each site should be monitored regularly for existing and new hazards, to promote remedial action as required. Some hazards (eg rips) may require daily or even hourly assessment. Other hazards (eg known submerged rocks or piers) would require less frequent monitoring (eg weekly or monthly) to determine whether the hazard has changed.

Sun, heat and cold

Guideline

The temperature of recreational water bodies should be in the range of 16–34°C. Recreational water users should be educated to reduce exposure to ultraviolet radiation, particularly during the middle of the day.

Recreational water environments can experience extreme temperature and ultraviolet radiation (UVR) conditions.

Unintentional exposure to cold water (< 16°C) can result in a debilitating shock response and hypothermia. At the other extreme, high air temperatures can lead to heat exhaustion and heatstroke. The temperature range in which people can stay in water without overheating or becoming too cold is very narrow compared to the range in air. It is not possible to define a single cut-off point below which water temperatures are dangerous, as this will vary according to the specific circumstances and physical condition of the person involved and the duration of their exposure.

Overexposure to solar UVR during recreation in, on or near the water may result in acute and chronic health effects on the skin, eyes and immune system. Acute effects include sunburn pain and blistering; chronic effects include skin cancer and cataracts.

Reducing both the occurrence of sunburn and cumulative UVR exposure can decrease harmful health effects and significantly reduce health care costs. The levels of UVR and consequently the UV indicator vary throughout the day. Emphasis should be placed on reporting the maximum UVR level on a given day. The maximum level typically occurs during the 4-hour period around solar noon.

Public education programs should be initiated to improve knowledge about the health risks of exposure to extremes of temperature and to exposure to UVR, and to change attitudes and behaviours. Education activities about recreational water environments should mainly address children, adolescents and their parents.

Microbial quality of recreational water

Guideline

Preventive risk management practices should be adopted to ensure that designated recreational waters are protected against direct contamination with fresh faecal material, particularly of human or domesticated animal origin.

Microbial quality of recreational water may be strongly influenced by factors such as rainfall in the catchment of the water body, potentially leading to relatively short periods of elevated faecal pollution.

The microbial quality of recreational water is categorised by a combination of sanitary inspection and microbial water-quality assessment. This approach provides information on possible sources of pollution, as well as numerical information on the likely level of

faecal pollution. The resulting classification supports activities in pollution prevention and provides a means to recognise and account for cost-effective local actions to protect public health.

Quantitative microbial risk assessment (QMRA) is used to estimate the risk to human health indirectly by predicting infection or illness rates for given densities of particular pathogens, assumed rates of ingestion and appropriate dose–response models for the exposed population.

For the purposes of classification where recreational water is used for whole-body (primary) contact recreation (ie where there is a risk of swallowing water), two principal components are required for assessing faecal contamination:

- assessment of evidence for the likely influence of faecal material; and
- counts of suitable faecal indicator bacteria (usually enterococci).

These two components are combined to produce an overall microbial classification of the recreational water body.

Management strategies should include sanitary inspection of the areas affecting the recreational water body, to identify all sources of faecal pollution and periods when control may be most effective.

The inspection should include the following steps:

- plan the sanitary inspection and develop a checklist of issues that need to be considered;
- assemble and review available information;
- carry out a field inspection;
- conduct interviews and/or undertake a workshop with key stakeholders; and
- assess the contamination sources to determine the level of risk.

The combined outcome of the microbial water quality assessment and the sanitary inspection is a five-level classification for recreational waters, ranging from ‘very good’ to ‘very poor’.

Cyanobacteria and algae in fresh water

Guidelines

Fresh recreational water bodies should not contain:

- ≥ 10 µg/L total microcystins; or $\geq 50\,000$ cells/mL toxic *Microcystis aeruginosa*; or biovolume equivalent of ≥ 4 mm³/L for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or
 - ≥ 10 mm³/L for total biovolume of all cyanobacterial material where known toxins are not present; or
 - cyanobacterial scums consistently present.
-

Cyanobacteria (or blue-green algae) are a common and naturally occurring component of most recreational water environments. They are of public health concern because some types produce toxins that can have a harmful effect on recreational water users. Furthermore, production of toxins is unpredictable, making it difficult to quantify the toxicity of waters and define the restrictions that should be placed on their use.

A single guideline value is not appropriate. Instead, two guideline values have been established for risks associated with known toxins and the probability of health effects from high levels of cyanobacterial material.

The first level recognises the probability of adverse health effects from ingestion of known toxins, in this case based on the toxicity of microcystins.

The second level covers circumstances in which there are very high cell densities of cyanobacterial material, irrespective of the presence of toxicity or known toxins. Increased cyanobacterial densities increase the likelihood of non-specific adverse health outcomes, principally respiratory, irritation and allergy symptoms. A situation assessment and alert levels framework for the management of cyanobacteria and algae in recreational waters has been developed that allows for a staged response to the presence or development of blooms.

These guidelines use a framework for determining the suitability of a water body for recreational use. The framework combines environmental grading of the water based on prior data for cyanobacteria with historical information on physicochemical conditions to identify risk factors.

Cyanobacteria and algae in coastal and estuarine water

Guideline

Coastal and estuarine recreational water bodies should not contain:

- ≥ 10 cells/mL *Karenia brevis* and/or have *Lyngbya majuscula* and/or *Pfiesteria* present in high numbers.
-

In coastal and estuarine waters, algae range from single-celled forms to the seaweeds that form a common and naturally occurring component of most marine and estuarine ecosystems.

These guidelines address exposure through dermal contact, inhalation of sea-spray aerosols and possible ingestion of water or algal scums. They do not include dietary exposure to marine algal toxins.

As with cyanobacteria in fresh water, the suitability of water for recreational use is assessed by combining environmental grading based on long-term analysis of data with a water body assessment.

Dangerous aquatic organisms

Guideline

Direct contact with venomous or dangerous aquatic organisms should be avoided. Recreational water bodies should be reasonably free of venomous organisms (eg box jellyfish and bluebottles). Where hazards associated with dangerous aquatic organisms are known, appropriate warning signs should be clearly displayed.

Venomous and potentially dangerous organisms are found in Australian recreational waters. Such organisms are generally of local or regional importance, and the risk associated with the organisms varies.

Injuries from encounters with dangerous aquatic organisms are usually sustained in one of the following ways:

- accidentally brushing past a venomous sessile or floating organism (eg box jellyfish, bluebottle) when bathing;
- inadvertently treading on a dangerous organism (eg stonefish);
- unnecessarily handling a venomous organism (blue-ringed octopus, cone shell) during seashore exploration;
- invading the territorial waters of large animals (eg shark, crocodile) when swimming or at the waterside;
- swimming in waters used as hunting grounds by large predators (eg shark);
- intentionally interfering with or provoking dangerous aquatic organisms; and
- exposure to free-living microorganisms (eg the protozoan *Naegleria fowleri* in warm fresh waters).

Many serious incidents can be avoided through public education and awareness. It is important to identify and assess the hazards that various aquatic organisms pose in a given region and bring the results to public attention. Awareness raising should target groups at particular risk and may include both local and visiting populations. In addition, at locations where hazards involving dangerous aquatic organisms have been identified, procedures should be developed for treating injuries.

Chemical hazards

Guideline

Water contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes. Recreational water should have a pH in the range 6.5–8.5 (a pH range of 5–9 is acceptable in recreational waters with very poor buffering capacity) and a dissolved oxygen content greater than 80%.

The health risks associated with chemical contamination in recreational waters are very much smaller than the potential risk from other hazards. Because of dilution or attenuation of chemicals, it is unlikely that recreational water users will come into contact with concentrations high enough to cause adverse effects following a single exposure. Chronic exposure is unlikely to result in adverse effects at the concentrations in recreational water, and with the exposure patterns of most recreational water users. However, it is important to ensure that chemical hazards are recognised and controlled.

The danger of chemical contamination will depend on the local area. The frequency, extent and likelihood of exposure are crucial parts of assessing the risk from a contaminant. Site inspection of point sources may be a useful way to monitor chemical discharges.

Contamination by naturally occurring contaminants is less likely to pose a health hazard than contamination by industrial, agricultural and municipal pollution. While some small recreational water bodies may contain water from mineral-rich strata with high concentrations of some substances, such waters are more likely to contain metals, such as iron, that may cause the aesthetic degradation of the water.

If it is probable that contamination is occurring and there is significant exposure of users, chemical analysis will be required to support a quantitative risk assessment. The assessment should consider both the expected dose and the expected frequency of exposure.

When potential sources of contamination are known to exist upstream of the recreational area, further tests should be required and a quantitative risk assessment should be implemented. Management strategies should focus on catchment protection.

Aesthetic aspects

Guideline

Recreational water bodies should be aesthetically acceptable to recreational users. The water should be free from visible materials that may settle to form objectionable deposits; floating debris, oil, scum and other matter; substances producing objectionable colour, odour, taste or turbidity; and substances and conditions that produce undesirable aquatic life.

No guideline values have been established for aesthetic aspects. However, these aspects are important for maximising the benefit of recreational water use. The principal aesthetic concern is that obvious pollution, turbidity, scums or odour of the water body will cause revulsion. Such aesthetic problems may cause nuisance for local residents and tourists, as well as environmental problems, and may lessen the psychological benefits of tourism.

Guidelines for aesthetic aspects depend on the social and cultural value of the water body. Adverse health effects cannot be expressed solely in quantitative terms, but the importance of aesthetic factors in ensuring the maximum health benefit from recreational use of the water body is discussed.

The general aesthetic acceptability of recreational water can be expressed in terms of criteria for transparency, odour and colour. It has been suggested that values for light penetration, colour and turbidity should not be significantly worse than natural background levels.

Safety hazards from turbid or unclear water depend on the intrinsic nature of the water body. Ideally, water at swimming areas should be clear enough for users to estimate the depth, to see subsurface hazards easily and to detect the submerged bodies of swimmers or divers, who may be difficult to see.

The public often perceives the quality of recreational water to be very different from its actual microbial or chemical quality. Poor aesthetic quality may, however, imply poor microbial or chemical quality.

A monitoring program should be implemented to give the public information on the aesthetic aspects of recreational water bodies in combination with data on microbial water quality. While microbial water-quality monitoring should be conducted at prescribed intervals, aesthetic aspects can be assessed more frequently (eg daily).

PART I THE GUIDELINES

I INTRODUCTION

I.1 OVERVIEW

I.1.1 Need for recreational water use guidelines

Water-based recreational activities are popular in Australia. Although the country has an extensive coastline, there are highly localised pressures on accessible areas, particularly around major urban areas. The same is true for estuarine and freshwater rivers and lakes which are increasingly being developed and managed for recreational purposes.

Water-quality guidelines are necessary to protect human health during recreational activities such as swimming and boating, and to preserve the aesthetic appeal of water bodies. Such guidelines are used in monitoring and managing a range of physical, microbial and chemical characteristics that determine whether a body of water is suitable for recreational use.

Use of recreational waters can adversely affect health; for example, gastroenteritis can be caused by swallowing water containing disease-causing organisms (pathogens). However, any potential adverse effects must be weighed against the enormous benefits to health and wellbeing of recreational water use (eg rest, relaxation and exercise) and the positive impacts on local economies that rely on water-associated recreational activities (WHO 2003).

I.1.2 Aim of these guidelines

The primary aim of this document — the National Health and Medical Research Council (NHMRC) *Guidelines for Managing Risks in Recreational Water* — is to protect human health. The guidelines provide a best-practice, hands-on, practical approach aimed at helping those managing recreational water quality. They should be used to ensure that recreational coastal, estuarine and freshwater environments are managed as safely as possible, so that as many people as possible get as much benefit as possible from recreational water use.

These guidelines are not mandatory; rather, they have been developed:

- as a tool for local, state and territory authorities and other stakeholders (including local councils, health authorities, environmental agencies, policy makers and water managers at all levels), for use in developing legislation and standards appropriate for local conditions and circumstances; and
- to encourage the adoption of a nationally harmonised approach to managing the quality of water used for recreational purposes.

Although the guidelines are intended to be applied at designated and classified water bodies, this does not mean that water quality can be allowed to deteriorate at unclassified water bodies.

1.2 PREVENTIVE RISK MANAGEMENT APPROACH

These guidelines replace the *Australian Guidelines for Recreational Use of Water* (NHMRC 1990). They differ from the previous guidelines in that they advocate a preventive approach to the management of recreational water, focusing on assessing and managing hazards and hazardous events within a risk-management framework (Box 1.1 explains these terms). This preventive approach replaces the traditional reliance on percentage compliance with counts of faecal indicators to protect the microbial quality of water.¹

Box 1.1 Hazards, hazardous events and risks

Although the terms 'hazard' and 'risk' are often used interchangeably, their meanings differ. In these guidelines, the terms hazard, hazardous event and risk are used as follows:

- a *hazard* is a biological, chemical, physical or radiological agent that has the potential to cause harm (ie loss of life, injury or illness)
- a *hazardous event* is an incident or situation that can lead to the presence of a hazard (ie what can happen and how)
- a *risk* is the likelihood of identified hazards causing harm in exposed populations in a specified timeframe; it includes the severity of the consequences.

The distinction between hazard and risk needs to be understood so that attention and resources can be directed to actions based primarily on the level of risk rather than simply on the existence of a hazard (NHMRC/NRMMC 2004).

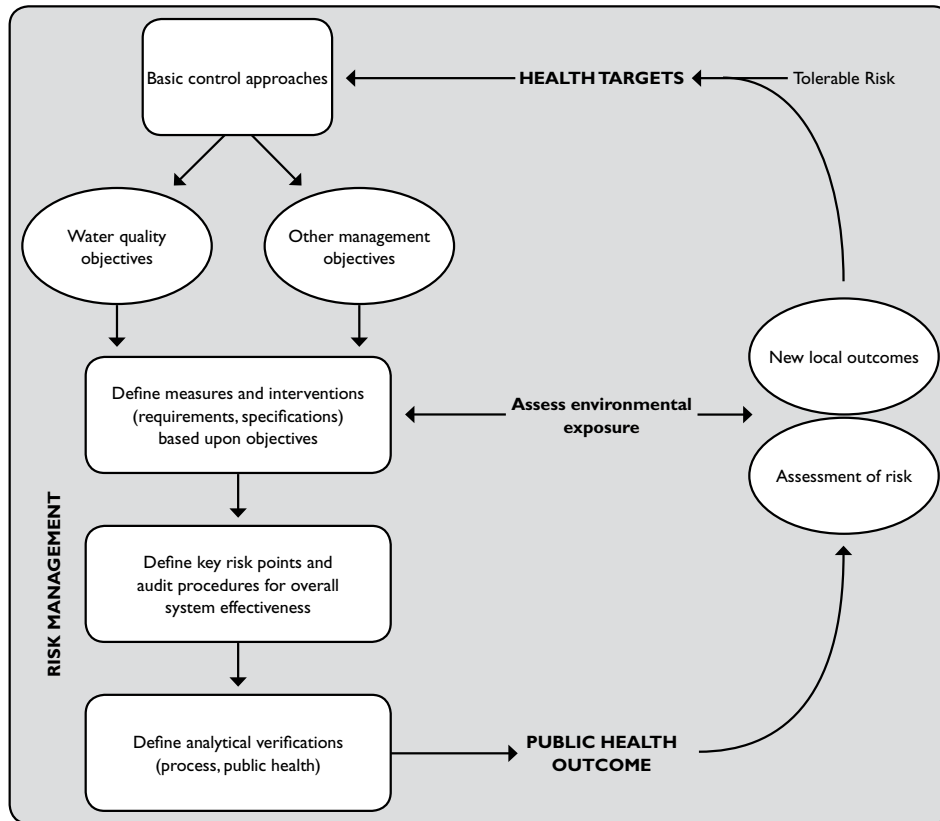
The approach outlined in this document is consistent with that developed by the World Health Organization (WHO) between 1999 and 2001. The WHO approach formalised the use of risk assessment and management frameworks for all water sources and uses (illustrated in Figure 1.1), and started with the development of 'Annapolis Protocol' for recreational waters.² The aim of the protocol was to regulate recreational water quality in a way that reflected public health risk more accurately than the traditional approach, and that provided scope for different management options (WHO 1999). The protocol described a scheme for grading recreational water according to health risk, based on analysis of long-term data.

The approach developed in the Annapolis Protocol relies on identifying surrogate indicators of increased risk and taking action to manage those risks. For example, rainfall causing increased run-off into a water body and consequently influencing pathogen contamination could be used as a surrogate indicator of increased risk. An appropriate action to reduce this risk might be to advise the public not to use the water body for a particular time. Applying surrogate indicators in this way allows for 'real-time' management of faecally derived pathogens in recreational water. It also means that periods when health risks are high and recreational activity is controlled do not need to be counted towards the seasonal classification of the water body.

¹ Faecal indicators are organisms that act as surrogates for potential pathogens (disease-causing organisms) associated with faecal contamination.

² The 'Annapolis Protocol' derives its name from the fact that it was developed through a joint meeting of the United States Environmental Protection Agency and the WHO in Annapolis in 1998.

Figure I.1 Harmonised approach to assessment of risk and management for microbial hazards suitable for any water-related exposure



Source: adapted from Bartram et al (2001)

This document combines much of the international consensus on healthy recreational water use with current understanding of Australian waters, to provide guidance relevant to local conditions. It incorporates many recent directions of the WHO, including the organisation's guidelines for recreational waters (WHO 2003). It also draws on two other publications: *Best Practice Environmental Management Guidelines — Catchments for Recreational Water: Conducting and Assessing Sanitary Inspections* (WSAA 2003) and the New Zealand *Microbial Water Quality Guidelines for Marine and Freshwater Recreational Areas* (NZMFE 2002).

The preventive risk management framework used in this document includes elements of hazard analysis critical control point (HACCP) methods and ISO 9001. It relies on an understanding of the full range of the potential hazards that require management in recreational waters, including:

- incidents and physical hazards;
- heat, cold and ultraviolet radiation (from the sun);
- microbial contamination;
- toxic algae and cyanobacteria;
- chemical contamination; and
- dangerous or venomous organisms.

Because of the wide range of potential hazards to users of recreational water, the approach used in this document for managing risks differs from that described in the *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004). Management of recreational water should be based on the principles described here, rather than on an adaptation of the *Australian Drinking Water Guidelines*.

It is difficult, expensive and impractical to measure the level of all contaminants in the water directly. Instead, the approach to determining the quality of recreational water outlined in these guidelines involves developing an understanding of hazards within the catchment, how these hazards affect the quality of the water, and what local events (such as recent rainfall) may influence the water quality. In verifying microbial quality of recreational water, the presence of potentially pathogenic microorganisms may be inferred by monitoring for indicator organisms (particularly enterococci), which are not themselves a direct health concern.

1.3 SCOPE AND APPLICATION OF GUIDELINES

These guidelines apply to a wide range of public and private recreational water environments, such as coastal and estuarine waters (including tidally washed pools and marine baths that interchange with sea water) and freshwater bodies (rivers, streams, lakes, weirs and dams). Although the guidelines focus on management of public water bodies, they also apply to any natural water body used for recreational purposes.

These guidelines do not directly address the environmental impacts of recreational use of water; however, such impacts should be considered, because a healthy environment is important for human health. Other areas not covered by these guidelines are:

- exposures associated with foodstuffs collected from recreational water or its surroundings (particularly those associated with shellfish and crustaceans);
- protection of aquatic life;
- occupational exposures of people working in recreational water environments (especially susceptible population groups or individuals, such as people undergoing immunosuppressive treatment or those with acquired immunodeficiency syndrome [AIDS]);
- water with special significance for cultural reasons;
- risks associated with ancillary facilities that are not part of the recreational water environment (eg toilet facilities in adjacent areas are not considered beyond the need for them to be in order to minimise contamination of the recreational water body);
- seasickness;
- the 'bends' (decompression sickness) and other phenomena relevant only to subsurface and deep-sea diving;
- guidance on rescue, resuscitation or treatment;
- swimming pools (apart from tidally washed saltwater pools) and spas; and
- therapeutic uses of waters (eg hydrotherapy pools).

I.4 USES AND USERS OF RECREATIONAL WATER

I.4.1 Definitions

These guidelines use the following definitions:

- *recreational water bodies* — any public coastal, estuarine or freshwater areas where a significant number of people use the water for recreation;
- *recreational use* — includes all activities relating to sport, pleasure and relaxation that depend on water resources (eg sunbathing, swimming, diving, boating, fishing and sailboarding); and
- *users of recreational water bodies* — includes
 - the general public
 - children
 - tourists (eg hotel guests and clients of camping parks)
 - competitive swimmers
 - specialist sporting users (eg anglers, canoeists, whitewater rafters, boat users, scuba divers)
 - surfers.

I.4.2 Susceptible groups

Certain groups of users may be more exposed to hazards than others; for example, children, the elderly and those with disabilities, tourists and people from culturally and linguistically diverse backgrounds. These groups are discussed below.

Children

Children usually spend more time in the water than adults and are more likely to swallow water or contaminated sand or sediment, either intentionally or unintentionally (WHO 2003). Particularly when unattended, children may also be at high risk of incidents involving themselves and others, because of their desire for attention and their limited awareness of formal rules of safety and hygiene.

The elderly and those with disabilities

The elderly and those with disabilities may have limitations of strength, agility or stamina that impair their ability to recover from difficulties in the water. Elderly or immunocompromised people may also be at higher risk of health damage from microbial deterioration of water quality, because they are more susceptible to pathogenic organisms.

Tourists and other visitors

Tourists and other visitors to a region may overestimate their personal ability, be unaware of local conditions and hazards in and around the water, and have no immunity to local pathogens.

People from culturally and linguistically diverse backgrounds

People from culturally and linguistically diverse backgrounds may not be familiar with safety aspects of water-related activities, for example rock fishing, using lifejackets when boating, and swimming between the red and yellow flags at patrolled beaches (Jones 2003).

I.5 DESIGNATION OF RECREATION ACTIVITIES

Development of strategies to reduce the risks associated with the use of recreational water requires broad classifications of recreational activities. For risks arising from contact with, or ingestion of, water, an understanding of the different degrees of contact associated with different recreational water uses is essential. The amount of water contact directly influences the degree of contact with infectious and toxic agents and physical hazards, and the likelihood of being injured or contracting illness (WHO 2003). Routes of exposure to infectious and toxic agents in water will vary, depending on the type of water contact, but skin and mucous membranes are the most common exposure routes.

Recreational activities can be classified by the degree of water contact as follows:

- *Whole-body contact (primary contact)* — activity in which the whole body or the face and trunk are frequently immersed or the face is frequently wet by spray, and where it is likely that some water will be swallowed or inhaled, or come into contact with ears, nasal passages, mucous membranes or cuts in the skin (eg swimming, diving, surfing or whitewater canoeing).
- *Incidental contact (secondary contact)* — activity in which only the limbs are regularly wet and in which greater contact (including swallowing water) is unusual (eg boating, fishing, wading), and including occasional and inadvertent immersion through slipping or being swept into the water by a wave.
- *No contact (aesthetic uses)* — activity in which there is normally no contact with water (eg angling from shore), or where water is incidental to the activity (such as sunbathing on a beach).

In whole-body contact activities, the probability that some water will be ingested is high, although data on the quantities swallowed during recreational water use are difficult to obtain (WHO 2003). Inhalation can be important where there is a significant amount of spray, such as in waterskiing or even sunbathing at a surf beach. In water sports, the skill of the participant will also be important in determining the extent of involuntary exposure, particularly ingestion.

I.6 HAZARDS, HAZARDOUS EVENTS AND POTENTIAL OUTCOMES

Physical hazards

Drowning, near-drowning and spinal injuries are the most serious public health problems associated with the recreational use of water. Drowning is a major cause of death in Australia (AIHW 1995, Mackie 1999, ABS 2000). Spinal injury or permanent damage caused by near-drowning can have a major impact on the quality of life of the victim and a significant impact on health-care resources. Physical hazards are covered in detail in Chapter 3.

Sun, heat and cold

Health effects associated with the recreational use of water include hypothermia and hyperthermia, and exposure to ultraviolet radiation (UVR) leading to cancer or damage to the skin, eyes and immune system. Hazards from sun, heat and cold are covered in detail in Chapter 4.

Microbial contaminants

Water contaminated by human or animal excreta may contain a range of pathogenic microorganisms, such as viruses, bacteria and protozoa. These organisms may pose a health hazard, particularly when the water is used for recreational activities that involve whole-body contact, as there is reasonable risk that pathogens will enter the body during such activities.

Until recently, gastroenteritis was considered the main health effect likely to arise from microbially contaminated recreational water, but respiratory infections are now also thought to be important (Corbett *et al* 1993, WHO 2003). In most cases, the ill-health effects from exposure to water contaminated with pathogenic microorganisms are minor and short lived. However, contaminated water can cause more serious diseases, such as hepatitis, giardiasis, cryptosporidiosis, campylobacteriosis and salmonellosis (Philipp 1991), particularly in children, the elderly and the severely immunocompromised.

Hazards associated with microbial pathogens are covered in detail in Chapter 5.

Algae and cyanobacteria

Exposure to algae and cyanobacteria and/or their associated toxins are usually considered less of a concern than exposure to pathogenic microorganisms. However, several species of cyanobacteria and microscopic algae can be acutely toxic when ingested or absorbed through the skin, or can irritate the skin, eye or mucous membranes. These toxins can also cause risks in food; however, such risks are dealt with in other guidelines. Hazards from algae and cyanobacteria are covered in detail in Chapters 6 and 7.

Hazardous organisms

Some health risks are associated with wildlife in and around recreational water bodies. These include envenomation from vertebrates and invertebrates, and laceration and fatal trauma from various marine creatures, including sharks and crocodiles.

Various events, such as heavy rainfall, can have multiple consequences for the quality of a recreational water body by changing the physical profile of the catchment and the distribution of wildlife. Hazardous organisms are covered in detail in Chapter 8.

Chemicals

Chemical contaminants at concentrations that typically occur in recreational water are usually considered less of a concern than exposure to pathogenic microorganisms. However, certain chemicals can be acutely toxic when ingested or absorbed through the skin, or can irritate the skin, eye or mucous membranes. Chemical hazards are covered in detail in Chapter 9.

Aesthetic factors

Aesthetic issues play an important role in the public's perception of a recreational water area. The principal aesthetic concern is revulsion associated with obvious pollution of the water body, turbidity, scums or odour. Pollution may cause nuisance for local residents and tourists and environmental problems, and may lessen the psychological benefits of tourism.

Hazards associated with aesthetic quality of recreational water are covered in detail in Chapter 10.

Potential adverse health outcomes

Table 1.1 shows examples of the adverse health outcomes associated with various hazards encountered by recreational water users.

Table 1.1 Examples of adverse health outcomes associated with hazards encountered in recreational water environments

Type of adverse health outcome	Examples of associated hazards
Drowning (Chapter 3)	• Being caught in tidal or rip current • Being cut off by rising tide • Falling overboard • Being caught by submerged obstacle • Falling asleep in an inflatable and drifting into deep water far from shore • Slipping off rocks or being washed off by waves • Misjudging swimming ability
Impact injury (Chapters 3 and 8)	• Impact against hard surface or sharp object (broken glass, jagged metal), resulting from the action of the participant (eg diving, collision) or from the force of wind and water • Needlestick injuries from used needles • Cuts (eg from coral or oysters) and abrasions from slipping on wet rocks • Attack by aquatic animals (eg shark, moray eel, crocodile)
Physiological (Chapter 4)	• Chilling (hypothermia), leading to coma or death • Acute exposure to heat, leading to hyperthermia (eg heat exhaustion and heatstroke) • Acute exposure to ultraviolet radiation (UVR) from sunlight, leading to sunburn • Cumulative exposure to UVR, leading to skin cancer (basal and squamous cell carcinoma, melanoma)
Infection (Chapter 5)	• Ingestion or inhalation of, or contact with, pathogenic bacteria, viruses and parasites, which may be present in water through contaminated discharges from run-off or faecal contamination from people or animals using the water, or may be present naturally
Poisoning and toxicoses (Chapters 6, 7, 9)	• Sting of poisonous and venomous animal (eg jellyfish, snake, stonefish) • Ingestion or inhalation of, or contact with, blooms of toxicogenic cyanobacteria in fresh or marine water or dinoflagellates in marine water • Ingestion or inhalation of, or contact with, chemically contaminated water

Source: WHO (2003)

I.7 RISK ASSESSMENT

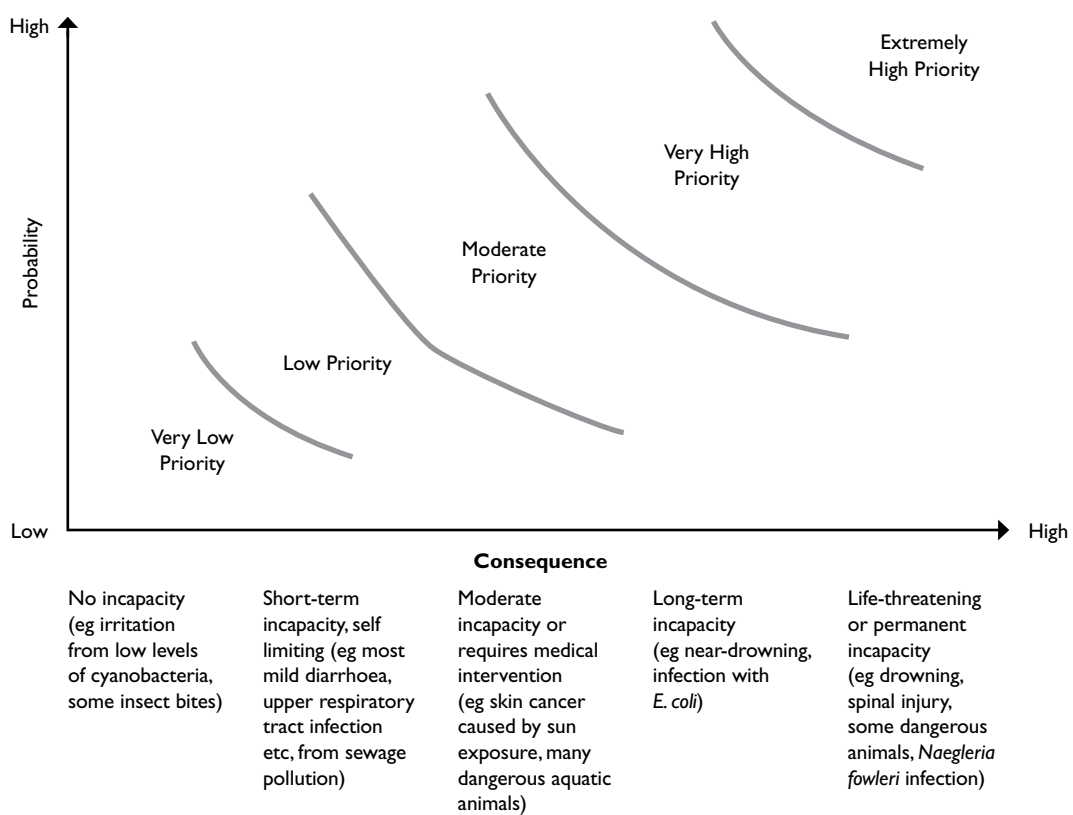
These guidelines require that risk be reduced to a tolerable level rather than being eliminated altogether (complete elimination of risk is impossible). For most healthy people, water conforming to the guideline value will pose only a minimal increase in daily risk. However, water conforming to the guidelines may still pose a potential health risk to high-risk user groups such as the very young, the elderly and those with impaired immune systems.

Determining risk involves considering the probability that a hazard or hazardous event will occur, and the consequences if it does. This is illustrated in Figure 1.2, which compares health hazards encountered during recreational water use. A severe health outcome, such as permanent paralysis or death because of diving into shallow water, may affect only a few swimmers each year, but may warrant a high management priority.

At the other end of the scale, minor skin irritations may affect many swimmers each year, but do not result in any incapacity and so require lower management priority.

This ‘risk versus severity’ approach (ie how likely is it that something will happen, and how bad will it be if it does) has been applied throughout these guidelines. For each hazard discussed, the severity of the hazard can be related to the risk, as shown in Figure 1.2. Where necessary, authorities can then reduce the risk by highlighting or prioritising protective or remedial management measures; they can also initiate further research or investigation into the risk. Risk reduction is discussed in Section 1.8 below.

Figure 1.2 Schematic comparison of health hazards encountered during recreational water use



Source:WHO (2003)

Adhering to the guideline values and using the framework set out in the guidelines should ensure that recreational water users are informed of health risks, and can make appropriate decisions to avoid exposing themselves to significant risks.

1.8 MEASURES TO REDUCE RISKS IN WATER RECREATION

These guidelines focus on identifying circumstances (hazardous events) that may create hazards, and developing procedures to address those hazards. Since short-term exposure to hazards can lead to health effects, it is important to develop and implement standards and monitoring regimes that allow preventive and remedial actions to be taken within realistic timeframes. Also required are programs for assessing conditions and practices, and threshold values that can be used as targets.

Table 1.1 lists and classifies the main adverse health outcomes associated with exposure to hazards encountered in recreational water bodies. The tables below provide examples of potential control measures and bases for reducing risks in water recreation that involves whole-body contact (Table 1.2), incidental contact (Table 1.3) and non-contact (Table 1.4). A recreational use may present more than one hazard; the particular hazards for each use will depend on the circumstances. Therefore, measures to reduce risk will be specific to each form of recreational activity and to particular circumstances. The chapters in Part 2 of this document provide detailed examples of hazards associated with particular types of recreational activity.

Table 1.2 Hazards and measures for reducing risks in whole-body (primary) contact recreational use

Examples of whole-body (primary) contact recreational activities		Associated risks and hazards^a
Scuba diving and snorkelling		I-11
Swimming		I-11
Surfing		I-3, 5-9
Water-skiing		I-11
White water canoeing, rafting		I-3, 5-7, 9-11
Windsurfing (sailboarding)		I-11
Children's exploratory activities and wading		I-11
Principal hazard	Potential risk reduction measures	
1. Drowning	Where appropriate: safety rails, lifebelts/lifejackets, warning notices, broadcast weather alerts, education, legislation regarding use of lifejackets while boating, supervision and availability of rescue services. Personal care.	
2. Waterborne infection ^b	Avoiding body contact after heavy rain. Licensing, control and treatment of discharges of sewage, effluents, storm overflows. Improvements where indicated as appropriate due to unsatisfactory microbial quality. Personal awareness of local conditions.	
3. Sunburn, skin damage, skin cancer, eye damage and heat illness	Generalised and localised education and publicity programs including advice to limit exposure (between 10am and 3pm), seek shade, wear protective clothing (including hat), apply sunscreen, wear sunglasses, maintain hydration.	
4. Cyanobacterial, marine algal toxicoses	Control of eutrophication, monitoring and reporting cyanobacterial populations, curtailing recreation during blooms, avoiding contact, washing body and equipment after recreation.	
5. Impact injury	Notices indicating hazards. Personal awareness raising and avoidance, wearing head and body protection where appropriate. Supervision and presence of lifeguards and rescue services. Removal/mitigation of the hazard.	
6. Injury; treading on broken glass, jagged metal waste, or needle stick injuries, infection following skin injury.	Litter control, cleaning of recreational area. Provision of rubbish bins. Prohibiting use of glass on beaches, and provision of sharps disposal facilities. Cover all injuries with waterproof dressings.	
7. Collision with or entrapment by wrecks, piers, weirs, sluices and underwater obstructions.	Notices to mariners, marker buoys, posted warnings. Personal awareness. Legislation requiring boat training. Rescue services to respond to incidents and mitigate injuries. Appropriate oversight (eg harbour/beach patrols).	
8. Stings from sea animals.	Local awareness raising where the problem occurs.	
9. Attack by aquatic animals (eg sharks, crocodiles).	Posting warnings, personal awareness raising, avoidance.	

Examples of whole-body (primary) contact recreational activities	Associated risks and hazards ^a
10. Bites of mosquitoes and other insect vectors of disease.	Health warnings; avoidance of infested regions, personal protection (eg clothing, insect repellents).
11. Leptospirosis (fresh water) ^c	Riparian management to control rodents; litter collection. Treating and covering cuts and abrasions before water exposure. Seeking medical advice if influenza-like symptoms are noticed a few days after recreational use of water.

a Numbers refer to principle hazards listed within table

b Infections caused by pathogens derived from faecal pollution

c Leptospirosis is associated with urine from animals and may be a concern in warmer regions of Australia

Table 1.3 Hazards and Measures for reducing risks in incidental (secondary) contact recreational use

Examples of incidental (secondary) contact recreational activities	Associated risks and hazards ^a
Rowing, sailing and canoeing	1-11
Wading and paddling	1-11
Fishing	1-11
Principal hazard	Potential risk reduction measures
1. Drowning	Where appropriate: safety rails, lifebelts/lifejackets, warning notices, broadcast weather alerts, education, legislation regarding use of lifejackets while boating, supervision and availability of rescue services. Personal care.
2. Waterborne infection ^b	Avoiding body contact after heavy rain. Licensing, control and treatment of discharges of sewage, effluents, storm overflows. Improvements where indicated as appropriate due to unsatisfactory microbial quality. Personal awareness of local conditions.
3. Sunburn, skin damage, skin cancer, eye damage and heat illness	Generalised and localised education and publicity programs including advice to limit exposure (between 10am and 3pm), seek shade, wear protective clothing (including hat), apply sunscreen, wear sunglasses, maintain hydration.
4. Cyanobacterial, marine algal toxicoses	Control of eutrophication, monitoring and reporting cyanobacterial populations, curtailing recreation during blooms, avoiding contact, washing body and equipment after recreation.
5. Impact injury	Notices indicating hazards. Personal awareness raising and avoidance, wearing head and body protection where appropriate. Supervision and presence of lifeguards and rescue services. Removal/mitigation of the hazard.
6. Injury; treading on broken glass, jagged metal waste, or needle stick injuries, infection following skin injury.	Litter control, cleaning of recreational area. Provision of rubbish bins. Prohibiting use of glass on beaches, and provision of sharps disposal facilities. Cover all injuries with waterproof dressings.
7. Collision with or entrapment by wrecks, piers, weirs, sluices and underwater obstructions.	Notices to mariners, marker buoys, posted warnings. Personal awareness. Legislation requiring boat training. Rescue services to respond to incidents and mitigate injuries. Appropriate oversight (eg harbour/beach patrols).
8. Stings from sea animals.	Local awareness raising where the problem occurs.
9. Attack by aquatic animals (eg sharks, crocodiles).	Posting warnings, personal awareness raising, avoidance.
10. Bites of mosquitoes and other insect vectors of disease.	Health warnings; avoidance of infested regions, personal protection (eg clothing, insect repellents).
11. Leptospirosis (fresh water) ^c	Riparian management to control rodents; litter collection. Treating and covering cuts and abrasions before water exposure. Seeking medical advice if influenza-like symptoms are noticed a few days after recreational use of water.

a Numbers refer to principle hazards listed within table

b Infections caused by pathogens derived from faecal pollution

c Leptospirosis is associated with urine from animals and may be a concern in warmer regions of Australia

Table 1.4 Hazards and measures for reducing risks in non contact (aesthetic) recreational activities

Examples of noncontact (aesthetic) recreational		Associated risks and hazards ^a
Angling from shore		1-6
Boating under power		1-6
Picnics		1-6
Walking		1-6
Sunbaking		2-5
Bird watching		1-6
Principal hazard	Potential risk reduction measures	
1. Falling in, drowning.	Where appropriate: safety rails, lifebelts/lifejackets, warning notices, broadcast weather alerts, education, legislation regarding use of lifejackets while boating. Personal care.	
2. Sunburn, skin damage, skin cancer, eye damage and heat illness.	Generalised and localised education and publicity programs including advice to limit exposure (between 10am and 3pm), seek shade, wear protective clothing (including hat), apply sunscreen, wear sunglasses, maintain hydration.	
3. Injury; treading on broken glass, jagged metal waste, or needle stick injuries, infection following skin injury.	Litter control, cleaning of recreational area. Provision of rubbish bins. Prohibiting use of glass on beaches, and provision of sharps disposal facilities. Cover all injuries with waterproof dressings.	
4. Reduction in aesthetic appeal from fish deaths, anaerobic conditions, oil and other pollution; visible algal blooms.	Control and licensing of discharge from sewage works, industry, sewer outfalls, agriculture, landfills and watercraft.	
5. Bites of mosquitoes and other insect vectors of disease.	Health warnings; avoidance of infested regions, personal protection (eg clothing, insect repellents).	
6. Collision with or entrapment by wrecks, piers, weirs, sluices and underwater obstructions.	Notices to mariners, marker buoys, posted warnings. Personal awareness. Legislation requiring boat training. Rescue services to respond to incidents and mitigate injuries. Appropriate oversight (eg harbour/beach patrols).	

^a Numbers refer to principle hazards listed within table

1.9 GUIDELINES AND GUIDELINE VALUES

A guideline can be any of the following:

1. A level of management.
2. A concentration of a constituent that does not represent a significant risk to the health of individual members of significant user groups.
3. A condition under which the hazardous concentrations described in Point 2 are unlikely to occur.
4. A combination of Points 2 and 3.

In deriving guidelines and guideline values, both the severity and the frequency of associated health outcomes need to be taken into account. The *frequency* here refers to the expected number of events that occur for a particular level of hazard. Risks can vary from negligible — an adverse event occurring at a frequency below one per million — to those requiring active risk management; for example, fairly regular events that might occur at a frequency of more than one in a hundred (Calman 1996, WHO 2003).

For most parameters, there is no clear-cut value below which health effects are excluded; therefore, the derivation of guideline values and any conversion of guidelines to standards includes an element of valuation or judgment about the frequency, nature and severity of associated health effects. This valuation process is one in which societal values play an important role; thus, the conversion of guidelines into state or territory legislation and standards should take into account environmental, social, cultural and economic factors.

The existence of a guideline value does not imply that environmental quality should be allowed to degrade to this level. Indeed, a continuous effort should be made to ensure that recreational water environments are of the highest attainable quality.

When a guideline is not achieved, this should be a signal to:

- investigate the cause and identify the likelihood of future incidents;
- liaise with the authority responsible for public health to determine whether immediate action should be taken to reduce exposure to the hazard; and
- determine whether measures should be put in place to prevent or reduce exposure under similar conditions in the future.

Many of the hazards associated with recreational water use may occur over very short periods (eg injuries and infection following exposure to microorganisms). This means that short-term deviations above guideline values and conditions are important to health, and measures should be in place to ensure and demonstrate that recreational water environments are continuously safe during periods of actual or potential use. In practice this may be difficult to achieve; in which case, appropriate warnings should be issued.

1.10 SUMMARY GUIDELINES FOR RECREATIONAL WATER

Table 1.5 summarises the major hazards for recreational water, the guidelines, comments and where further information can be found.

Table 1.5 Summary of the guidelines for recreational water

Characteristic	Guideline	Comment	Supporting information
Physical hazards	Recreational water bodies and adjacent areas should be free of physical hazards, such as floating or submerged objects that may lead to injury. Where permanent hazards exist, for example rips and sandbars, appropriate warning signs should be clearly displayed.	Injuries related to these objects may result during activities such as swimming, diving and water skiing.	Chapter 3
Sun, heat and cold water temperature	The temperature of recreational water bodies should be in the range 16–34°C. Recreational water users should be educated to reduce exposure to ultraviolet radiation (UVR), particularly during the middle of the day.	Exposure to cold water (<16°C) can result in hypothermia (excessive heat loss) or a shock response. Prolonged exposure to waters > 34°C may result in hyperthermia (heat exhaustion or heat stress). Levels of UVR vary throughout the day, with a maximum occurring during the 4 hours around noon.	Chapter 4
Microbial quality	Preventive risk management practices should be adopted to ensure that designated recreational waters are protected against direct contamination by fresh faecal material, particularly of human or domesticated animal origin.	The main health risks are from enteric viruses and protozoa.	Chapter 5
Cyanobacteria and algae in fresh waters	Fresh recreational water bodies should not contain: • $\geq 10 \mu\text{g/L}$ total microcystins; $\geq 50\,000$ cells/mL toxic <i>Microcystis aeruginosa</i>; or biovolume equivalent of $\geq 4 \text{ mm}^3/\text{L}$ for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or • $\geq 10 \text{ mm}^3/\text{L}$ for total biovolume of all cyanobacterial material where known toxins are not present; or • cyanobacterial scums consistently present.	A single guideline value is not appropriate. Instead, two guideline values have been established, based on known risks associated with known toxins and probability of health effects caused by high levels of cyanobacterial material. A situation assessment and alert levels framework for the management of algae/cyanobacteria in recreational waters has been developed that allows for a staged response to the presence and development of blooms.	Chapter 6

Characteristic	Guideline	Comment	Supporting information
Cyanobacteria and algae in coastal and estuarine waters	Coastal and estuarine recreational water bodies should not contain: • ≥ 10 cells/mL <i>Karenia brevis</i> and/or have <i>Lyngbya majuscula</i> and/or <i>Pfiesteria</i> present in high numbers.	A situation assessment and alert levels framework for the management of algae/cyanobacteria in recreational waters has been developed that allows for a staged response to the presence and development of blooms.	Chapter 7
Dangerous aquatic organisms	Direct contact with venomous or dangerous aquatic organisms should be avoided. Recreational water bodies should be reasonably free of, or protected from, venomous organisms (eg box jellyfish and bluebottles). Where the presence of dangerous aquatic organisms are known, appropriate warning signs should be clearly displayed.	Risks associated with dangerous aquatic organisms are generally of local or regional importance and vary depending on recreational activities.	Chapter 8
Chemical hazards	Water contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes.	Chemical contamination can result from point sources (eg industrial outfalls) or from run-off (eg from agricultural land). All chemical contaminants should be assessed on a local basis.	Chapter 9
pH	6.5–8.5	A wider pH range of 5–9 is acceptable for water with a very low buffering capacity.	Chapter 9
Dissolved oxygen	> 80%	When considered with colour and turbidity, dissolved oxygen is an indicator of the extent of eutrophication of the water body.	Chapter 9
Aesthetic aspects	Recreational water bodies should be aesthetically acceptable to recreational users. The water should be free from visible materials that may settle to form objectionable deposits; floating debris, oil, scum and other matter; substances producing objectionable colour, odour, taste or turbidity; and substances and conditions that produce undesirable aquatic life.	Consumer complaints are a useful guide to the suitability of water for recreational use.	Chapter 10

2 MONITORING

The approach to assessing risks and managing hazards in recreational water outlined in Chapter 1 is based on a preventive strategy, which focuses on developing:

- an understanding of all potential influences on a recreational water body; and
- monitoring programs that can provide a real-time indication of water quality.

Management authorities responsible for recreational waters should establish a program for evaluating existing hazards and monitoring the area for any changes that may occur; such an approach will allow authorities to implement a responsive strategy to protect public health. Threats to human health may include natural hazards, such as surf, rip currents or aquatic organisms, or may arise from artificial sources, such as discharges of wastewater.

The design and implementation of programs for monitoring recreational water should be based on a framework of good practice; this chapter presents such a framework.

The framework consists of a series of statements of principle or objectives that, if adhered to, will lead to the design and implementation of a credible monitoring program. The framework applies in principle to the monitoring of all waters used for recreational activities that involve repeated or continuous direct contact with the water. In many circumstances, various approaches or methods can be applied to achieve the objectives of the framework. Although diverse approaches may be equally valid in isolation, adopting different approaches within a single program may mean that results will not be comparable across locations or enforcement programs.

The framework of good practice incrementally builds up the component parts of a successful program — identifying key health issues, monitoring and assessment strategies, and principal management considerations.

2.1 DESIGN OF MONITORING PROGRAMS

A monitoring program for recreational water should be based on a three-tier system:

- **Surveillance mode (green level)** involves routine sampling to measure contaminants (eg physical, microbial, cyanobacterial and algal).
- **Alert mode (amber level)** requires investigation into the causes of elevated contaminant levels, and increased sampling to enable a more accurate assessment of the risks to recreational users.
- **Action mode (red level)** requires the local government authority and health authorities to warn the public that the water body is considered unsuitable for recreational use.

In designing and implementing monitoring programs, all interested parties (legislators, non-government organisations, local communities, laboratories etc) should be consulted. Every attempt should be made to address all relevant disciplines and involve relevant expertise.

A monitoring program should include the following components, each of which is discussed below:

- objectives;
- scope;
- quality assurance program;
- logistical requirements;
- hierarchy of authority, responsibility and actions;
- training; and
- evaluation.

2.1.1 Objectives

The first step in designing a monitoring program or study should be to identify the objectives. Ideally, these will be based on assessments of the frequency and severity of adverse health outcomes. Identifying the objectives in this way means that the monitoring program can then be designed to produce the greatest public health benefit.

A statement of the program's objectives should include the following:

- objectives described in a way that can be related to the scientific validity of the results obtained from monitoring;
- an indication of the required quality of any data; and
- an indication of the form data should take, if they are to be compared between laboratories or sites (eg results from water quality analyses), to ensure comparability of results.

2.1.2 Scope

The scope of any monitoring program or study should be defined. Normally, this would mean defining criteria for inclusion or exclusion of recreational water use areas, preparing an inventory of areas to be monitored and developing a catalogue of basic characteristics of those recreational water areas. It may be necessary to refine the program objectives in the light of the information gathered at this stage.

The catalogue of characteristics should be prepared in a standard format and should be updated both periodically (usually annually) and in response to specific incidents. As a minimum, it should include the extent and nature of recreational activities at each area and the types of hazards to human health that may be present or encountered. Unless potential hazards are specifically excluded, the list of hazards would normally include drowning and injury-related hazards, known or anticipated dangerous aquatic organisms, the microbial quality of the water, and the presence of cyanobacteria or harmful algae. Section 2.6 gives further information on what kind of details the catalogue should include on these potential hazards. Monitoring programs often also take into account aesthetic aspects and amenity parameters, because of the importance of these factors to health and wellbeing.

2.1.3 Quality assurance program

Any monitoring program must include a quality assurance (QA) program based on internal controls and external controls (ie interlaboratory comparisons). The QA program should cover the integrity of all observations, interviews, field sampling and water quality analyses as well as data input, analysis and reporting. It should not infringe on health and safety. A QA officer, reporting directly to senior management, should be appointed. The officer should regularly audit all aspects of the operation, and pay special attention to procedures, traceability of the data and reporting.

Essential elements of QA programs include the writing and implementation of a quality manual and standard operating procedures. All standard operating procedures should be regularly overhauled and updated as necessary. Any deficiencies should be reported and appropriate remedial action taken. Standard operating procedures should include:

- maintenance and updating of inventories and catalogues;
- operating procedures for all major equipment;
- all sampling and analytical procedures;
- sample receipt, screening and storage; and
- reporting.

Where samples are taken for laboratory analysis, they should be registered on arrival at the laboratory. The applied laboratory procedures should conform to the standard operating procedures defined at the laboratory. Where possible, all analytical procedures should follow defined protocols (eg those produced by organisations such as Standards Australia, International Organization for Standardization or American Public Health Association). All equipment should be calibrated regularly and the operational procedures should be submitted to quality control staff, to guarantee traceability of the data.

Criteria should be developed for dealing with participating laboratories that consistently fail to comply with minimum analytical quality. These criteria should be stated before data collection.

Laboratory accreditation can be a valuable part of activities relating to analytical quality; for example, through pursuit of the requirements of the National Association of Testing Authorities.

2.1.4 Logistical requirements

The planning of any monitoring program or study should take into account socioeconomic, technical or scientific, and institutional capacities; staffing; equipment availability; consumable demands; travel and safety requirements and sample numbers. In taking these factors into account, it is important not to compromise the achievement of the objectives or scientific validity of the program.

2.1.5 Hierarchy of authority, responsibility and actions

The hierarchy of authority, responsibility and actions within a program should be defined. All people taking part in the program should be aware of their roles and interrelationships.

2.1.6 Training

Staff should be adequately trained and qualified, including in health and safety aspects.

2.1.7 Evaluation

The monitoring program should be evaluated both periodically and whenever the general situation or any particular influence is changed. Commitment to support such evaluations should be built into the program's design and authorisation.

2.2 DATA COLLECTION

Data and information for monitoring recreational water quality should be collected using the most effective combination of methods of investigation. Methods include:

- observation;
- historical review of deaths, injuries and incidents (including details of lifeguard positioning, number of rescues effected, preventive actions and attendance figures);
- water quality sampling and analysis;
- interview of appropriate people; and
- review of published and unpublished literature.

Frequency and timing of analytical sampling and selection of sampling sites should reflect the type of recreational water use area, the types and density of use, and temporal and spatial variations in the area (which may arise from seasonality, tidal cycles, rainfall, and discharge and abstraction patterns).

Analytical sampling should provide a dataset suitable for statistical analysis.

Procedures for dealing with inconsistencies, such as omissions in records, indeterminate results (eg indecipherable characters, results outside the limits of the analytical methods) and obvious errors, should be agreed before data collection.

2.3 DATA HANDLING

Monitoring data should be handled and interpreted objectively, without personal or political interference, and in accordance with relevant state or territory privacy legislation.

2.3.1 Pre-analysis requirements

Before analysis starts, there should be agreement with a statistical expert on how raw data will be transformed, to ensure that they meet the conditions for statistical analysis. Also, procedures should be defined for handling censored data (i.e. 'less than' and 'greater than' data).

Data handlers and collectors should agree on a common format for recording results of analyses and surveys, and should be aware of the ultimate size of the data matrix. The preferred approach is to use a database or spreadsheet that includes automatic logical verifications (ie allows only entries for certain ranges of dates and numbers). Forms

and survey instruments should be compatible with this format. People responsible for handling data should agree with those responsible for interpreting and presenting data on a format for the output of results. Data entry should be checked to ensure accuracy.

The statistical methodologies should be reviewed by a statistical expert, whose comments should be taken into account in finalising methods.

2.3.2 Discrepancies

When data is received from collectors, record forms should be examined and the agreed procedure followed. Discrepancies should be referred immediately to the data collector for correction or amendment. Where correction is not possible, resampling is usually the preferred option (with due regard for prevailing conditions). Estimating may be preferable to leaving gaps in the record. However, estimates must be recorded as such, and the methodology of the estimate outlined.

2.3.3 Data storage

Ideally, arrangements should be made to store data in more than one location and format, to avoid the hazards of loss and obsolescence. At all locations, data should be backed up regularly, transcribed accurately, handled appropriately and analysed to prevent errors and bias in the reporting.

Data should be handled and stored in such a way as to ensure that the results are available in the future for further study and for assessing temporal trends. Storage should provide protection against damage, deterioration or loss.

Training and review

A system should be in place to ensure that employees are properly trained to fill out records, and that records are regularly reviewed by a supervisor, signed and dated.

2.4 DATA INTERPRETATION

Data should be interpreted and assessed by experts, who should frame recommendations for management actions, to be submitted to decision makers. Interpretations should always refer to the objectives and should propose improvements, including simplifications, in the data gathering activities. Interpretations should also identify future research needs and lead to the development of local guidelines for environmental planning.

Interpretation of results should take account of all available sources of information, including those derived from the inventory, the catalogue of basic characteristics, sanitary and hazard inspection, water quality sampling and analysis, and interviews, including historical records of these.

2.5 DATA REPORTING

The findings should be discussed with the appropriate local, regional and/or national authorities and others involved in management (including integrated water resource management), such as the industrial development and national planning boards.

Results should be reported to all concerned parties, including the public, legislators and planners. Any information relating to the quality of recreational water use areas should be clear and concise, and should integrate safety, microbial and aesthetic aspects.

In issuing information to concerned parties (eg the public, regulators, nongovernmental organisations, legislators) it is essential that their requirements are kept in mind.

Where specific or extreme events that may threaten public health occur, the relevant public health authority should be informed and recommendations should be made to the water user population about the risks of dangerous water conditions or poor water quality.

Reports addressing the quality of recreational water use areas should be accompanied by reference to local and visitor perceptions of the aesthetic quality and risks to human health and safety.

The usefulness of the information obtained from monitoring is limited unless a supportive administrative and legal framework (together with an institutional and financial commitment to appropriate follow-up action) exists at local or state and territory levels.

2.6 ASPECTS RELEVANT TO SPECIFIC HAZARDS

This section looks at particular hazards that may need to be considered in developing a monitoring program. As noted in Chapter 1 (Figure 1.2), to maximise public health gains, management authorities should prioritise their response measures according to the frequency, severity and preventability of hazards. For example, measures to prevent drowning would be a higher priority than general beach cleaning. The hazards mentioned below are covered in detail in Part 2 of this document.

2.6.1 Drowning and injury hazards

In relation to drowning and injury hazards, a catalogue of basic characteristics should include, where relevant:

- hazards such as beach slopes, tides, flows and currents, and actual user groups;
- nearby hazardous areas such as cliffs, shallow waters dangerous for diving and weirs; and
- other such hazards as identified from local knowledge and records of health effects.

The catalogue should also include information about measures to prevent or ameliorate hazard exposure or outcomes. Examples of such measures are: lifeguard provision; staff training; signs; emergency telephone numbers; access to first aid; medical facilities; fencing; warning systems for adverse conditions; and emergency routes.

Monitoring and assessment programs should particularly address any hazards and preventive measures that are subject to change.

The hazard assessment should take into account the severity and likelihood of adverse health outcomes, and the extent of exposure.

2.6.2 Microbial water quality assessment and sanitary inspection

A sanitary inspection is needed (in addition to microbial water quality analysis) to identify all real and potential sources of microbial contamination. The inspection should assess how such sources may affect the quality of the recreational water use area and the health of water users. It should also include full consideration of the temporal and spatial influences of pollution on water quality.

Before sampling, the selected testing laboratory should be contacted to determine their preferred sampling and storage procedures or protocols.

Timing and scope of inspection

Immediately before the main bathing season, an exhaustive sanitary inspection should be carried out. During the season, inspections of specific conditions should be conducted in conjunction with routine sampling. Pertinent information should be recorded on standardised checklists and used to update the catalogue of basic characteristics. If a problem is identified, it may be necessary to collect supplementary samples or information to characterise the problem. It is critical to:

- identify significant events (eg rain events);
- characterise their impact (eg based on millimetres of rainfall in the catchment); and
- determine the time taken for the area to return to baseline conditions.

Visual faecal pollution or sewage odour should be considered a definite sign of elevated microbial pollution, and necessary steps should be taken to prevent health risks to bathers.

Standard operating procedures for sanitary inspections, water sampling (including depth) and analyses should be well described to ensure uniform assessments.

Collection and handling of samples

The location of sample points and the distances between them should reflect local conditions and may vary widely between sites. Examples of local conditions that need to be considered are: overall water quality; recreational use; predicted sources of faecal pollution; temporal and spatial variations due to tidal cycles, rainfall, currents, onshore winds and point or nonpoint discharges. Care needs to be taken not to resuspend sediments when collecting samples.

Sterile sample containers should be used for microbial samples. Meticulous care should be taken to avoid accidental contamination during handling and sample collection. Every sample should be clearly identified with time of collection, date and location.

A sampling depth relevant for the exposure of concern should be selected and adhered to consistently, in order to allow comparison between locations.

Samples should be kept in the dark, kept as cool as possible (in a chilled, insulated container) and delivered to the laboratory promptly after collection. Samples should be analysed as soon as possible and preferably within 8 hours of collection. Sample storage should not exceed 24 hours at 4–8°C.

Additional information that should be collected at the time of sampling includes water temperature, weather conditions, water transparency, presence of faecal material, abnormal discolouration of the water, floating debris, cyanobacterial or algal blooms, flocks of seabirds and any other unusual factors. All information should be recorded on standardised checklists.

Selection of indicators

Local conditions should be taken into account when selecting appropriate microbial indicators. Should indicators other than enterococci be present, their relationship to enterococci should be determined (see Section 5.3.5).

Influence of specific and extreme events

The influence on the area of specific events, such as rain, especially in relation to the duration of the peak contamination period, should be established. If such events occur, previously agreed procedures should be implemented.

Extreme events, such as epidemics and engineering or natural disasters, may require additional measures.

When unexpectedly high microbial results are obtained, resampling should be undertaken to help determine whether the results were caused by a sporadic event or by persistent contamination. If the problem is persistent contamination, the source of pollution should be established and appropriate action taken.

2.6.3 Cyanobacteria and algae

Monitoring of recreational water use areas should be sufficient to identify the risk of blooms, and should take into account the actual or potential accumulation of toxic cyanobacteria and algae.

Sampling points should be sited to represent different water masses in the investigation area (stratified waters, waters coming from river mouths etc) and the sources of nutrients (discharges, upwellings etc). Possible transport mechanisms of toxic phytoplankton should be considered, wind-induced accumulations of scum should be identified and sampling schemes should be arranged accordingly.

In areas of high risk, sampling for algae should be carried out at least weekly; this should be increased to daily sampling during the development of blooms.

Monitoring of toxicity (using bioassays, or chemical or immunological procedures) is justified only where significant hazards to human health are suspected. In such cases, long-term information on phytoplankton populations (toxic, harmful and others) should be collected where appropriate.

Analyses of toxins should be undertaken only where standard, replicable and reliable analyses can be performed.

Where monitoring is seen as essential, factors that should be considered include: temperature; salinity (in marine coastal areas); dissolved oxygen; transparency; presence of surface water stratification; phytoplankton biomass (chlorophyll); surface current circulation (transport of algae); and meteorological patterns such as seasonal rainfall, storms and special wind regimes.

2.6.4 Other biological and chemical hazards

Monitoring for locally important biological or chemical hazards other than those discussed above is justified only where significant hazards to human health are suspected. Occurrence of such hazards may be highly localised.

Monitoring of these hazards should be undertaken only where known parameters can be assessed using standard, replicable and reliable analyses.

The significance of locally important hazards will depend on the type of hazard. The assessment approach should take account of the hazard's magnitude and frequency, the severity and occurrence of health effects, and other local factors.

2.6.5 Aesthetic aspects

Selection of aesthetic pollution parameters for monitoring should take into account local conditions. Monitoring of parameters must be feasible. Possible parameters include surface accumulation of tar, scums, odours, plastic, macroscopic algae or macrophytes (stranded on the beach and/or accumulated in the water) or cyanobacterial and algal scums, dead animals, sewage-related debris and medical waste.

Assessment of aesthetic pollution indicators should take into account the perceptions and requirements of the local and any visiting populations regarding specific polluting items.

2.7 PROGRESSIVE IMPLEMENTATION OF MONITORING

To protect health, it is necessary to develop systems for monitoring human-health hazards according to public-health priorities (ie monitoring most closely the hazards of highest priority). This will normally mean that several aspects of monitoring (eg beach safety, pollution control) will be developed in parallel. There are different levels of monitoring (as there are different levels of management). Typically, monitoring involves local activities through basic, intermediate and full-scale monitoring. Each of the major hazard groups should be dealt with at each level of monitoring.

Extensive guidance on the development of practical and effective monitoring programs for the safety of recreational water environments is presented in Bartram and Rees (2000).

PART 2 SUPPORTING INFORMATION

3 PHYSICAL HAZARDS

Guideline

It is acknowledged that recreational water and adjacent areas should be free of physical hazards, such as floating or submerged objects that may lead to injury, as much as a reasonable person would deem realistic. Where permanent hazards exist (eg rips and sandbars), appropriate warning signs should be clearly displayed.

3.1 OVERVIEW

Various injury-related health outcomes may arise through the recreational use of water and adjacent areas, the most common are:

- drowning and near-drowning;
- major impact injuries (including spinal and head injuries);
- slip, trip and fall injuries (including bone fractures, facial injuries and abrasions); and
- cuts, lesions and punctures.

Drowning, impact injuries and puncture injuries represent the highest priority for recreational water-quality management programs, because they can cause death or lead to permanent or temporary incapacitation.

This chapter looks at the assessment (Section 3.2), management (Section 3.3) and monitoring (Section 3.4) of physical hazards that can lead to injuries. Bites, stings and other injuries (including envenomation) from aquatic organisms are addressed in Chapter 8.

3.2 ASSESSMENT OF RISKS ASSOCIATED WITH PHYSICAL HAZARDS

The assessment of physical hazards in a beach or water environment is critical to ensuring public safety. Five related types of physical characteristics may present hazards to recreational water users:

- water depth, particularly when greater than chest height;
- variable beach and surf zone topography, such as the intertidal area, bars, channels and troughs;
- breaking waves;
- currents and rips; and
- localised hazards, such as reefs, rocks, shore platforms, inlets, offshore winds, tidal currents, cold water and kelp beds.

The sections below cover each of these characteristics in detail.

An assessment of physical hazards should catalogue the characteristics that may have an impact on public health. These can be identified from local knowledge (including surf life saving organisations), risk management audits and records of health effects.

The assessment should take into account several key considerations, including:

- presence and nature of natural or artificial hazards (eg submerged rocks, piers);
- severity of the hazard characteristics in relation to health outcomes;
- ease of access to the area;
- availability of remedial actions;
- frequency and density of use;
- level of development for recreational use; and
- ability to prevent or ameliorate hazard exposures or outcomes.

Some of this information may be available in the *Australian Beach Safety and Management Program* (ABSAMP³), an inventory of all Australian beaches and their characteristics.

Information about measures to prevent or ameliorate hazard exposure or outcomes should be included in the catalogue of basic characteristics (see Section 2.1 in Chapter 2). This information should include, for example, lifeguard provision, staff training, signs, emergency telephone numbers, access to first aid, medical facilities, fencing, warning systems for adverse conditions, and emergency routes (WHO 2003).

When assessing the significance of hazards, account should be taken of the severity and likelihood of adverse health outcomes, and the extent of exposure, as discussed in Section 1.2 of Chapter 1. Assessment programs should also take into consideration those hazards and preventive measures that are subject to gradual or rapid change.

3.2.1 Water depth

Water depth and poor water clarity have contributed to drowning and near-drowning (Quan *et al* 1989). Knee-depth water can be a problem for toddlers or young children, while chest-depth water can be hazardous to poor and panicking swimmers. In a current, it is only possible to maintain footing and wade against the current when the water is below chest depth (Short 1993).

The role of water depth in impact injuries has not been conclusively determined. However, minimum depths for safe diving are greater than many people think, because the velocities reached from ordinary dives are such that the sudden sighting of the bottom, even in clear water, may not give the diver enough time to decelerate (Yanai and Hay 1995). Most diving injuries occur in relatively shallow water (1.5 m or less); few happen in very shallow water (eg less than 0.6 m), where the hazard may be more obvious (Gabrielsen 1988, Branche *et al* 1991). Inexperienced or unskilled swimmers require greater depths for safe diving.

Familiarity with the water body is not necessarily protective against diving injuries. A study from South Africa noted that the typical injurious dive is into a water body known to the diver (Mennen 1981).

³ <http://www.slsa.asn.au>

3.2.2 Variable beach and surf zone topography

The actions of currents, rips and tides can change the topography, structure and stability of river or lake beds or banks, or of the ocean floor. The changing structure of the floor of the water body can also influence the direction and strength of currents and rip tides.

These changes may lead to potential hazards, particularly for recreational water users unfamiliar with local conditions.

3.2.3 Breaking waves

Waves are formed by the wind blowing across the ocean surface. Wave size is determined by the intensity and duration of wind, the distance over which it blows, the topography of the ocean floor and the shape of the beach. The stronger the wind, the greater the wave action. Table 3.1 describes wave types. Choppy waves on lakes and dams can make swimming dangerous, even though the water appears relatively calm.

Table 3.1 Wave types

Wave type	Description
Plunging waves ('dumpers')	Break with such force that they can throw a swimmer to the bottom. They usually occur at low tide when sandbanks are shallow. This type of wave is a common cause of spinal injuries.
Surging waves	May not break as they approach the water edge, because the water beneath them is deep. They can be dangerous, especially around rocks, because of their ability to knock swimmers off their feet and carry them into deep water.
Spilling waves	Occur when the crest of the wave tumbles down the face of the wave. As the tide gets lower and the sandbank shallower, these waves will form tunnels or tubes. These are generally the safest waves.

3.2.4 Rips and currents

Rip currents are the most dangerous feature of surf beaches (Short 1993). A rip is a strong current of water running out to sea. Rips occur when incoming waves force too much water into the area between the sandbar on which they break and the shore, and the force of water forms a channel or pathway beyond the break. Inexperienced surf swimmers may struggle against a rip, exhaust themselves and drown. Table 3.2 describes the types of rips that may be present in a coastal recreational water body.

Under average wave conditions (< 1.5 m high), rip currents attain maximum velocities of 1.5 m/sec (5.4 km/h). Elite swimmers can swim at 7 km/h (Short 1993).

When the sea is not too rough, an experienced observer can identify a rip by apparently calm patches in the surf line or by streaks of foamy or discoloured deeper water where sand has been stirred from the bottom.

Some of the strongest currents can be experienced in entrances to coastal lakes and estuaries. Such currents are caused by ebb (outgoing) and flood (incoming) tidal flows.

River currents are often stronger than they appear, particularly around the outside of a bend. Submerged objects, such as branches, rocks and rubbish, can injure or entangle swimmers. River conditions can also change rapidly because of heavy rainfall or the release of water from storage areas.

Table 3.2 Description of rip types

Type of rip current	Description
Permanent	Remain in the same area for months or years, because of stability in the ocean floor, prevailing conditions or permanent fixtures, such as drainage pipes and piers.
Fixed	Last from several hours to several months, and are accompanied by a hole or gully in the sand on the ocean floor.
Flash	Appear suddenly, usually without warning, caused by a large and rapid build-up of surge. Seaward pull may be intense and relatively short lived.
Travelling	Move along the beach, propelled by a strong current from the shore.

3.2.5 Localised hazards

Assessment of the local recreational water environment should take into consideration potential hazards particular to the specific location. These may include reefs, rocks, offshore platforms, inlets, offshore winds, tidal currents, cold water, aquatic plants, weirs and locks. The construction of jetties, piers, wharfs and other artificial structures can also contribute to the hazards.

An assessment should be carried out before every high-use season or after a major storm event, to monitor for variations in local hazards.

3.3 MANAGEMENT OF RISKS ASSOCIATED WITH PHYSICAL HAZARDS

Physical hazards in or around a recreational water body should be removed. If a hazard cannot be removed it should be mitigated, if possible, or measures should be taken to prevent or reduce human exposure. Where physical hazards cannot be dealt with in these ways, alternative measures should be implemented. For example, open or rough water, rough waves, rip currents and bottom debris should all be the subject of general education, general warning notices or special warnings, especially at times of increased risk.

This section first looks at three of the main adverse health outcomes associated with the use of recreational water bodies — drownings (Table 3.3), impact injuries (Table 3.4) and cuts and lesions (Table 3.5). The tables, shown below, list contributing factors influencing the occurrence of these adverse health outcomes, and typical preventive and management approaches used to reduce their occurrence. This section then goes on to cover particular measures to manage risk:

- beach ratings (Section 3.3.1);
- education (Section 3.3.2);
- warning signs (Section 3.3.3);
- lifesaving (Section 3.3.4); and
- zoning (Section 3.3.5).

Table 3.3 Contributing factors and preventive and management actions — drowning

Contributing factors
Alcohol consumption Bottom surface gradient, stability Cold Currents (including rip, river and tidal currents) Impeded visibility (including coastal configuration, structures and overcrowding) Lack of local knowledge Lack of parental supervision Offshore winds (especially with flotation devices) Overestimating skills Overloading of boats Poor or inadequate equipment (eg lifejackets in boats) Pre-existing disease/frailty Underwater entanglement Water transparency Waves (coastal, boat, chop)
Preventive and management actions
Access to emergency response (eg telephones with emergency numbers) Appropriate location of access points away from known fixed hazards Availability of resuscitation skills/facilities Continuous adult supervision of children Coordination with user-group associations on hazard awareness and safe behaviours Development of rescue and resuscitation skills among general public and user groups Local hazard warning signs/notices Provision of properly trained and equipped lifeguards Provision of rescue services Public education about hazards and safe behaviour Regulations that discourage unsafe actions (eg exceeding recommended boat loadings) Restriction of alcohol provision Wearing of adequate lifejackets when boating

Table 3.4 Contributing factors and preventive and management actions — impact injuries

Contributing factors
Adjacent surface type (eg of waterfronts and jetties)
Conflicting uses within one area
Diving into shallow water
Poor underwater visibility
Underwater objects (rocks, walls, piers)
Preventive and management actions
Adjacent fencing (eg of docks and piers)
General awareness of hazards and safe behaviour
Lifeguard supervision
Selection of appropriate surface types
Separation of recreational activities
Warning signs

Table 3.5 Contributing factors and preventive and management actions — cuts and lesions

Contributing factors
Presence of broken glass, cans, medical waste
Walking and entering water barefoot (particularly near coral reefs or where there are oysters on rocks)
Preventive and management actions
Beach cleaning
General public awareness of litter control
General public awareness of safe behaviours (including use of footwear)
Local first aid availability
Provision of litter bins
Provision of warning signs
Regulation (and enforcement) prohibiting glass containers
Solid-waste management

3.3.1 Beach rating

The morphodynamic (ie shape changing) factors that are considered potential hazards (Short 1993) and that contribute to the determination of beach safety are:

- the overall water depth and its variability;
- the size of the breaking waves;
- the prevalence and intensity of rips;
- the existence of long shore troughs and currents; and
- in the higher energy states, the occurrence of wave set-up and set-down (ie fluctuations in mean water depth).

Table 3.6 outlines beach and surf zone morphology, and notes the typical beach hazards associated with each of six types of beach state around the southern Australian coast. Table 3.7 shows beach safety rating and generalised hazards, derived from combining beach state with wave height.

Table 3.6 Beach type and safety rating^a

Beach state	Characteristic	Hazards	Beach safety rating ^b and hints
Dissipative	Waves dissipate energy over a wide surf zone, 2–3 m breakers, straight bars, trough and beach	High waves and wide surf zone restrict most bathers to the swash zone; safest bathing in the swash zone	8 — stay close to shore; do not bathe in outer breakers
Long shore bar — trough	Bar and trough parallel to the shore. 1.5–2 m breakers, moderate rip current and straight beach	Deep trough and distance to outer bar restrict most bathers to the swash zone and inner trough; safest bathing is in the swash zone and in the trough away from rips	7 — stay close to shore and avoid deep troughs and rips
Rhythmic bar and beach	Consists of rhythmic (undulating) bar, trough and beach. 1.5 m breakers, distinct rip troughs separated by detached bars	Pronounced changes in depth and current between bar and rips; safest bathing is on or behind the bars when waves are small; hazardous during high tide when waves are large	6 — wade or swim to shallower bars, avoid deep troughs and rips
Transverse bar and rip	Consists of attached bars, rip troughs and undulating beach, 1.0–1.5 m breakers, distinct rip troughs separated by attached bars over 150–300 m	Pronounced changes in depth and current between bars and rips; safest bathing is on the bars	5 — bathe on shallow bars adjacent to rips; however, bathers can be washed off the bars into rips; inexperienced bathers may unknowingly enter rips
Low-tide terrace	Shallow bar or terrace often exposed at low tide, 0.5–1.0 m breakers	Safest bathing; safe at low tide; deeper water and weak rips at high tide	3 — watch for plunging waves at low tide
Reflective	Waves tend to reflect back off the beach, 0–1 m breakers, only occurs on very low-wave beaches and on harbour beaches	Safest bathing; safe except for deep water close inshore and shore break when waves are higher; steep beach and abrupt drop-off to deeper water can make access difficult for elderly people and children	2

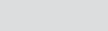
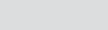
^a Beach type and associated beach safety ratings shown here represent the average wave conditions on beaches in the microtidal (< 2 m tide range) regions of southern Australia (South Queensland, New South Wales, Victoria, Tasmania, South Australia and Southern Western Australia)

^b Beach safety rating is on a scale of 0–10, where 10 represents the greatest hazards

Notes: The calculation of the beach safety rating will include an assessment of the beach state and wave height. A beach safety rating based on increasing wave height can be assigned to the beach using Table 3.7. In addition to consideration of the wave types and subsurface topography of the recreational water body, the assessment of the overall beach safety rating also needs to take into account local factors. These will include the proximity of headlands, oblique waves and the state of the tides, which will influence the direction and intensity of rip currents

Source: Short (1993)

Table 3.7 Beach safety rating and generalised hazards, by beach state and wave height

Beach state	Wave height (m)							
	<0.5	0.5	1.0	1.5	2.0	2.5	3.0	> 3.0
Dissipative	4	5	6	7	8	9	10	10
Long shore bar — trough	4	5	6	7	7	8	9	10
Rhythmic bar beach	4	5	6	6	7	8	9	10
Transverse bar rip	4	4	5	6	7	8	9	10
Low-tide terrace	3	3	4	5	6	7	8	10
Reflective	2	3	4	5	6	7	8	10
Beach safety rating Safest: 1–3 Moderately safe: 4–6 Low safety: 7–8 Least safe: 9–10		Key to hazards  Water depth and/or weak currents  Shorebreak  Rips and surf-zone currents  Rips, currents and large breakers						

Source: Short (1993)

3.3.2 Education

Most injuries can be prevented by appropriate measures, especially those implemented at a local level. A relatively low-cost way of promoting aquatic safety is through public education before people even set foot on the beach. Once the person arrives at the beach, additional public education efforts can further enhance public safety.

Education programs should focus on behaviour that increases safety, such as:

- not littering;
- checking water conditions before entering the water;
- not diving into shallow waters (eg less than 2 m deep);
- respecting others (important in overcrowded conditions);
- being aware of hazards;
- being aware of water conditions;
- supervising young children;
- acquiring cardiopulmonary resuscitation (CPR) skills;
- restricting alcohol consumption during recreational activities; and
- acquiring swimming and lifesaving skills.

Surf Life Saving Australia⁴ and the Royal Surf Lifesaving Society can supply various educational packages, programs and pamphlets to water safety providers if required.

Table 3.8 lists some basic safety messages that could be adopted as part of an overall beach-safety awareness campaign.

⁴ <http://www.slsa.asn.au>

Table 3.8 Basic safety messages for recreational water users

• Always swim in designated, patrolled areas between the flags • Ask a lifesaver about swimming conditions before entering the water • Check current strength • Obey instructions from lifesavers • Learn to swim and survive • Do not swim alone • Do not dive into unfamiliar water or shallow breaking waves • Check for submerged objects • Take note of and obey any posted beach safety notices • If you get into trouble, signal for help • If you are unsure of the water condition or your swimming ability, do not enter the water • Do not swim if you are affected by alcohol or drugs

3.3.3 Warning signs

When a beach or body of water has been identified as not suitable for recreational use, the public should be notified. Signs should be placed in conspicuous places along the beach or shoreline, in accordance with Australian Standards (AS 2416–2002) and best-practice recommendations of the *Aquatic and Recreational Signage Style Guide*. Australian Standard AS 2416 (*Design and Application of Water Safety Signs*) covers the signposting of hazards and prohibitions related to places where water sports or recreational activities may take place, or where there are other activities close to bodies of water such as the seaside, rivers, creeks, dams and open drains. The standard includes:

- signs to notify people of beach flags controlling the swimming area;
- signs prohibiting activities that might be hazardous (eg diving, waterskiing and bodyboarding); and
- signs warning of hazards that might not be apparent (eg deep water, shallow water and hazardous sea creatures).

Signs should remain in place only as long as necessary and be removed promptly when the health hazard no longer exists.

Use of signs should be combined with education or awareness-raising measures, otherwise they may go unnoticed (WHO 2001).

Design and content of signs

Signs should be concise and clear about the health risk and recommended course of action. They should use simple, understandable text and symbols in bright colours, and should include attention-catching words such as ‘WARNING’ for hazardous conditions and ‘DANGER’ for dangerous conditions.

Standard symbolic signs for water safety (as outlined in AS 2416) should be posted at the recreational water body to advise of potential hazards.

The authority making the determination should be clearly indicated on the signs. Signs should indicate the following, as appropriate:

- description of hazards and risks involved;
- patrol hours;
- meaning of flags and/or emergency signals; and
- on less-frequented beaches and in inland recreational areas, location of phone, emergency numbers and closest first aid facilities.

Regulatory, warning, information and permissive signs

AS 2416 includes regulatory signs; such signs contain instructions and failure to comply with the instructions is either an offence at law or a breach of beach-safety procedures. Regulatory signs are subdivided into:

- *prohibition signs* — which indicate that an action or activity is not permitted; and
- *mandatory signs* — which indicate that an instruction must be carried out.

Warning signs advise of a particular hazard or hazardous condition, or that an activity is not advised.

Information and permissive signs provide information about water-safety features or indicate a location where a particular activity is permitted.

3.3.4 Lifesaving

Lifesavers and lifeguards are important in reducing injuries and drownings in recreational waters. Patrolled beaches can be identified by the presence of red and yellow flags, which designate the safest area to swim based on the lifesavers' daily assessment of the beach for hazards before each patrol begins. The International Lifesaving Federation and the Australian Water Safety Council have endorsed red and yellow as the colours to identify lifesavers and lifeguards in Australia and around the world. Lifesavers and lifeguards should:

- be located where they can observe the identified bathing area;
- always work in pairs, with appropriate backup support during rescues;
- be equipped with a rescue box, first aid equipment, radio, binoculars and an appropriate rescue craft, all well maintained;
- be provided with technical support and physical training, with their competency reassessed every year; training should include both normal operating procedures and emergency procedures; and
- be clearly identifiable to the public by wearing uniforms in the standard international lifesaving colours of red and yellow while on duty (AWSC 2004).

3.3.5 Zoning

Zoning may be used to separate activities that are incompatible for reasons of safety. For example, activities such as boating, jet-skiing and surfing pose a risk to swimmers; therefore, areas for these activities should be separated from bathing areas. Rod and spear fishers' activities should also be separated from bathing areas, as they can present health risks to other users of recreational water bodies by attracting predator species or by discarding tackle that can cause puncture wounds.

Wherever possible, lines, buoys, markers and buffer zones should be used to separate incompatible activities, designate areas for safe swimming and prevent swimmers from entering dangerous areas.

3.4 MONITORING OF RISKS ASSOCIATED WITH PHYSICAL HAZARDS

This section should be read in conjunction with Section 2.6.1, on the design and implementation of monitoring programs for drowning and injury hazards.

Any recreational water site should be monitored regularly for existing and new hazards, to promote remedial action as required. Some hazards (eg rips) may require daily or even hourly assessment. Other hazards (eg known submerged rocks or piers) will require less frequent monitoring; for example, weekly or monthly assessment. The frequency and extent of the monitoring, maintenance and cleaning programs will be influenced by the nature of the hazards, their severity, the availability of remedial actions and the density of use of the area.

A monitoring protocol of injury hazards for a recreational water area may comprise the following:

- determining what is to be inspected and how frequently;
- monitoring changing hazards and use patterns periodically;
- establishing a regular pattern of inspection of conditions and controls;
- developing a series of checklists suitable for easy application;
- establishing a method for reporting faulty equipment and maintenance problems
- developing an incident reporting system;
- motivating and informing participants in the inspection process through in-house training; and
- using outside experts to critically review the scope, adequacy and methods of the inspection program.

Frequency and timing of the monitoring program should reflect the types of recreational water area, types of use and density of use. They should also reflect temporal and spatial variations in the recreational area, caused by factors such as seasonality, tidal cycles, rainfall and, discharge and abstraction patterns.

4 SUN, HEAT AND COLD

Guideline

The temperature of recreational water bodies should be in the range 16–34°C. Recreational water users should be educated to reduce exposure to ultraviolet radiation (UVR), particularly during the middle of the day.

4.1 OVERVIEW

Extreme temperature conditions can exist in recreational water environments. Ultraviolet radiation (UVR) and temperature deserve particular attention because global climate change and ozone depletion are likely to aggravate existing health risks (WHO 2003).

When people engage in outdoor activities and recreation by the shore of a lake or at the beach, they are often exposed to high levels of UVR from the sun and reflected UVR from water surfaces for long periods. UVR can cause both acute and long-term damage to health.

People exposed to cold water (< 16°C) are at increased risk of suffering a debilitating shock response and hypothermia. At the other extreme, high air temperatures may result in hyperthermia (eg heat exhaustion and heatstroke).

This chapter looks at the assessment (Section 4.2), management (Section 4.3) and monitoring (Section 4.3.2) of sun, heat and cold in recreational water bodies.

4.2 ASSESSMENT OF RISKS ASSOCIATED WITH EXPOSURE TO SUN, HEAT AND COLD

4.2.1 Risks associated with sun

Overexposure to solar UVR, in or on the water or on shore, may result in acute and chronic health effects on the skin, eyes and immune system. Acute effects include sunburn pain and blistering; chronic effects include skin cancer and cataracts. Australia has the highest incidence of skin cancer in the world (Cancer Council NSW and NSW Health 2001). Most people get sunburnt when the temperature is between 18°C and 27°C because they cannot feel the heat from the sun, assume there is no risk from UVR, and so prolong their exposure. Epidemiological evidence indicates that childhood exposure to UVR is a strong determinant of risk of melanoma and skin damage later in life.

Overexposure to solar UVR can be a problem for swimmers because UVR passes easily through the first 30 cm of water (Huovinen *et al* 2000).

Table 4.1 outlines the UVR indicator values and associated exposure categories.

Table 4.1 Global solar UVR indicator

UVR indicator values ^a	Exposure category	Level of sun protection required	'Sound bite' messages
< 3	Low	None required	You can safely stay outside
3 – < 6	Moderate	Protection required	Seek shade during midday hours. Slip on protective clothing, slap on a hat, wrap on sunglasses and slop on sunscreen.
6 – < 8	High		
8 – < 11	Very high	Extra protection required	Avoid being outside during midday hours. Make sure you seek deep shade. Protective clothing, a hat, sunglasses and sunscreen are a must.
≥ 11	Extreme		

^a Each point on the indicator scale is equivalent to 25 milliwatts/m² of UVR at the earth's surface for UVR wavelengths between 290 and 400 nanometres (<http://www.bom.gov.au/>).

Note: Even for very sensitive, fair-skinned people, the risk of short-term and long-term UVR damage below UVR indicator level 3 is limited, and under normal circumstances no protective measures are needed. Above the threshold value of 3, protection is necessary and should include all protective means available. At the very high or extreme exposures of UVR indicator level 8 and above, this message must be reinforced, and people should be encouraged to use more sun protection and avoid being outdoors around the midday hours.

Source: WHO (2003)

4.2.2 Risks associated with heat and cold

A comfortable temperature for most people is between 20°C and 28°C. Factors influencing thermal comfort include air temperature, humidity, wind speed and fluxes in shortwave and longwave radiation. The human body regulates heat efficiently and will normally cope effectively with a moderate rise in ambient temperature. However, the temperature range in which people can stay in water without overheating or overcooling is very narrow compared to the range in air.

It is not possible to define a single cut-off point below which water temperatures are dangerous, as this will vary with the specific circumstances, the physical condition of the person involved and the duration of exposure. For example, the following populations appear to be more affected by weather extremes, probably because their bodies are less able to cope (CDC 1995, WHO 2003):

- the elderly;
- the very young (< 4 years) — for example, young children may spend long periods in the water; they are at a higher risk of hypothermia because of their higher surface area to mass ratio, particularly if they have low body fat;
- people with impaired mobility;
- people suffering from pre-existing chronic diseases (eg heart failure, diabetes); and
- frequent consumers of alcohol.

Research has shown that even strong swimmers can experience difficulties and drown within minutes of cold-water immersion unless they are habituated to cold (Golden and Hardcastle 1982). The immediate effect of sudden immersion in cold water (< 15°C) can be a debilitating, short-term reflex response occurring over about 2–3 minutes called cold shock. This response involves life-threatening respiratory and cardiovascular effects, including rapid breathing, increased heart rate and a surge in blood pressure.

Apparent temperature, which combines temperature and humidity, is measured by a heat indicator. When both temperature and humidity are high, the heat indicator can be as much as 18°C above the actual temperature. The high humidity restrains the evaporation of sweat, reducing the body's cooling capability and increasing the risk of heat stress. Figure 4.1 shows a plot of the heat indicator under different combinations of temperature and humidity, with dangerous levels shown in red.

In cold conditions, temperature and wind speed combine to produce a wind chill (see Figure 4.2). A brisk cold wind can reduce the subjective temperature by 10°C or more, compared to the actual reading, because it reduces the amount of body heat retained.

Table 4.2 outlines the health outcomes associated with exposure to water temperatures, wind chill and heat. Water temperatures of 21°C or less should prompt concern. Exercise in water increases the rate of heat loss because increased heat production from shivering and exercise is generally accompanied by increased muscle blood flow and hence a higher heat conductance to the skin.

Figure 4.1 Heat indicator at different combinations of temperature and humidity

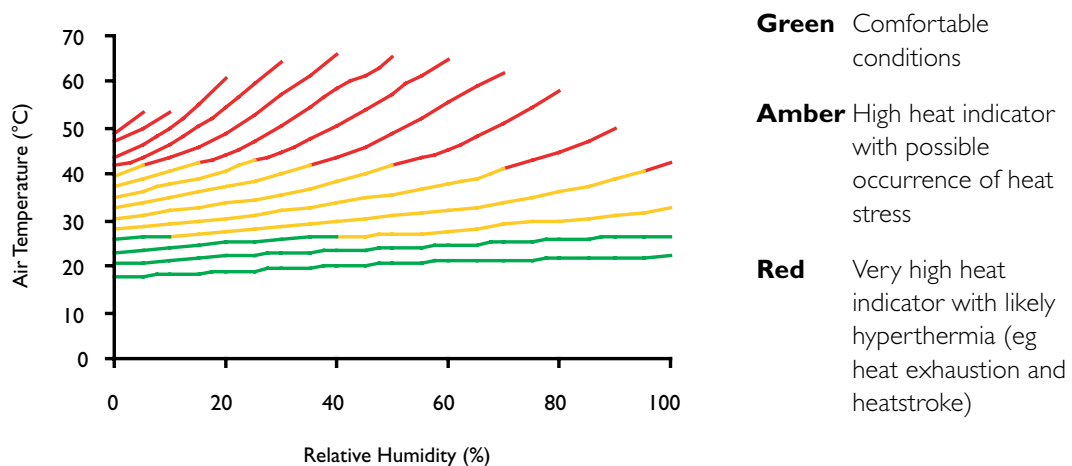


Figure 4.2 Wind chill at different combinations of temperature and wind speed

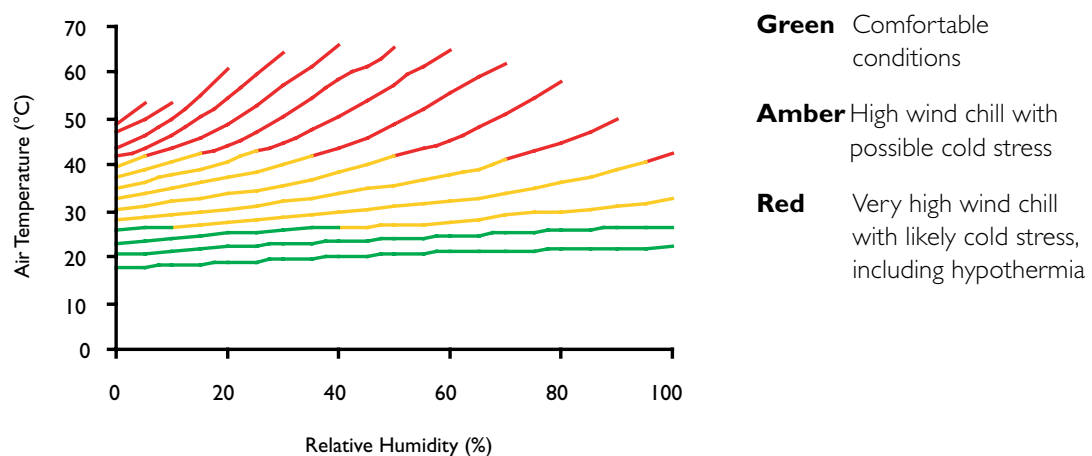


Table 4.2 Health outcomes associated with exposure to water temperatures, wind chill and heat indicator

Category ^a	Water temperature(°C)	Wind chill (°C)	Heat indicator	Health outcome
Red (very poor)	na		> 54	Heatstroke and heat exhaustion are highly likely
Yellow (poor)	> 34		40–54 32–40	Heatstroke and health exhaustion are likely Heat illness is likely to occur after 2 hours Heatstroke and heat exhaustion are possible
Green (good)	32–34 28–32		27–32	Comfortable temperature zone Fatigue is possible with prolonged exposure Shivering and sensation of cold is likely after 1–3 hours
Yellow (poor)	21–28 16–21	20–27 10–20		Shivering and sensation of cold is most likely after less than 1 hour Cold stress is possible with prolonged exposure Diving reflex ^b may occur (children and elderly should be watched carefully) Cold stress possible
Red (very poor)	10–16 <10°C	<10		Diving reflex is likely to occur Cold stress including hypothermia is likely No swimming without wetsuit

na = data not available

^a Colour coding is used throughout these guidelines to provide an indication of graded recreational water conditions^b Diving reflex — cardiovascular and metabolic adaptations to conserve oxygen; the heart rate decreases and the blood pressure remains stable or increases slightly while reducing blood flow to all areas of the body except the brain

4.3 MANAGEMENT OF EXPOSURE TO SUN, HEAT AND COLD

4.3.1 Management of risks from the sun

Damage to the skin, eyes and immune system from exposure to UVR is mostly preventable (Wei *et al* 2003). Reducing both the occurrence of sunburn and cumulative UVR exposure can decrease harmful health effects and significantly reduce health-care costs. Parental sun protection behaviour is the single greatest influence of the behaviour of young children (Cancer Council NSW and NSW Health 2001).

Levels of UVR (and consequently the UV indicator) vary throughout the day. In reporting the UV indicator, most emphasis is placed on the maximum UVR level on a given day. This usually occurs during the 4-hour period around solar noon, which, depending on the geographical location and whether daylight saving time is applied, takes place between 10am and 2pm.

Information relating to the UV indicator should be especially targeted at vulnerable groups within the population, such as children, young people, outside employees and tourists. It should inform people about the range of UVR-induced health effects, including sunburn, skin cancer and skin ageing.

Risks from the sun can be managed by reducing UVR exposure through:

- education;
- shade;
- clothing;
- sunscreen; and
- sunglasses.

Desirable actions or outcomes for each of these measures are summarised in Table 4.3 and discussed in the text below.

Table 4.3 Measures to reduce exposure to UVR

Components	Desirable actions or outcomes
Education	Erect signage about the importance of sun protection Ensure that employees are role models for users of facilities Conduct sun-protection information sessions for employees Ensure that sun-protection information is available to patrons Avoid being outdoors between 10am and 3pm
Shade	Review available shade at local recreational facilities Ensure that sufficient shade, either natural or built, is available, and planned when new recreational facilities are being developed Investigate the opportunities to make portable shade structures available
Clothing	Ensure that employees wear broad-brimmed hats, sunglasses and long-sleeved shirts on patrol Encourage the sale of broad-brimmed hats in local kiosks
Sunscreen	Encourage the sale of low-priced (or subsidised) SPF 30+ broad-spectrum, waterproof sunscreen in local kiosks Provide employees with (sun protection factor) SPF 30+ broad-spectrum, waterproof sunscreen
Sunglasses	Encourage use of Australian Standard (AS 1067:2003) approved sunglasses to reduce eye exposure to UVR

Source: Anti-Cancer Council of Victoria (1999), WHO (2003)

Education

Public education should aim to improve knowledge about the health risks of sun exposure and to change attitudes and behaviours. Education activities in the context of recreational water environments should mainly target children, adolescents and their parents. A day's activities should be planned to minimise an individual's, particularly a child's, exposure around the midday hours (between 10am and 3pm) when UVR is most intense. Recreational water users should be encouraged to limit exposure, seek shade, wear protective clothing (including hats), apply sunscreen and wear sunglasses.

Shade

The provision of suitable shade, either natural or artificial, should be considered as part of any management strategy for recreational water bodies.

Trees with broad canopies and dense foliage are best, although a tree may need more than 10 years to reach maturity. The height of the canopy should be optimised to allow sufficient clearance beneath and sufficient shade (shade decreases as the height of the canopy increases). When planning to plant trees, local conditions should be taken into account to ensure that the maximum benefit will be achieved in providing shade from the midday and afternoon sun.

Artificial shade structures include sails, shadecloth and solid-roofed structures. A roofing material such as metal sheeting is highly effective in blocking direct UVR. However, attention should be paid to the reflection of UVR from surrounding surfaces. Rigid translucent materials provide excellent UVR protection when manufactured to a suitable standard but ventilation may be required to minimise heat build-up. Polyvinylchloride (PVC)-coated polyester can be expensive and, if not correctly designed, can let UVR through gaps. Shade sails are usually made from shadecloth. Often, large open spaces between the sails allow considerable UVR through. The Australian Standard for UVR protection from synthetic shadecloth is AS 4174–1994 *Synthetic Shade Cloth*.

Clothing

Broad-brimmed and legionnaire hats made of closely woven materials are recommended for sun protection. The degree of protection depends on the penetration of UVR through the material, which is determined largely by the structure or weave of the material, with tightly woven materials giving greater protection. UVR is transmitted and scattered through the interstices of the material instead of penetrating the fabric. For a given fabric type, darker colours generally transmit less UVR.

When selecting suitable clothing for use at recreational water facilities, users should be encouraged to choose:

- clothes that cover the arms, legs and neck, with long sleeves, collars and if possible long pants or skirts, in lightweight fabrics like cotton, hemp or linen (most polyester–cotton and cotton clothing protects against 95% of UVR); and
- garments with an ultraviolet protection factor (UPF) greater than 15.

Sunscreens

Sunscreens and lip balms are physical and chemical topical preparations that reduce the transmission of solar UVR into the skin by absorption, reflection or scattering. Physical sunscreens (sunblocks such as zinc oxide, titanium dioxide or red ferric oxide) function by reflecting and scattering and provide protection against a broad spectrum of UVR and visible wavelengths.

Sunscreen preparations are evaluated using the sun protection factor (SPF). The SPF is defined as the ratio of the least amount of UVR required to produce minimal erythema (redness of the skin) after application of a standard quantity of the sunscreen, to that required to produce the same erythema without sunscreen application. The maximum protection factor is SPF 30+. The current regulation for sunscreens is documented in the standard AS/NZS 2604–1998 *Sunscreen Products — Evaluation and Classification*.

Actual SPF factor values depend critically on the thickness of the application and on such other factors as absorption into the skin, sweating, contact with water and regular 2-hourly reapplication (Cancer Council NSW and NSW Health 2001).

A report from a working group of the International Agency for Research on Cancer (IARC) concluded that topical sunscreens reduce the risk of sunburn in humans and that sunscreens probably prevent squamous cell carcinomas when used mainly during unintentional sun exposure (Vainio *et al* 2000). The IARC working group was unable to draw any conclusions about the cancer-preventive activity of topical use of sunscreens against basal cell carcinomas and cutaneous melanoma.

Use of sunscreens can extend the duration of intentional sun exposure, such as sunbathing, but this may increase the risk for cutaneous melanoma. The IARC working group warned against relying solely on sunscreens for protection from UVR and indicated that sunscreens should be used in combination with other sun-protective measures wherever possible (Vainio *et al* 2000, Garvin and Eyles 2001).

The Australian Cancer Council recommends the use of SPF 30+ sunscreen to protect exposed skin. The sunscreen needs to be applied thickly and reapplied regularly, even on cloudy days or in cold weather, and after swimming.

Sunglasses

All sunglasses in Australia must meet an Australian Standard (AS 1067 — *Sunglasses and Fashion Spectacles*). Correct use of sunglasses should begin during childhood. Lens shape and contour should be considered. Wrap-around glasses give almost complete protection, whereas regular frames allow up to 5% of the UVR to reach the eyes. Polychromatic or coloured glasses are less effective in blocking out UVR. Polarisation has little effect on the UVR-absorbing properties of lenses. Similarly, mirror finishes do not significantly reduce UVR absorption.

4.3.2 Cold

Water temperature should be measured daily at 30 cm below the surface and reported to inform the public of the risks associated with (mainly cold) water temperatures. Precautions by recreational water users and authorities against cold stress include:

- avoiding lengthy exposure;
- changing wet clothing as soon as possible;
- wearing appropriate clothing;
- providing and using shelter or heated rest rooms; and
- encouraging consumption of hot drinks and not alcohol.

Managers of recreational areas should also bring to the attention of their staff and recreational users the fact that the swimming capability of children and elderly people may be rapidly impaired by cold water, putting these users at higher risk of drowning.

Adults should pay particular attention when children are paddling or playing water sports, as the water will increase the loss of body heat.

4.3.3 Heat

A good-quality drinking water supply should be maintained close to the recreational water area and positive steps should be taken to encourage people to drink small quantities of water regularly to avoid dehydration and heat-related illness. Provision of shade, showers and mist sprays can also dramatically reduce the incidence of heat stress. Water fountains, shade structures and shelter from heat should be provided in hot conditions; shelter from cold should be available in cold conditions.

5 MICROBIAL QUALITY OF RECREATIONAL WATER

Guidelines

Preventive risk management practices should be adopted to ensure that designated recreational waters are protected against direct contamination with fresh faecal material, particularly of human or domesticated animal origin.

5.1 OVERVIEW

Contamination of recreational water with fresh faecal matter from humans or animals can lead to health problems because of the presence of disease-causing microorganisms (pathogens).

To categorise recreational water by its microbial quality it is best to use a combination of sanitary inspection and microbial water-quality assessment. This approach provides information on possible sources of pollution and numerical data on the likely level of faecal pollution. It involves the following steps:

- initial assessment of the waterbody's water quality and sanitary status, including source waters;
- definition of categorisation and audit parameters for major environmental conditions likely to be encountered and the trigger values by which different conditions are distinguished;
- classification of overall suitability according to intended use and scale of use;
- definition of access restrictions by environmental conditions;
- ongoing management, involving
 - periodic sanitary survey and water-quality auditing to ensure that the suitability classification is valid
 - frequent activities in sanitary assurance and reactive management to ensure that the access allowed is appropriate to the current environmental conditions or to alter the access status in response to changes in environmental conditions (where improved conditions are desirable);
- proactive management to upgrade the water body's suitability classification (or classification system) and to assess the appropriateness of changes in suitability classification; and
- management support activities, such as data management and development of sanitary survey and complaints response systems.

The results of the categorisation based on sanitary inspection and microbial water-quality assessment can be used to:

- classify water bodies in order to support informed personal choice;
- provide on-site guidance to users on relative microbial safety;
- assist in the identification and promotion of effective management interventions; and
- provide a basis for regulatory requirements and an assessment of compliance with them.

A flow diagram summarising microbial water quality assessment and management for recreational waters is provided in Appendix 2.

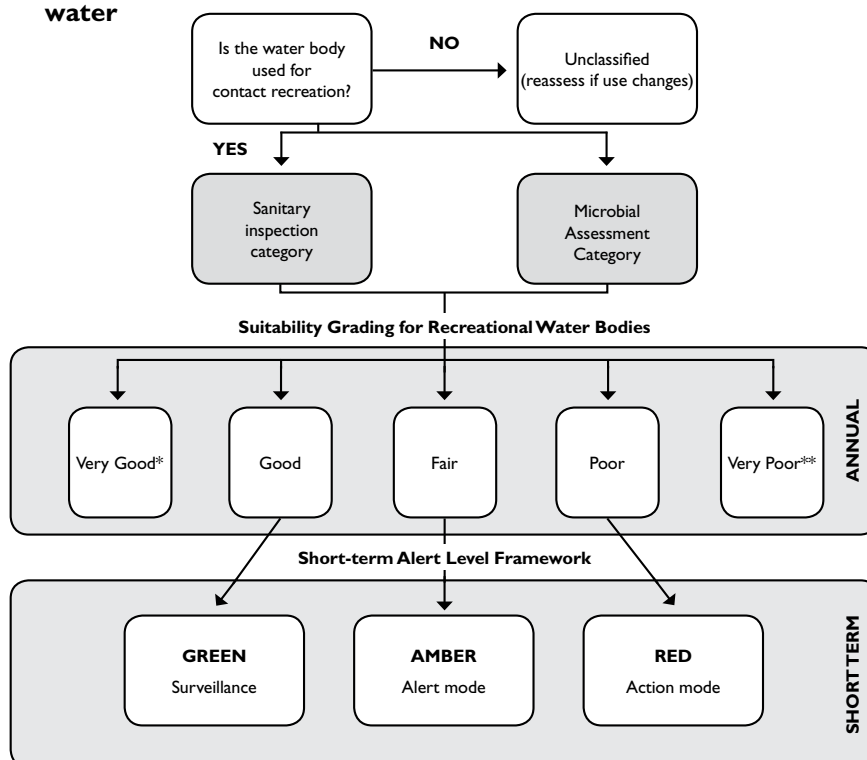
In some instances, the microbial quality of recreational water may be strongly influenced by factors such as rainfall within the catchment, potentially leading to short periods of elevated faecal pollution. There is some evidence that advising against the use of recreational water bodies at times of increased risk has benefits (eg NSW Beachwatch⁵).

Routine microbiological monitoring is suggested to be replaced by automated modelling of potential faecal pollution (Ashbolt and Bruno 2003), or at least reduced leaving microbiological testing for verification and specific investigations into catchment sources and control. Where this approach could be used to prevent human exposure to pollution hazards, this can be taken into account both in classifying the water body and in providing appropriate advice.

Combining classification (based on both sanitary inspection and microbial water quality assessment) with prevention of exposure at times of increased risk leads to the framework for assessing recreational water quality outlined in Figure 5.1 and the monitoring program shown in Table 5.1 (more information on monitoring is given in Section 5.5.5). Waters that are of very good quality would require minimal monitoring, as would waters with very poor quality in which body-contact activities should not be allowed.

The resulting classification can be used to support activities in pollution prevention (eg reducing stormwater overflows) and as a way to recognise and account for cost-effective local actions to protect public health (eg advisory signage about rain impacts).

Figure 5.1 Simplified framework for microbial quality assessment of recreational water



* No Alert required

** This beach should be closed for recreational activity

⁵ <http://www.environment.nsw.gov.au/beach/index.asp>

Table 5.1 Monitoring of microbial alert levels for recreational water

Green level Surveillance mode	Amber level Alert mode	Red level Action mode
Monitoring is consistent with the long-term classification, although the water body may be subject to short-term advisories, eg to avoid primary and secondary contact for several days after rain. Continue routine sampling. ^a	Monitoring is not fully consistent with the long-term classification, requiring investigation into the cause of the elevated levels. Increased sampling enables a more accurate assessment of the risks to recreational users. The water body remains subject to short-term advisories, eg to avoid primary and secondary contact for several days after rain. ^a	Monitoring indicates unacceptable risks to recreational users to an extent requiring the local authority and health authorities to warn the public that the water body is considered to be unsuitable for primary and secondary contact.

^a The determination of the period after a rainfall event during which the recreational water body is considered to be unsuitable for whole-body immersion will depend on local factors, including activities within the catchment and the exchange rate of water (eg currents, environmental flows etc).

5.2 HEALTH EFFECTS ASSOCIATED WITH FAECAL POLLUTION

5.2.1 Range of pathogens

Recreational waters usually contain a mixture of faecally derived pathogenic microorganisms (eg *Cryptosporidium*) and nonpathogenic faecal indicator microorganisms (eg thermotolerant faecal coliforms). These microorganisms may be derived from sewage effluents, the recreational population using the water (from defecation and/or shedding), livestock (cattle, sheep etc), industrial processes, farming activities, domestic animals (eg dogs) and wildlife.

Environmental conditions vary significantly within Australian states and territories. The relationship between thermotolerant coliforms and enterococci may depend on a number of factors, including exposure to sunlight, temperature, salinity and the differences between pollution sources.

The pathogens that may be transmitted through contaminated recreational water are diverse. Table 5.2 provides general information on the pathogens relevant for Australian recreational water management. The range of pathogens changes in response to increases in human and animal populations, influences from wastewater and the delivery of pathogens of human or animal origin to the recreational water.

Table 5.2 Waterborne pathogens and their significance in recreational water

Pathogens/indicator organisms	Health significance	Relative infectivity	Important animal
Viruses			
Coxsackie	High	High	No
Rotaviruses	High	High	No
Adenoviruses	High	High	No
Noroviruses	High	High	No
Hepatitis A	High	High	No
Hepatitis E	High	High	Potentially pigs
Parasitic protozoa			
<i>Cryptosporidium parvum</i> oocysts	High	High	Yes
<i>Cryptosporidium hominis</i> oocysts	High	High	No

Continued over page ➤

Pathogen/indicator organism	Health significance	Relative infectivity	Important animal
<i>Entamoeba histolytica</i>	High	High	No
<i>Giardia lamblia</i> cysts	High	High	Yes
Bacteria			
<i>Campylobacter</i> spp	High	Moderate	Yes
<i>Clostridium perfringens</i> spores	Nil (indicator)	Low	Yes
<i>Escherichia coli</i>	High (rare strains), most are indicators	High (for non-indicator strains)	Yes
Intestinal enterococci	Nil (indicators)	Low	Yes
<i>Salmonella</i> spp	High	Low	Yes
<i>Shigella</i> spp	High	Moderate	No

Note: Waterborne transmission of the pathogens listed has been confirmed by epidemiological studies and case histories. Part of the demonstration of pathogenicity involves reproducing the disease in suitable hosts. Experimental studies in which volunteers were exposed to known numbers of pathogens provided relative information. As most feeding studies involve healthy adult volunteers, such data are applicable to only a part of the exposed population and extrapolation to more sensitive groups remains to be studied in more detail (WHO 2004).

5.2.2 Health effects and numbers of pathogens

Infections and illness due to recreational water contact are usually mild and are therefore difficult to detect through routine surveillance systems (Ferson *et al* 1993). Even where illness is more severe, it may still be difficult to attribute it to water exposure. However, targeted epidemiological studies have shown a number of adverse health outcomes (including gastrointestinal and respiratory infections) to be associated with faecally polluted recreational water overseas (WHO 2003). This may result in a significant burden of disease and economic loss. For estuarine and coastal waters, the pathogen group most likely to be present is human viruses, which are found in sewage or human excreta (WHO 2003).

The number of microorganisms (ie the dose) that may cause infection or disease depends on the specific pathogen, the form in which it is encountered, the conditions of exposure and the host's susceptibility and immune status. For viral and protozoan illnesses this dose might be very few viable infectious units (Fewtrell *et al* 1994, Teunis *et al* 1996, Haas *et al* 1999, Okhuysen *et al* 1999, Teunis *et al* 1999). An emerging issue on the bacterial pathogen scene is various haemorrhagic *Escherichia coli* (from domestic farm animal faecal matter) such as type O157:H7, which are highly infectious in low numbers (Teunis *et al* 2004). Moreover, the human body rarely experiences a single, isolated encounter with a pathogen and the effects of multiple and simultaneous pathogenic exposures are poorly understood (Esrey *et al* 1985).

Due to the 'species barrier', the density of pathogens of public health importance is generally assumed to be less in aggregate in animal excreta than in human excreta, thus representing a significantly lower risk to human health. As a result, the use of faecal bacteria alone as an indicator of risk to human health may significantly overestimate risks where the indicator organisms derive from sources other than human excreta. Nevertheless, there are human health risks associated with pollution from animal excreta and some pathogens, such as *Cryptosporidium parvum*, *Campylobacter* spp and *E. coli* O157:H7 can be transmitted through this route.

The types and numbers of pathogens in sewage will differ depending on the incidence of disease and carrier states in the contributing human and animal populations and the seasonality of infections. Hence, numbers will vary greatly across different regions and times of year. A general indication of pathogen numbers in raw sewage is given in Table 5.3.

In both marine and freshwater studies of the impact of faecal pollution on the health of recreational water users, several faecal indicator bacteria (including *E. coli*, faecal streptococci and intestinal enterococci) have been used for describing water quality. These bacteria are not postulated as the causative agents of illnesses in swimmers but appear to correlate with disease outcomes (Prüss 1998).

Enteric illness

The most frequent adverse health outcome associated with exposure to faecally contaminated recreational water appears to be enteric illness, such as self-limiting gastroenteritis, which may often be of short duration and may not be formally recorded in disease surveillance systems (Corbett *et al* 1993). Transmission of pathogens that can cause gastroenteritis is biologically plausible and is analogous to waterborne disease transmission in drinking water, which is well documented. The association between gastrointestinal upset and bacterial indicators has been reported repeatedly (Prüss 1998).

Table 5.3 Examples of pathogens and indicator organism concentrations in raw sewage

Pathogens/indicator organisms	Disease or role	Numbers/100 mL
Bacteria		
<i>Campylobacter</i> spp	Gastroenteritis	10 ⁴ –10 ⁵
<i>Clostridium perfringens</i> spores	Indicator	10 ⁴ –10 ⁵
<i>Escherichia coli</i>	Indicator (except specific strains)	10 ⁶ –10 ⁷
Intestinal enterococci	Indicator	10 ⁵ –10 ⁶
<i>Salmonella</i> spp	Gastroenteritis	0.2–8000
<i>Shigella</i> spp	Bacillary dysentery	0.1–1000
Viruses		
Somatic coliphages (viruses to <i>E. coli</i>)	Indicator	10 ⁵ –10 ⁷
F-RNA coliphages (viruses to <i>E. coli</i>)	Indicator	10 ⁴ –10 ⁶
Polioviruses	Indicator (vaccine strains) Poliomyelitis	180 – 5 × 10 ⁵
Rotaviruses	Diarrhoea, vomiting	400 – 8.5 × 10 ⁴
Adenoviruses	Respiratory disease, gastroenteritis	not enumerated ^a
Noroviruses ^b	Diarrhoea, vomiting	not enumerated ^a
Hepatitis A	Hepatitis A	not enumerated ^a
Parasitic protozoa^c		
<i>Cryptosporidium</i> spp oocysts	Diarrhoea	0.1–39
<i>Entamoeba histolytica</i>	Amoebic dysentery	Non-detect–0.4
<i>Giardia lamblia</i> cysts	Diarrhoea	10–2 × 10 ⁴

a Many important pathogens in sewage have yet to be adequately enumerated, such as adenoviruses, noroviruses and hepatitis A virus

b Noroviruses were formerly known as Norwalk viruses

c Parasite numbers vary greatly due to differing levels of endemic disease in different regions

Sources: Höller (1988), Long and Ashbolt (1994), Yates and Gerba (1998), Bonadonna *et al* (2002), Contreras-Coll *et al* (2002)

Non-gastrointestinal illnesses

In addition to gastrointestinal illness associated with exposure to faecally derived pathogens, exposure to recreational water presents a number of other potential health risks including skin and respiratory infections. Other illnesses related to recreational water exposure (Leder et al 2002) are shown in Box 5.1.

Box 5.1 Non-gastrointestinal illness associated with recreational water exposure

Central nervous system infections

Naegleria fowleri — fulminant, almost invariably fatal, amoebic meningoencephalitis, after swimming in warm fresh waters; cases recorded in several Australian states

Acanthamoeba spp — universally fatal granulomatous encephalitis, which can occur in immunosuppressed people after exposure to fresh or sea water

Respiratory diseases

Viruses, particularly adenovirus

Mycobacterium avium — complex lung disease, particularly in immunosuppressed people

Liver or renal disease

Leptospira spp — via skin contact with water contaminated with animal (especially rodent) urine, often in association with water sports and adventure travel; a recent large outbreak occurred among participants in a Malaysian triathlon

Keratitis

Acanthamoeba spp — in people with corneal abrasions

Ear infections

Pseudomonas aeruginosa, *Staphylococcus aureus* — otitis externa and otitis media

Skin diseases

Pseudomonas aeruginosa

Atypical mycobacteria, especially *Mycobacterium marinum* (sea water)

Mycobacterium ulcerans (skin ulcers)

Source: Leder et al 2002

Respiratory illness

A cause–effect relationship between faecal pollution and acute febrile respiratory illness and general respiratory illness is biologically plausible. A significant dose–response relationship between acute febrile respiratory illness and faecal streptococci has been reported by Fleisher *et al* (1996). Acute febrile respiratory illness is a more severe health outcome than the more frequently occurring self-limiting gastrointestinal symptoms (Fleisher *et al* 1998). Nonetheless, when compared with gastroenteritis, probabilities of contracting acute febrile respiratory illness are generally lower and the threshold at which illness is observed is higher.

Ear infection

A cause–effect relationship between faecal pollution and ear infection is also biologically plausible and an association between ear ailments and faecal indicator levels was found in studies conducted in marine waters in the UK (Fleisher et al 1996). The statistical probabilities of ear infection are generally lower and are associated with higher faecal indicator concentrations than those for gastrointestinal symptoms and for acute febrile respiratory illness. Otitis externa has been associated with swimming in freshwaters and an outbreak due to *Pseudomonas aeruginosa* was shown to have occurred amongst swimmers in freshwater lakes during extremely hot weather, even where faecal indicator concentrations were considered acceptable (van Asperen et al 1995).

Eye problems

Increased rates of eye symptoms have been reported among swimmers and evidence suggests that swimming, regardless of water quality, compromises the eye's immune defences, leading to increased symptom reporting in marine areas (Corbett *et al* 1993). Despite biological plausibility, no credible evidence for increased rates of eye ailments associated with water pollution is available (Prüss 1998).

Skin problems

Some studies have reported increased rates of skin symptoms among swimmers and associations between skin symptoms and microbial water quality have also been reported (Ferley *et al* 1989, Cheung *et al* 1991). Other studies (Prüss 1998), however, have not found such associations and the relationship between faecal pollution and skin symptoms remains unclear. Indigenous bacteria such as *Mycobacterium ulcerans*, in waters can cause occasional skin infections in freshwater swimmers, and swimmers with exposed wounds or cuts may be at risk of infection but there is no evidence to relate this to faecal contamination.

Liver or renal disease

Leptospirosis, caused by bacteria of the genus *Leptospira* that are associated with urine from animals, particularly rodents, may be a concern in warmer regions of Australia.

5.3 APPROACHES TO RISK ASSESSMENT AND RISK MANAGEMENT

Regulatory schemes adopted by states and territories for the microbial quality of recreational water have largely been based on percentage compliance with faecal indicator organism counts. The limitations of the percentage compliance approach include the following.

- Management actions can be deployed only after human exposure to the hazard, because such actions are not prospective.
- In some situations, the traditional indicators of faecal pollution are also derived from nonhuman sources. The response to noncompliance, however, typically concentrates on sewage treatment or outfall management, as outlined in Section 5.6.2.
- Beaches are classified as either safe or unsafe, although there is actually a gradient of increasing variety and frequency of health effects with increasing faecal pollution of human and animal origin.

These limitations can largely be overcome by a monitoring scheme that combines microbial testing with the collection of broader data on the sources and transmission of pollution. There are two outcomes from such an approach:

- a recreational water environment classification based on long-term analysis of data; and
- immediate actions to reduce exposure, which may work from hour to hour or from day to day.

5.3.1 Risk assessment

The risk associated with human exposure to faecally polluted recreational waters can be assessed directly via epidemiological studies or indirectly through quantitative microbial risk assessment. Both methods have advantages and limitations, discussed over page.

Epidemiological studies

Epidemiological studies have been used to demonstrate a relationship between faecal pollution and adverse health outcomes (see Section 5.2). Some types of epidemiological studies are also suitable to quantify excess risk of illness attributable to recreational exposure. The problems and biases in a range of epidemiological studies of recreational water and the suitability of studies to determine causal or quantitative relationships have been reviewed by Prüss (1998).

A review of the literature may identify one or more key epidemiological studies that provide convincing data with which to assess the qualitative relationship between water-quality data (based on indicator organisms) and adverse health outcomes. A series of randomised epidemiological investigations conducted in the United Kingdom provided such data for gastroenteritis (Kay *et al* 1994), acute febrile respiratory illness and ear ailments associated with marine bathing (Fleisher *et al* 1996). Recent studies undertaken on German fresh waters (A Wiedenmann, Water Hygiene Officer for District Government Stuttgart, State Health Agency, Wiederholdstr, pers comm, September 2003) show equivocal results for a correlation between *E. coli* and intestinal enterococci and gastrointestinal disease, at similar thresholds to the United Kingdom marine beach studies but with no obvious dose-response relationship.

Because of the lack of epidemiological information, there is some uncertainty as to how enterococci viruses and relative inactivation under Australian conditions relate to the results seen under European conditions (Corbett *et al* 1993, Harrington *et al* 1993).

Quantitative microbial risk assessment

Quantitative microbial risk assessment can be used to estimate indirectly the risk to human health by predicting infection or illness rates for given densities of particular pathogens, assumed rates of ingestion and appropriate dose–response models for the exposed population. Application of this process to recreational water use is constrained by the current lack of specific water-quality data for many pathogens and the fact that pathogen numbers (as opposed to faecal indicator organism numbers) vary according to the prevalence of specific pathogens in the contributing population and may exhibit seasonal trends.

Screening-level risk assessment

Because of the difficulties identified above for quantitative microbial risk assessment, it may be helpful to use a general screening-level risk assessment as the first step to identify where further data collection and quantitative assessment may be most useful. A screening-level assessment involves choosing a representative pathogen (for which a dose–response model is available) from each microbial group and estimating total risk of infection or disease based on worst-case estimates of exposure of a healthy young adult to each pathogen group (bacteria, protozoa and viruses). Results from these studies can be used to indicate organisms or scenarios that require further investigation and to show where data are needed to estimate health risk more accurately for recreational waters.

Considerations in interpreting results of assessment

While the risk assessment approach has been applied for some time with chemicals, caution is required in interpreting the results of a quantitative microbial risk assessment because the risk of infection or illness from exposure to pathogens is fundamentally different from the risk associated with other contaminants, such as toxic chemicals. The main differences between exposures to pathogens and toxic chemicals are as follows:

- Exposure to chemical agents occurs via an environment-to-person pathway;
- Exposure to pathogens can occur via an environment-to-person pathway but can also occur through person-to-person contact (secondary spread) and infectious individuals may or may not be symptomatic;
- Infection can occur from acute (single or short-term) exposure, whereas disease associated with exposure to chemical contaminants typically occurs following chronic (multiple, long-term) exposures;
- Pathogens exhibit various characteristics that are not found in relation to toxic chemicals
 - whether a person becomes infected or ill after exposure to a pathogen may depend on the person's pre-existing immunity
 - different strains of the same pathogen have a variable ability to cause disease (differing virulence)
 - virulence can evolve and change as the pathogen passes through various infected individuals; and
- Pathogens are usually suspended unevenly in water.

Risk assessment framework

Although the differences between pathogens and toxic chemicals (outlined above) are widely acknowledged, the conceptual framework for chemical risk assessment has commonly been employed to assess the risk associated with exposure to pathogenic microorganisms as shown in Table 5.4.

Table 5.4 Risk assessment paradigm for any human health effect

Step	Aim
1 Identify issues	To identify issues for which assessment is useful and establish a context for the risk assessment by a process of identifying the concerns that the risk assessment needs to address (enHealth 2002).
2 Identify hazard	To describe acute and chronic health effects (toxicity, including neurotoxicity, carcinogenicity, mutagenicity, developmental toxicity and reproductive toxicity) associated with any particular hazard, including pathogens.
3 Assess exposure	To determine the size and nature of the population exposed and the route, amount and duration of the exposure.
4 Assess dose–response	To characterise the relationship between various doses administered and the incidence of the health effect.
5 Characterise risk	To integrate the information from preceding steps in order to estimate the magnitude of the public health problem and to evaluate the variability and uncertainty.

Frameworks have been developed specifically to assess the risks of human infection associated with exposure to pathogenic microorganisms and to account for some of the perceived shortcomings of the chemical risk framework (Teunis *et al* 1996, Ashbolt *et al* 1997). However, these frameworks have not yet been widely adopted. Some of their limitations are identified below (following Table 5.5).

In employing the microbial risk framework to carry out a screening level risk assessment, a representative pathogen is used to conservatively characterise a particular microbial group. For example, the occurrence of adenovirus, with its associated dose–response curve, may be used as a predictor for enteric viruses (Crabtree *et al* 1997). Conservative estimates of exposure to each pathogen group (viruses, bacteria, parasitic protozoa and helminths) may be used to characterise ‘total’ risks from each group. However, helminths are normally not assessed because they usually occur at low levels in sewage and are of low importance to recreational swimmers. The results of the initial assessment should indicate an order-of-magnitude estimate of risk, and should show whether further data are required and risks are likely to be dominated by a single class of pathogen or source (potentially defining options for risk management). This screening approach presumes that little net error is made by not accounting for either person-to-person transmission of disease or immunity.

Alternative approach to assessment

A more comprehensive approach to assessing the risks of human disease associated with exposure to pathogenic microorganisms is to employ a population-based disease transmission model. This type of approach has the advantage that it takes into account the potential for person-to-person transmission and immunity (Eisenberg *et al* 1996, Soller *et al* 2002). However, population-based transmission models require substantially more epidemiological and clinical data than screening-level risk assessment models. Therefore, application of disease transmission modelling may be more limited than the screening approach.

Benefits and limitations of quantitative microbial risk assessments

The use of quantitative microbial risk assessments allows potential advantages and limitations of risk-management options to be explored through numerical simulation to examine their potential efficacy. It also allows risks below epidemiologically detectable levels to be estimated for defined circumstances.

Given the somewhat limited array of microorganisms for which a dose–response relationship has been estimated, screening-level risk assessments are currently limited to a few microorganisms such as rotavirus, adenovirus, *Cryptosporidium parvum*, *Giardia lamblia* and *Salmonella spp* (Haas *et al* 1999). Box 5.2 outlines a screening-level quantitative microbial risk assessment approach for a recreational water example.

Box 5.2 Screening-level quantitative approach to assessing bather risk

For a recreational water body mainly affected by sewage, the concentration of pathogens may be estimated from the mean pathogen densities in sewage and their dilution in the recreational waters (based on the numbers of indicator organisms; see Table 5.5, below).

For an initial approximation of pathogen numbers, enterococci may be used as an indicator for the dilution of sewage-associated bacterial pathogens (eg *Shigella*), and spores of *Clostridium perfringens* or enterococci may be used for the enteric viruses and parasitic protozoa. Alternatively, direct measurement of the presence or absence of pathogens in large volumes of recreational water may be attempted (Reynolds *et al* 1998). Long and Ashbolt (1994) quoted a 17% reduction for adenoviruses, enteroviruses and reoviruses by primary treatment (discharge quality) and assumed rotavirus to be 10% of the total virus estimate.

Next, a volume of recreational water ingestion is required to determine the pathogen dose; in this instance 20–50 mL of water per hour of swimming has been assumed.

After the general concentrations of pathogens from the three microbial groups have been determined, selected representatives for which dose–response data are available are used (eg *Shigella*, *Cryptosporidium*, *Giardia*, rotavirus and adenoviruses). These specific pathogens may not necessarily be the major aetiological agents, but are used as representatives of the likely pathogens. Risks from viral, bacterial and protozoan pathogens can then be characterised per exposure by applying published dose–response models for infection and illness (Haas *et al* 1999).

According to Haas *et al* (1993), the annual risk can be calculated from a daily risk as follows:

$$P_{\text{ANNUAL}} = 1 - (1 - P_{\text{DAILY}})^N$$

Where:

P_{ANNUAL} is the annual risk of a particular consequence;

P_{DAILY} is the daily risk of the same consequence; and

N is the number of days on which exposure to the hazard occurs within a year.

Adapted from Ashbolt *et al* (1997)

Table 5.5 Geometric means of indicator organisms and pathogens in primary sewage effluent in Sydney

Thermotolerant coliforms	<i>Clostridium perfringens</i> spores	<i>Cryptosporidium</i>	<i>Giardia</i>	Rotavirus
(CFU/100 mL)	(CFU/100 mL)	(oocysts/L)	(cysts/L)	(PFU/L) ^a
1.33×10^7	7.53×10^4	24	14,000	470

CFU = colony-forming units; PFU = plaque-forming units

^a Long and Ashbolt (1994) quoted a 17% reduction for adenoviruses, enteroviruses and reoviruses by primary treatment (discharge quality) and rotavirus was assumed to be 10% of total virus estimate.

Source: Indicator bacteria and parasite data are from Long and Ashbolt (1994). Total enteric virus estimate of 5650 for raw sewage is from Haas (1983).

In addition to the limited array of microorganisms for which a dose–response relationship has been established, quantitative microbial risk assessments have a number of other limitations, outlined below:

- *Data on occurrence and distribution of pathogenic microorganisms in recreational water environments* — In addition to problems of enumeration of many pathogenic microorganisms from environmental samples, pathogens are present only in low concentrations. An enrichment step is often required; therefore results are often expressed as the presence or absence of pathogens in a certain volume sample.
- *Estimations of exposure* — More accurate estimates of exposure to contaminated recreational water are required. These include estimates of ingestion and inhalation volumes during various recreational activities, as well as frequencies of exposure.

- *Dose-response models* — Such models exist for only a small number of pathogenic microorganisms and the data they are based on, usually gained using healthy adults, tend to underestimate the infection risk for children and immunocompromised people. There is also a need to consider exposure to different strains of organisms and the influence of previous exposure.
- *Resuspension from surface sediment layer* — The likely rate of resuspension needs to be quantified to estimate exposure risk more accurately. This is of particular concern in sediments of small particle size and high organic carbon, which have been found to be conducive to faecal indicator survival (Craig *et al* 2002a, b).

In spite of these limitations, several of the quantitative microbial risk assessments available are useful in identifying the need for epidemiological studies and places where such studies are not available (Sydney and Honolulu; Ashbolt *et al* 1997, Mamala Bay Study Commission 1996). This approach is also a useful tool for estimating the risk of infection under different scenarios and, in difficult situations, it may assist in the management of health risks for recreational coastal waters.

Quantitative microbial risk assessments and hazard analysis critical control point (HACCP) methods have complementary features for identifying hazards and the context of exposures. HACCP can be used to qualitatively rank various hazardous scenarios and identify where data collection for quantitative microbial risk assessment may best be applied (see Section 5.3.2).

It is clear that quantitative microbial risk assessment can be a useful tool for screening the risk to public health at recreational water sites and for determining the potential efficacy of management alternatives by integrating a wide array of disparate data. Finally, this approach provides a useful tool that can be used with, or in place of, epidemiological investigations to assess risk to human health at recreational water sites.

5.3.2 Risk management

To meet health targets based on a tolerable risk of illness, achievable objectives need to be established for water quality and management. The framework for management of drinking water quality (NHMRC/NRMMC 2004), based on HACCP principles is an example of such an approach.

For recreational waters, the framework has been adapted as shown in Table 5.6. The values presented in the table do not take account of health outcomes other than gastroenteritis and acute febrile respiratory illness. Where other outcomes are of public health concern, their risks should also be assessed and appropriate action taken.

Table 5.6 Implementation of management approaches for recreational water quality

Assemble the team	Form a team to steer the overall process. Composition of the team should represent all stakeholders and (as much as possible) cover all fields of expertise. Consider representatives of health agencies, user groups, the tourism industry, the water and sewerage industry, communities, relevant authorities (eg resource management, environment), potential polluters, and experts in hazard and risk analysis and other fields.
Collate historical information	Summarise previous data from sanitary inspections, compliance testing, utility maps of sewerage, water and stormwater pipes and overflows. Determine animal faecal sources for each recreational water body. Check development applications and appropriate legal requirements. If no historical data are available, collect basic data to fill the data gap or deficiency.
Produce and verify flow charts	Produce and verify flow charts for faecal pollution from sources to recreational exposure areas. This may require a new sanitary inspection. The series of flow charts should illustrate what happens to feeder waters before they join the recreational water body in sufficient detail for potential entry points of different sources of faecal contaminants to be pinpointed and any detected contamination to be traced.
Core principles	
Hazard analysis	Identify human versus different types of animal faecal pollution sources and potential points of entry into recreational waters. Determine the significance of possible exposure risks (based on judgment and on quantitative and qualitative risk assessment, as appropriate). Identify preventive measures (control points) for all significant risks.
Control points	Identify those points or locations at which management actions can be applied to reduce the presence of, or exposure to, hazards. Examples include signage at beaches, municipal sewage discharge points, treatment works operations, stormwater overflows and illegal connections to drains.
Critical limits	Determine measurable control parameters and their critical limits. Ideally, assign target and action limits to pick up trends towards critical limits (eg > 10 mm rainfall in previous 24-hours or notification of sewer overflow by local agency).
Monitoring	Establish a monitoring regime to give early warning of exceedances beyond critical limits. Those responsible for the monitoring should be closely involved in developing monitoring and response procedures and protocols. Note that monitoring is not limited to water sampling and analysis but could also include, for example, visual inspection of water users and potential sources of contamination or flow and overflow gauges.
Management actions	Prepare and test actions to reduce or prevent exposure in the event of critical limits being exceeded. Examples include building an appropriate treatment and/or disposal system, training personnel, developing an early warning system, issuing a media release and (ultimately) closing the area for recreational use.
Validation/ verification	Obtain objective evidence that the envisaged management actions will ensure that the desired water quality will be obtained or that human recreational exposures will be avoided. This step would draw on the literature and in-house validation exercises. Obtain objective data from auditing management actions that the desired water quality or change in human exposure is in fact obtained and that good operational practices, monitoring and management actions are being complied with at all times.
Record keeping	Ensure that monitoring records are retained in a format that permits external audit and compilation of annual statistics. These should be designed in close liaison with those using the documents and records.

This risk management procedure should be used iteratively, with increasing detail, in proportion to the scale of the problem and the resources available. When applied to recreational waters, HACCP is mainly intended to address the need for information for immediate management action. However, the information this approach provides can also be used for longer term classification.

Water quality may deteriorate in response to events (such as rainfall) with predictable outcomes; alternatively, deterioration may be constrained to certain areas or subareas of a single recreational water body. It may be possible to discourage use of areas that are of poor quality or to discourage use at times of increased risk. Measures to predict times and areas of elevated risk and to discourage water contact during these periods may be inexpensive (especially where large point sources are concerned) and cost-effective.

The 95th percentile approach for microbial data interpretation

Many agencies have chosen to base criteria for recreational water compliance on either geometric mean values of water quality data collected in the bathing zone or percentage compliance levels (95% compliance levels are normally used; ie 95% of the sample measurements taken must lie below a specific value in order to meet the standard). However, both approaches have significant drawbacks (WHO 2003).

The geometric mean is statistically a more stable measure because it does not include characterisation of the inherent variability in the distribution of the water quality data. However, this variability is important because it produces the high values at the top end of the statistical distribution that are of greatest public health concern.

The 95% compliance system, on the other hand, reflects much of the top-end variability in the distribution of water quality data and has the merit of being more easily understood. However, it is affected by greater statistical uncertainty than the geometric mean and hence is a less reliable measure of water quality, requiring careful application to regulation (McBride and Ellis 2001). When calculating percentiles, it is desirable to know what method is being used as results will vary according to method (see Box 5.3). In addition, interpretation of results is greatly affected by the dispersion of the bacteria as measured by their standard deviation. Consequently, estimation of disease risk by 95th percentiles alone is prone to error.

In the Farnham Report (WHO 2001), it was recommended that guideline values be based on the 95th percentile approach. To determine the 95th percentile value parametrically, it is necessary to have data that are normally distributed. For microbiological data, this requires log transformation. A problem with microbiological results is that a large proportion of counts are below or just above the limits of detection. Determining what value to give these data can significantly influence the calculation of the 95th percentile (Hunter, 2002). For these reasons it is often more appropriate to use non-parametric methods to determine 95th percentiles, of which there are a number of different methods (Bartram and Rees, 2000).

For non-parametric analysis, data is ranked in ascending order and then using one of a number of formulas, the rank and corresponding value which gives the 95th percentile is determined. Hunter (2002) suggested that of the non-parametric methods available, the Hazen method gave the closest result to that determined using parametric methods. The formula for the Hazen method is as follows:

$$r = \frac{1}{2} + \frac{Pn}{100}$$

where;

r = the rank of the relevant percentile

P = the percentile value (95 in this example)

n = the number of data points in the set.

In this same paper, Hunter (2002) demonstrates that there was very little advantage from estimating 95th percentile values compared with the percentage exceedance approach other than offering a false sense of increased accuracy. The percentage exceedance approach (also termed percentage compliance) can be calculated simply using the ranked method in which all data points are ranked in increasing order and the data point corresponding to a rank of $0.95n$ is the 95th percentile. In addition, using complex formulae in the calculation of the 95th percentile may also increase the likelihood of error due to the complications associated with its calculation. Even when analysing small sample sizes (20 data points), any difference between the two methods is insignificant when compared to the inherently large sample-to-sample variation.

Using Australian recreational water quality data, we can demonstrate that for sample sizes consisting of greater than 100 data points, the difference between values estimated using the two methods is minimal (Box 5.3). The importance of using a sufficiently large sample size is illustrated when analysing less than 20 data points. Using the Hazen method, the corresponding value for the 95th percentile is the largest value of the data set (i.e. the 20th ranked value). Using the ranked method, the second largest value is used (i.e. the 19th ranked value). Due to the normally high variation in microbiological concentrations this can lead to large differences in the results obtained using the two methods. Further information and discussion regarding estimation of 95th percentile values is presented in Appendix 3.

Box 5.3. Values calculated using different methods for estimating 95th percentile for enterococci (CFU / 100 ml).			
Data source	Number of data points	95th Percentile (Hazen method)	95th Percentile (Ranked method)
Victoria	2337 (all)	292	292
	100*	350	310
	20	1200	489
South Australia	595 (all)	20	19
	100*	20	16
	20	76	72
SE Queensland**	817 (all)	2818	2818
	100*	1585	1513
	20	4786	3236

*The most recent data were used to derive values for sample sizes of 100 or 20 data points.

**Concentration of faecal coliforms (CFU / 100 ml) given as enterococci data not available.

5.3.3 Microbial assessment categories for marine waters

The microbiological values are expressed in terms of the 95th percentile of numbers of intestinal enterococci per 100 mL (directly measured or transformed from coliform data, where sufficient data is available) and represent readily understood levels of risk based on the exposure conditions of key epidemiological studies (Table 5.7). The values may need to be adapted to take account of local conditions but, until studies suggest any change, the values given are recommended for use in all recreational waters for tabulating against the sanitary inspection rankings discussed in the following sections (WHO 2003).

Table 5.7 relates to protection of 'healthy adult bathers' exposed to marine waters in temperate north European waters. It does not relate to children, the elderly or immunocompromised people who would have lower immunity and might require a greater degree of protection. There is no available data with which to quantify this and therefore no correction factors are applied.

Table 5.7 Basis of derivation of percentile values for determining microbial water-quality assessment categories

Category ^a	95 th percentile value for intestinal enterococci/ 100 mL (rounded values)	Basis of derivation	Estimation of probability
A	≤40	This value is below the NOAEL in most epidemiological studies.	GI illness risk: < 1% AFRI risk: < 0.3% The upper 95 th percentile value of 40/100 mL relates to an average probability of less than one case of gastroenteritis in every 100 exposures. The AFRI burden would be negligible.
B	41–200	The 200/100 mL value is above the threshold of illness transmission reported in most epidemiological studies that have attempted to define a NOAEL or LOAEL for GI illness and AFRI.	GI illness risk: 1–5% AFRI risk: 0.3–1.9% The upper 95 th percentile value of 200/100 mL relates to an average probability of one case of gastroenteritis in 20 exposures. The AFRI illness rate would be 19 per 1000 exposures or approximately 1 in 50 exposures.
C	201–500	This represents a substantial elevation in the probability of all adverse health outcomes for which dose–response data are available.	GI illness risk: 5–10% AFRI risk: 1.9–3.9% This range of 95 th percentile values represents a probability of 1 in 20 to 1 in 10 risk of gastroenteritis for a single exposure. Exposures in this category also suggest a risk of AFRI in the range of 19–39 per 1000 exposures or a range of approximately 1 in 50 to 1 in 25 exposures.
D	> 501	Above this level there may be a significant risk of high levels of illness transmission.	GI illness risk: > 10% AFRI risk: > 3.9% There is a greater than 10% chance of illness per single exposure. The AFRI illness rate at the guideline value of 500 enterococci per 100 mL would be 39 per 1000 exposures or approximately 1 in 25 exposures.

Modified from WHO (2003a); see Kay *et al.* (2004) for further discussion and formulae.

AFRI = acute febrile respiratory illness; GI = gastrointestinal; LOAEL = lowest observed-adverse-effect level;

NOAEL = no observed-adverse-effect level.

^a Categories A–D are the corresponding microbial assessment categories used as part of the classification procedure

Notes:

1. The 'exposure' in the key studies was a minimum of 10 minutes bathing involving three immersions. This is envisaged to be equivalent to many immersion activities of similar duration but it may underestimate risk for longer periods of water contact or for activities involving higher risks of water ingestion (see also note 7).
2. The 'estimated risk' refers to the excess risk of illness (relative to a group of nonbathers) among a group of bathers who have been exposed to faecally-contaminated recreational water under conditions similar to those in the key studies. The functional form used in the dose-response curve assumes no excess illness outside the range of the data (ie at concentrations above 158 faecal streptococci/100 mL). Thus, while a plateau effect is to be expected, the estimates of illness rate reported above are likely to be underestimates of the actual disease incidence attributable to recreational-water exposure unless the plateau actually occurs at the extremity of the data range.
3. This table relates to protection of 'healthy adult bathers' exposed to marine waters in temperate north European waters.

4. The table does not relate to children, the elderly or immunocompromised who would have lower immunity and might require a greater degree of protection. There is no available data with which to quantify this, and therefore no correction factors are applied.
5. Epidemiological data on freshwaters or exposures other than bathing (eg high-exposure activities such as surfing, wind-surfing, sailing or white-water canoeing) are currently inadequate to present a parallel analysis for defined reference risks. Thus, a single microbial value is proposed, at this time, for all recreational uses of water because there is not sufficient evidence to do otherwise. Nevertheless, it is recommended that consideration be given, where appropriate, to making some allowance for the severity and frequency of exposure encountered by special interest groups (eg bodysurfers, board riders, windsurfers, scuba divers and white-water canoeists). A quantitative microbial risk management approach might be useful for this purpose.
6. Where disinfection is used to reduce the density of indicator bacteria in effluents and discharges, the presumed relationship between enterococci (as indicators of faecal contamination) and pathogen presence may be altered. This alteration is, at present, poorly understood. In water receiving such effluents and discharges, enterococci counts may not provide an accurate estimate of the risk of suffering from mild gastrointestinal symptoms or acute febrile respiratory illness. In waters where animals and/or birds are the primary source of faecal material or in situations where environmental proliferation of indicator bacteria may occur, the health significance of microorganisms is reduced.
7. Risk attributable to exposure to recreational water is calculated after the method given by Wyer *et al.* (1999), using data from Kay *et al.* (1994) in which a $\log_{10}$ standard deviation of 0.8103 was assumed. If the true standard deviation for a beach were less than 0.8103, then reliance on faecal streptococci would tend to overestimate the health risk for people exposed above the threshold level and vice versa. Calculation of the risk to Australian recreational water users has been demonstrated (see above) and has not been shown to generate significantly different guideline compliance values to those in this table. It is possible to calculate the risk to bathers in any waters based on knowledge of the probability density function (PDF) of indicator organisms at the site and using the prevalence of gastroenteritis information from the Kay *et al.* (1994) study.
8. Where large data sets exist for a recreational water body, the derivation of the percentile values for microbial water quality categories can be re-scaled using Wyer *et al.* (1999), based on local conditions and burden of disease.
9. The values presented in this table do not take account of health outcomes other than gastroenteritis and acute febrile respiratory illness. Where other outcomes are of public health concern, then the risks should be assessed and appropriate action taken.
10. Guideline values should be applied to recreational water and at the times of recreational use. This implies care in the design of monitoring programs to ensure that representative samples are obtained. It also implies that data from periods of high risk may be omitted if effective measures were in place during such periods to discourage recreational exposure.

5.3.4 Microbial assessment categories for fresh and estuarine waters

It is not possible to directly derive microbial assessment categories for fresh water because of lack of data. Studies using a randomised trial design have been conducted in Germany at freshwater sites but have yet to be reported in the peer-reviewed literature. Initial reports (Wiedenmann *et al* 2002) suggest that these studies have identified thresholds of effect similar to those reported in Kay *et al* (1994). Until the full results of these investigations become available, there is inadequate evidence with which to directly derive a water-quality guideline value for fresh water.

The guideline value derived for coastal waters can be applied to fresh water until a review of more specific data has been undertaken.

However, significant differences exist in swimming-associated gastrointestinal illness rates in seawater swimmers compared to freshwater swimmers at a given level of faecal indicator organisms. Illness rates reported for seawater swimmers were about two times greater than for freshwater swimmers (Dufour 1984, WHO 2003). A similar higher rate of illness in seawater swimmers is seen when comparing the epidemiological study data of Kay *et al* (1994) and Ferley *et al* (1989), although the research groups used very different methodologies. The swimming-associated illness rate was about five times higher in sea water (Kay *et al* 1994) than in fresh water (Ferley *et al* 1989) at the same intestinal enterococcal densities. This difference may be due to the more rapid die-off of indicator bacteria than of pathogens (especially viruses) in sea water compared with fresh water (Box 5.4). This relationship would result in more pathogens in sea water than in fresh water when indicator organism densities are identical, which would logically lead to a higher swimming-associated gastrointestinal illness rate in seawater swimmers.

Therefore, applying the microbial assessment categories derived for sea waters (Table 5.8) to brackish or fresh waters is likely to result in a lower illness rate in freshwater users, providing a conservative (ie more protective) guideline in the absence of suitable epidemiological data for fresh waters.

Furthermore, salinity is highly variable in estuaries. It would be difficult to decide when or whether a freshwater or marine standard should be applied to a given compliance location were separate coastal and freshwater guideline values to be specified.

Box 5.4 Differential die-off of indicator pathogens in sea water and fresh water

Salinity appears to accelerate the inactivation of sunlight-damaged coliforms in marine environments, such that coliforms are appreciably less persistent than intestinal enterococci in sea water but this may reverse in waste stabilisation ponds due to different inactivation mechanisms (Sinton *et al* 2002). In contrast to bacterial indicators, Table 5.8 indicates that poliovirus, echovirus and coxsackie virus are inactivated at approximately the same rate in marine and fresh water. However, other factors such as water temperature (greater inactivation in warmer waters) are more important than salinity for virus inactivation (Gantzer *et al* 1998).

Hence, it appears likely that bacterial indicator organisms have different die-off characteristics in marine and fresh waters, whereas human viruses are inactivated at similar rates in these environments. Therefore, after events such as rainfall or sewage release bacterial indicators may return to background levels within a day or two but in the absence of sufficient dilution or washout, suspended viruses may be of concern for longer periods.

Table 5.8 Survival of Enterovirus in sea water and river water

Virus strain	Die-off rates (in days) ^a	
	Sea water	River water
Polio I	8	15
Polio II	8	8
Polio III	8	8
Echo 6	15	8
Coxsackie	2	2

^a Maximum number of days required to reduce the virus population by 3 logs (ie 99.9% temperature and sunlight effects not provided but critical Gantzer *et al.* (1998)

5.3.5 Regulatory microorganisms of importance in recreational water

Where a microorganism is used as a regulatory parameter of public health significance in recreational waters, ideally:

- there should be adequate information available from which to derive guideline values (eg from epidemiological investigations);
- the microorganism should be sufficiently stable in water samples for meaningful results to be obtained from analyses;
- there should be a standard method for analysis;
- the microorganism should be economical to analyse;
- analysis should be simple, and thus make low demands on staff training;
- analysis should require only basic equipment that is readily available;
- the microorganism should have a low virulence and infectiousness and be easy to handle; and
- the indicator should always be present in faecal material.

Microorganisms commonly used in recreational water regulation and their suitability for different environments are shown in Table 5.9. Further information on the faecal indicator organisms is provided in Box 5.5.

Table 5.9 Suitability of different organisms as regulatory parameters for assessing faecal pollution

Organism	Suitability as indicators for recreational water
Established organisms	
Intestinal enterococci	Meet all of the above requirements. Currently considered the most suitable indicator for both marine and fresh water.
<i>Escherichia coli</i>	Intrinsically suitable for fresh water but not marine water. However, there are currently insufficient data with which to develop guideline values for this microorganism in fresh water (WHO 2003, Wiedenmann <i>et al</i> 2002).
Total coliforms	Inadequate, in particular because they are not specific to human faecal material
Thermotolerant (faecal) coliforms	Although a better indicator than total coliforms, include organisms not faecally derived (eg <i>Klebsiella</i> can derive from pulp and paper mill effluents). As there are no adequate studies on which to base guideline values, thermotolerant coliforms are unsuitable as regulatory parameters.
Salmonellae	Salmonellae have been used for regulatory purposes. However, their direct health role has not been supported by outbreak data except for <i>S. typhi</i> and <i>S. paratyphi</i> , which are not currently problems in Australia. They are unlikely to contribute significantly to the transmission of disease via the recreational water route because of their low infectivity and typically relatively low numbers in sewage and their rapid inactivation in waters, particularly sea waters.
Enteroviruses	Enteroviruses have been used for regulatory purposes. They are costly to assay and require specialised methods that include a concentration step for their analysis, which is imprecise. Although enteroviruses are always present in sewage and there are standard methods, their numbers are variable and not related to health outcomes (Fleisher <i>et al</i> 1996). Hence, there are insufficient data with which to develop guideline values. Their direct health significance varies from negligible (eg vaccine strains) to very high.
Emerging interest	
Bacteriophages (somatic coliphages, F-RNA coliphages and bacteriophages to <i>Bacteroides fragilis</i> GA17)	Bacteriophages (or phages) are seen as good models of human virus behaviour in aquatic environments (Contreras-Coll <i>et al</i> 2002). Unlike human viruses. However, they come from human and animal faecal sources, so they do not indicate the presence of human viruses, but tell us of their likely survival in the aquatic environment should they be present. Somatic coliphages are the most numerous in sewage, followed by F-RNA coliphages (which are more temperature sensitive but can be further identified to largely animal or human genogroups), with the <i>Bacteroides</i> phages less numerous in faeces but most persistent in the environment.
<i>Campylobacter</i> spp	<i>Campylobacter</i> are particularly numerous in fresh waters affected by agriculture. There are no health-effects data to indicate whether they are a better indicator of human health outcomes than <i>E. coli</i> or intestinal enterococci but campylobacters are known pathogens via water exposure (Savill <i>et al</i> 2003).

If elevated levels of usual indicator organisms (eg intestinal enterococci or *E. coli*) are detected, the water sample should be assessed for another indicator to determine whether environmental growth is a factor. If further tests fail to resolve the origin of the indicator organism, *Clostridium perfringens* should be measured.

Box 5.5 Faecal indicator bacteria

Thermotolerant (faecal) coliforms and *E. coli* have traditionally been used to assess the level of faecal contamination of waters from both humans and animals. While it is now widely recognised that *E. coli* are preferable to thermotolerant coliforms (because many members of the latter can grow in the environment), epidemiological studies do not show a clear dose–response relationship between these coliforms and bathers' disease outcomes. In contrast, faecal streptococci and enterococci have shown a clear dose–response relationship to disease outcomes in marine waters and are probably equivalent to *E. coli* in fresh waters (WHO 2003). Therefore, WHO advocates the use of enterococci as the single preferred faecal indicator. It is important to note that the *E. coli* cultured from water in the assay of faecal pollution are not the rare types that can cause disease, such as the enterohaemorrhagic and toxigenic *E. coli*.

Faecal streptococci have been used as an indicator of faecal pollution in recreational water; however, the group includes species with differing sanitary significance and survival characteristics (Gauci 1991, Sinton and Donnison 1994). Streptococcal species prevalence also differs between animal and human faeces (Rutkowski and Sjogren 1987, Poucher *et al* 1991). The taxonomy of this group has been subject to extensive revision (Ruoff 1990, Devriese *et al* 1993, Janda 1994, Leclerc *et al* 1996). The group contains species of two genera — *Enterococcus* and *Streptococcus* (Holt *et al* 1993). Although several species of both genera are included under the term enterococci (Leclerc *et al* 1996), the species most predominant in the polluted aquatic environments are *Enterococcus faecalis*, *E. faecium* and *E. durans* (Sinton and Donnison 1994 Audicana *et al* 1995, Lewis *et al* 2002).

Enterococci are usually taken to include all the species described as members of the genus *Enterococcus* that fulfil the following criteria:

- growth at 10°C and 45°C;
- resistance to 60°C for 30 minutes;
- growth at pH 9.6 and at 6.5% NaCl; and
- the ability to reduce 0.1% methylene blue.

Since the most common environmental species fulfil these criteria, in practice the terms faecal streptococci, enterococci, intestinal enterococci and *Enterococcus* group may refer to the same bacteria.

In order to allow standardisation, the International Organization for Standardization (ISO 1998) has defined the intestinal enterococci as the appropriate subgroup of the faecal streptococci to monitor (ie bacteria capable of aerobic growth at 44°C and of hydrolysing 4-methylumbelliferyl-β-D-glucoside in the presence of thallium acetate, nalidixic acid and 2,3,5-triphenyltetrazolium chloride, in specified liquid medium). In this chapter the term intestinal enterococci is generally used, except where a study reported the enumeration of faecal streptococci, in which case the original term is generally retained.

It may be important to identify human versus animal enterococci, because greater human health risks (primarily via enteric viruses) are likely to be associated with human faecal material — hence the emphasis on human sources of pollution in the sanitary inspection categorisation of beach classification (see Table 5.13). Grant *et al* (2001) presented a good example of this approach. They demonstrated that enterococci from stormwater, impacted by bird faeces and wetland sediments and from marine vegetation, confounded the assessment of possible bather impact in the surf zone at southern Californian beaches. There will, however, be cases where animal faeces are an important source of pollution in terms of human health risk (eg haemorrhagic *E. coli*-like strain O157:H7).

Source: WHO (2003)

5.4 ASSESSMENT OF FAECAL CONTAMINATION OF RECREATIONAL WATER ENVIRONMENTS

Most infections associated with recreational water are derived from human sources, particularly virus infections and acute febrile respiratory illness in enclosed freshwater bodies such as lakes and lagoons.

The two main requirements for assessing faecal contamination of recreational waters are:

- sanitary inspection (with a category determined through assessment of the degree of influence of faecal material), described in detail in Section 5.4.1; and
- counts of suitable faecal indicator bacteria (ie a microbial water-quality assessment), described in detail in Section 5.4.2.

These components are required for classification only where a recreational water body is used for whole-body (primary) contact recreation (ie where there is a meaningful risk of swallowing water). The two components are combined to produce an overall classification.

5.4.1 Sanitary inspection

Aim of inspection

The sanitary inspection should aim to identify all sources of faecal pollution, although human faecal pollution is likely to be the main factor in determining the overall sanitary inspection category for an area. For public health purposes the most important sources of faecal contamination of recreational water are typically:

- sewage;
- riverine discharges — where the river is receiving water from sewage discharges and is
 - used directly for recreation, or
 - discharges near a coastal or lake area used for recreation; and
- contamination from bathers (including excreta).

Other potential sources of human faecal contamination include septic tanks near the shore (leaching directly into groundwater and then seeping into the recreational water) and shipping and local boating (including moorings and special events such as regattas).

The inspection should include the following steps (WSAA 2003), most of which are covered in detail in the example in Appendix 4:

- plan for the sanitary inspection and develop a checklist of issues that need to be considered;
- assemble and review available information, including existing long-term monitoring data;
- carry out the field inspection;
- conduct interviews and/or undertake a workshop with key stakeholders; and
- assess the contamination sources to determine the level of risk, possibly via a ‘reconnaissance survey’ in which samples are taken from upstream recreation sites (largely during events) to ascertain the likely sources of faecal contamination. Various chemical biomarkers and microbial source tracking (MST) parameters can aid in the resolution of human, bird and herbivore faecal sources (Simpson *et al* 2002, Roser *et al* 2003).

Appendix 4 provides an example of an approach for undertaking sanitary inspections of recreational water quality.

Information to be collected

Information to be collected during sanitary inspections should at least cover the following:

- sewage outfalls, stormwater discharges
 - presence or absence
 - type of sewage treatment (including onsite systems)
 - effectiveness of outfall type
 - location of pumping stations and overflow points;

- riverine discharges
 - presence or absence
 - type of sewage treatment
 - population size from which sewage originates
 - river flow in the bathing season;
- bather shedding;
- bather density in the swimming season; and
- dilution (mixing of water in recreational water area).

Additional information may concern, for example:

- rainfall (duration and quantity) that results in run-off;
- wind (speed and direction) that affects outfall plumes;
- tides and currents or water release (eg in dam-controlled rivers); and
- coastal or riverine physiography (effect on natural flushing).

Effect of rainfall

Indicator organism densities in recreational waters can reach high levels after rainfall if:

- treatment plants are overwhelmed (causing sewage to bypass treatment);
- animal wastes are washed from forests, pastures and urban land;
- sewage overflows directly into waterways or into stormwater because rainfall causes the capacity of the sewer system to be exceeded due to
 - rain infiltrating cracks in the pipe
 - illegal connections from the stormwater system; and
- sediment-trapped pathogens are resuspended (this is a particular problem in freshwater river catchments).

Because of these factors, the effect of rainfall on recreational water quality can be highly variable but characteristic for each recreational water area. The first flush from rainfall may increase pathogen loads in the recreational water, particularly in water bodies with continuous flow from large catchment areas. It is acknowledged that the greatest risk in most cases is during wet weather conditions even though dry weather conditions may predominate.

Assessing risks to human health

The risks to human health through direct sewage discharge, riverine discharge contaminated with sewage and bather contamination have been ranked in this chapter (Tables 5.10 and 5.11, below). The risk estimation has taken into account the likelihood of human exposure and the degree of treatment of sewage. In assessments of sewage and riverine discharges to recreational areas the estimation has also taken into account the pollutant load.

Because both human and animal excreta can affect human health, local knowledge of possible sources and environmental pathways of animal pathogens to humans should form part of the sanitary inspection.

In adapting guidelines, local circumstances must be considered. For example, sewage being discharged into an estuary with small tidal interchanges may have a different effect from the same quantity of sewage being discharged into an estuary with large tidal interchanges. Similarly, a river discharging into an enclosed bay may present a higher risk than one discharging directly into the open sea.

Often several contamination sources may be significant at a single location. In a sanitary inspection, a recreational water environment may be most readily categorised after evaluating all identified pollution sources for which a semiquantitative estimate of load is possible.

The remainder of this section gives information on risks associated with:

- sewage discharges (including stormwater discharges);
- riverine discharges;
- bather shedding; and
- animal inputs.

This information will be useful in placing recreational water environments in an appropriate sanitary inspection category (by determining their susceptibility to human faecal pollution) but it cannot account fully for local and regional factors.

Sewage discharges (including stormwater discharges)

Sewage-related risk arises from the likelihood of pollution and (where pollution occurs) the degree of inactivation through treatment. Sewage discharges or outfalls may be classified into three principal types:

- those where discharge is directly onto the beach (above low-water level and intertidal areas);
- those where discharge is through ‘short’ outfalls (discharge is into the water but sewage-polluted water is likely to contaminate the recreational water area); and
- those where discharge is through ‘long deepwater’ outfalls (sewage is diluted and dispersed and the design criteria for the outfall ensure that sewage is unlikely to pollute recreational water areas).

Direct discharge of crude, untreated sewage (eg through short outfalls that carry a mixture of raw sewage and stormwater) into recreational areas presents a serious risk to public health. Public health authorities or other relevant authorities should take measures to protect public health where this occurs and should cooperate with appropriate authorities to either eliminate this practice or to minimise recreational use of affected areas. For direct beach discharges and short outfalls the risk increases with the size of the contributing population.

Although outfall length is relevant, it is usually less important than proper location and effective diffusion. An effective outfall is one that is properly designed with sufficient length and depth of diffuser discharge to ensure that sewage is unlikely to reach the recreational area.

In public health terms, it is generally assumed that dispersion, dilution, sedimentation and inactivation (through sunlight, predation, natural die-off etc) after discharge from a piped outfall will lead to a certain degree of safety. In practice, a number of factors reduce the efficiency of these processes, with the most important being factors that lead to the rapid movement of sewage into recreational areas. For example, where sewage is warmer and less saline than the receiving water, it may mix poorly and form

a floating slick that will be easily influenced by wind and may therefore severely pollute even distant recreational areas. Properly designed and operated diffusers on the outfall should prevent the formation of such slicks. Also, it is possible to reduce the risk from floating slicks by recognising periods of high risk (eg during onshore winds) and taking appropriate action, such as posting advisory notices or zoning or banning water contact activities. Coastal currents and tides may give rise to similar problems and may be recognised and dealt with the same way.

Some regions (eg North Sydney, Lower Molonglo) control sewage pollution by holding sewage in storage for various periods. Where sewage is retained throughout the swimming season, water users are effectively protected from the source of pollution. Such an approach has limited practical application and will be fully effective only where there is a strict cut-off in recreational activity at the end of the swimming season. The efficacy of shorter term retention (eg retaining sewage during the day and discharging it at night) is less certain and is strongly influenced by the nature of the discharge, the geographical configuration of the area and environmental factors as discussed above.

The degree of treatment applied to sewage varies widely and includes:

- no treatment (discharge of raw, untreated sewage);
- ‘preliminary’ treatment (coarse screening to remove large solids);
- primary treatment (physical sedimentation or settling);
- secondary treatment (high-rate biological processes, such as trickling filter or activated sludge) after suitable primary treatment;
- tertiary treatment (advanced wastewater treatment after primary and secondary treatment), including coagulation–sand filtration, ultraviolet radiation, microfiltration);
- tertiary treatment plus disinfection; and
- lagooning (low-rate biological treatment).

Treatments that will significantly reduce indicator organism and pathogen contamination are lagooning, primary plus secondary treatment, tertiary treatment and disinfection.

Some treatments (notably disinfection) may affect the validity of microbial water-quality assessment because they have different effects on indicator and pathogenic organisms. This will tend to lead to underestimates of risk, particularly from disinfection-resistant enteric viruses and *Cryptosporidium*. Where the principal human faecal pollution source is disinfected sewage, supplementary investigations should be undertaken because of the likely underestimate of health risk based on Table 5.7.

The potential risk to human health through exposure to sewage from outfalls can be categorised as shown in Table 5.10. The classification is based on a qualitative assessment of risk of contact or exposure under ‘normal’ conditions, which include the normal operation of sewage treatment works and normal hydrometeorological and oceanographic conditions.

Urban stormwater run-off and sewer overflows are included in the category of direct beach outfalls. Septic systems and stormwater are assumed to be equivalent to primary treatment.

Table 5.10 Risk potential to human health through exposure to sewage through outfalls (including stormwater run-off)

Treatment	Discharge type		
	Directly on beach ^a	Short outfall ^a	Effective outfall ^b
None	Very high	High	na
Preliminary	Very high	High	Low
Primary (including septic tanks)	Very high	High	Low
Secondary	High	High	Low
Secondary plus disinfection ^{c,d}	Moderate	Moderate	Very low
Tertiary	Moderate	Moderate	Very low
Tertiary plus disinfection ^d	Very low	Very low	Very low
Lagoons	High	High	Low

na = not applicable

a The risk is modified by population size. Risk is greater for discharges from large populations and less for discharges from small populations.

b This assumes that the design capacity has not been exceeded and that climatic and oceanic extreme conditions are considered in the design objective (ie no sewage on the beach zone)

c Disinfection alone is inadequate

d Additional investigation recommended to account for the likely lack of prediction with faecal indicator organisms as outlined in Table 5.7, Footnote 6

Note: Where disinfection is used to reduce the density of indicator bacteria in effluents and discharges, the presumed relationship between enterococci (as indicators of faecal contamination) and pathogen presence may be altered. This alteration is, at present, poorly understood. In water receiving such effluents and discharges, enterococci counts may not provide an accurate estimate of the risk of suffering from mild gastrointestinal symptoms or acute febrile respiratory illness. In waters where animals and/or birds are the primary source of faecal material or in situations where environmental proliferation of indicator bacteria may occur, the health significance of microorganisms is reduced.

Adapted from WHO 2000 **Monitoring Bathing Waters - A Practical Guide to the Design and Implementation of Assessments and Monitoring Programmes** edited by Jamie Bartram and Gareth Rees

Riverine discharges

Rivers discharging into recreational water areas may carry a heavy load of microorganisms from diverse sources, including municipal sewage (treated or otherwise) and animal husbandry. Following rainfall, microbial loads may be significantly increased due to:

- surface run-off;
- urban and rural stormwater overflows, including natural watercourses (torrents) that drain only stormwater;
- exfiltration from sewers or septic absorption trenches; and
- resuspension of sediments.

Therefore, coastal pollution levels may be elevated after rainfall and risk may be higher in some coastal areas at such times. Once the hazard is recognised and characterised, simple advisory measures may be taken prospectively to alert water users to the risks and/or recreational water use may be prevented.

Recreational areas on rivers will be subject to influences similar to those indicated above. In addition, where water flow is managed either for recreation (eg where water is impounded before discharge) or for other purposes, the act of impoundment and discharge may itself lead to elevated microbial levels through resuspension of sediment.

Rivers may be receiving environments for sewage effluents treated to varying degrees. Effluent may be much less diluted in riverine environments than in their coastal equivalents and there may be different relationships between pathogens and indicator organisms in saline and nonsaline waters.

Riverine discharges may be categorised according to the sewage effluent load and the degree of dilution in a manner similar to that described in Table 5.11 below. Where human faecal waste is not present but animal waste is present (eg from animal husbandry) this should be taken into account. Because water can take a relatively long time to travel from sources to recreational areas, an understanding of the system's hydrology is also important in determining when and for how long a hazard exists.

Table 5.11 Risk potential to human health from exposure to sewage through riverine flow and discharge

Population and flow characteristics ^{a,b}	Treatment level				
	None	Primary	Secondary	Secondary with disinfection ^c	Lagoon
High population with low river flow	Very high	Very high	High	Low	Moderate
Low population with low river flow	Very high	High	Moderate	Very low	Moderate
Medium population with medium river flow	High	Moderate	Low	Very low	Low
High population with high river flow	High	Moderate	Low	Very low	Low
Low population with high river flow	High	Moderate	Very low	Very low	Very low

- a The population factor includes, in principle, all the population upstream from the recreational water body to be classified
- b Stream flow of primary concern is the lowest typical flow during the bathing season (excluding stormwater; see Table 5.7)
- c Additional investigations recommended to account for the likely lack of prediction with faecal organisms as outlined in Table 5.7

Bather shedding

Bathers can influence water quality directly (Eisenberg *et al* 1996), mainly through bather density and degree of dilution (Table 5.12). Low dilution is assumed to represent no water movement (eg lakes, lagoons and coastal embayments). The likelihood of bathers defecating or urinating into the water is substantially increased if toilet facilities are not readily available. Therefore, if bather density is high and no sanitary facilities are available at the recreational area, the classification should be increased to the next class.

Papadakis *et al* (1997) collected water and sand samples from two beaches, counted the swimmers present on the beaches and tested for numbers of coliforms, thermotolerant coliforms, enterococci, *Staphylococcus aureus*, yeasts and moulds. The number of swimmers on the beach correlated strongly with *S. aureus* counts in water samples, particularly on the more popular of the two beaches. Also, yeasts of human origin in water samples correlated with the number of swimmers on the more popular beach.

The effect of bathers on water quality is most commonly seen as microbial buildup during the day, reaching peak levels by the afternoon. Where dispersion is limited, bather-derived faecal pollution may present a significant health risk, as evidenced by

epidemiological studies (Calderon *et al* 1991) and several outbreaks of disease. There is insufficient evidence to judge the contribution that bather-derived pollution makes in other circumstances. Furthermore, some viral pathogens, such as hepatitis A, are also shed in urine and would not be picked up by counts of faecal indicator bacteria.

Table 5.12 Risk potential to human health through exposure to sewage from bathers

Bather shedding	Category
High bather density; high dilution ^a	Low
Low bather density; high dilution	Very low
High bather density; low dilution ^{a,b}	Moderate
Low bather density; low dilution ^b	Low

a Move up to next category if no sanitary facilities are available at site

b Dilution low if no water movement

Sheltered coastal areas and shallow lakes may also be subject to accumulation of sediments which may be associated with high microbial loads that may be resuspended by water users or rainfall events. The health risks associated with resuspended sediments remain poorly understood but resuspension should be noted as a potential risk during sanitary inspections.

Animal inputs

Although human faecal inputs are the most important factor in determining the sanitary inspection category, it is important to determine major sources of animal faecal pollution. Although these will generally be less important human health risks than human pollution, they may have a significant impact on microbial water quality and potential health risk. An emerging issue here is the potential for the highly virulent haemorrhagic *E. coli* (such as strain O157 H7), that can be excreted by cattle and sheep (Fegan and Desmarchelier 2002), to reach recreational areas.

5.4.2 Microbial water-quality assessment

Stages in the assessment

The various stages involved in an assessment of the microbial quality of a recreational water environment are described elsewhere (Bartram and Rees 2000, Chapter 9) and are summarised below.

- **Stage 1** — Initial sampling to determine whether significant spatial variation exists. Sampling at spatially separated sampling sites should be carried out during the initial assessment on different days. Timing of samples should take into account the likely period of maximum contamination from local sewage discharges and maximum bather shedding (eg the afternoon or day of peak bather numbers).
- **Stage 2** — Assessment of spatial variation based on data from Stage 1.
- **Stage 3** — Intensive (more detailed) sampling and assessment of results in situations where there is no evidence of significant spatial variation.

The initial classification is determined from results of the sanitary inspection category and microbial water-quality assessment. It is suggested that microbial water quality for all recreational waters be classified into four categories (A–D) using the 95th percentile of the intestinal enterococci distribution.

- **Stage 4** — Definition, separate assessment and management of affected areas, in situations where spatial variation is evident at Stage 2.
- **Stage 5** — Confirmatory monitoring in the following year, using a reduced sampling regime and a repeat of the sanitary inspection.

If the subsequent classification is ‘very good’ or ‘very poor’, less frequent monitoring can be justified (see Table 5.14, below).

Sampling program

The sampling program should cover the range of conditions occurring while the recreational water environment is in use. When determining the water classification all results from that body of water on days when the area was open to the public, should be used. For example, if an unexpectedly high result is obtained it is not acceptable to resample and then use the resample, but not the original sample, for classification purposes. On the other hand, reactive samples taken after an adverse event to investigate the full impact of that event need not be included in the analysis but should be used to further characterise the area and the impacts of adverse events.

The number of samples collected must be sufficient to allow an appropriate estimation of the indicator organism densities to which water users are exposed. Previous recommendations based on 20 or fewer samples are considered inappropriate, given the usual variation in faecal indicator organisms because the precision of the estimate of the 95th percentile is low. Increasing sample numbers, for example towards 100 samples, would increase precision, but may take some years to collect if historical data either do not exist or are no longer representative.

The number of results available can be increased significantly, with no additional cost, by pooling data from multiple years. This practice is justified unless there is reason to believe that local pollution conditions have changed, causing the results to deviate from established behaviour. For practical purposes, data from 100 samples from a five-year period and a rolling five-year dataset may be used. In many situations, such as where more extensive sampling is undertaken, a much shorter period will be required. In some circumstances fewer samples may be required for example, where the water quality is very poor and no change in catchment management is likely to have reduced it, there is little point in further sampling and the recreational zone should simply be declared unsuitable.

Datasets that contain many values below the limit of detection can be difficult to manage. Both parametric (Shapiro–Wilk) and nonparametric (Hazen and Blom) approaches to dealing with this problem and arriving at an estimate of the 95th percentile are discussed in Section 5.3.2. In subsequent analyses however, it is better to use appropriate dilutions to ensure that values below the limit of detection are rare or completely avoided.

Several methods are available for estimating bacterial numbers in recreational water (eg see Bartram and Rees 2000). Where a change is made between indicator organisms (eg from thermotolerant coliforms to intestinal enterococci) or the microbial method employed, limited data may be available in the initial years of implementation. To overcome this, correction factors appropriate to local conditions (normally derived by comparing the results of local analyses) may be applied to historical records to permit their use. Another strategy is to collect data on both old and new indicator organisms during a transition period. Although this increases costs it provides a ‘break-in’ period.

Most importantly, data collection can be reduced by modelling, if sufficient data are available to model the likely intestinal enterococci in recreational waters, such as with rainfall (NSW Environment Protection Authority 2002). The use of such surrogates can provide ‘real-time’ estimates of risk for body-contact management in recreational water (see Section 5.5.4).

5.5 CLASSIFICATION OF RECREATIONAL WATER ENVIRONMENTS

Classification of recreational waters is achieved by combining the categories for sanitary inspection category (Section 5.4.1) and microbial water-quality assessment (Section 5.4.2), using a matrix such as that shown in Table 5.13.

The classification emphasises faecal contamination from humans, with lesser importance placed on faecal contamination from other sources such as drainage from areas of animal pasture and intensive livestock rearing, the presence of gulls or the use of the area for dogs or horses.

The assessment framework enables local management to respond to sporadic or limited areas of pollution and thereby upgrade a recreational water body’s classification, provided that appropriate and effective actions are taken to control exposure. In contrast to a ‘pass or fail’ approach, this form of classification provides incentives for taking action locally and reducing pollution. It also produces a generic statement of the level of risk, thereby supporting informed personal choice, and it helps to identify appropriate management and monitoring actions.

Table 5.13 Classification matrix for faecal pollution of recreational water environments*

		Microbial water quality assessment category (95 th percentiles — intestinal enterococci/100 mL)				Exceptional circumstances ^c
		A ≤ 40	B 41–200	C 201–500	D > 500	
Sanitary inspection category (Susceptibility to faecal influence)	Very low	Very good	Very good	Follow up ^b	Follow up ^b	ACTION
	Low	Very good	Good	Follow up ^b	Follow up ^b	
	Moderate	Good ^a	Good	Poor	Poor	
	High	Good ^a	Fair ^a	Poor	Very poor	
	Very high	Follow up ^a	Fair ^a	Poor	Very poor	
	Exceptional circumstances ^c	ACTION				

a Indicates possible discontinuous/sporadic contamination (often driven by results such as rainfall). This is most commonly associated with the presence of sewage – contaminated stormwater. These results should be investigated further, and initial follow-up should include verification of the sanitary inspection category and ensuring that samples recorded include ‘event’ periods. Confirm analytical results, review possible analytical errors.

b Implies nonsewage sources of faecal indicators (eg livestock), which need to be verified.

c Exceptional circumstances are known periods of higher risk such as during an outbreak involving a human or other pathogen that may be waterborne (eg avian botulism — where outbreaks of avian botulism occur, swimming or other aquatic recreational activities should not be permitted), or the rupture of a sewer in a recreational water catchment area etc. Under such circumstances the classification matrix may not fairly represent risk/safety.

* In certain circumstances there may be a risk of transmission of pathogens associated with more severe health effects through recreational water use. The human health risk depends greatly on specific (often local) circumstances. Public health authorities should be engaged in the identification and interpretation of such conditions.

5.5.1 Initial classification

The outcome of the sanitary inspection and the microbial water quality assessment, based on Table 5.13 and Figure 5.1, is a five-level classification for recreational water environments — ‘very good’, ‘good’, ‘fair’, ‘poor’ and ‘very poor’. There is also a requirement for follow-up where there is potential discrepancy between the results of the microbial water-quality assessment and the sanitary inspection (discussed in Section 5.5.2). If the assessment of spatial variation shows that higher microbial contamination levels are limited to only part of the recreational water environment, separate assessment and management for each part is required.

Where multiple sources of contamination exist, all sources should be taken into consideration in determining the susceptibility to faecal influence. Contributions from riverine discharges and bather densities need to be determined based on local knowledge of hydrological conditions.

Where an area is well managed to ensure that recreational activities are not undertaken during periods when the quality of the water body is influenced by rainfall, samples taken during such a period should not be used in the overall assessment of the ranking.

5.5.2 Follow-up of initial classification

Where the sanitary inspection and water-quality data produce potentially incongruent results, further assessment will be required. This could include reassessing the sanitary inspection (ie identifying further potential sources and assessing their risk) and additional analysis of water quality, with specific consideration given to the sampling protocol and analytical methodology.

Factors that may lead to incongruent assessments include:

- analytical errors;
- failure to appreciate the importance of nonpoint sources in the initial inspection;
- sampling points that are not representative of sewage influence;
- failure to note that stormwater drains which are present do not discharge during the bathing season;
- basing the assessment on insufficient or unrepresentative data; and
- extreme events, whether anthropogenic or natural in origin, that arise from damaged infrastructure or inappropriate sewage disposal practices (eg shipping damage to marine outfalls, connections from foul drains to surface water).

Where sanitary inspection indicates low risk but microbial water-quality assessment data indicate water of low quality, suggests that there are sources of diffuse pollution that have not been identified. In this case, specific studies demonstrating the relative levels of human and nonhuman contamination may be appropriate; for example, analysis of appropriate biomarkers and inspections of mammal and bird numbers. Confirmation that contamination is primarily from nonhuman sources may allow reclassification to a more favourable level, but care will be needed because the risk will depend on the type of nonhuman pollution and because the nonhuman source may still be a source of a number of important pathogens.

Similarly, where microbial water quality assessment indicates a low risk that is not supported by the sanitary inspection, consideration should be given to the sampling design, the analytical methodology used and the possibility that the sanitary inspection overrated potential pollution sources.

5.5.3 Provisional classification

There will be occasions when there is a pressing need to issue advice on the classification of a recreational water environment even though the information required for moving to the classification (or reclassification) step is incomplete. Three scenarios may be envisaged:

- where there are no data of any kind available as to the microbial water quality of the water body or its susceptibility to faecal influence (eg new developments);
- where the data available for the microbial water quality assessment, the sanitary inspection or both are incomplete; and
- where there is reason to believe that the existing classification no longer accords with changed circumstances but the data required for completing classification are insufficient.

In these circumstances it may be necessary to issue a provisional classification in which case it should be made clear that the advice is provisional and subject to change.

A provisional classification should be time limited and there should be a commitment to obtaining the necessary data to follow the steps described in Figure 5.1 to provide a definite classification as soon as possible.

5.5.4 Reclassification, including health advisories and upgrading

Because contamination may be triggered by specific and predictable conditions (eg rainfall run-off), local management actions can reduce or prevent exposure at such times. Provided such actions can be shown to be effective, the recreational water environment classification may be upgraded to a more favourable level. However, a reclassification should initially be provisional and time limited. It may be confirmed if the efficacy of management interventions (eg advisories) is verified during the following bathing season, otherwise it will automatically revert to its original classification.

Some events triggering water contamination can be measured by simple means, such as rainfall gauges, detectors on stormwater overflows and the like. Others may require more sophisticated approaches, such as modelling. Two main approaches have been used for real-time prediction of faecal indicator organism concentrations at recreational area compliance points. One method is to use background conditions to calibrate a statistical model, typically based on the relationships of multiple predictor variables, such as:

- preceding rainfall;
- wind direction;
- tides and currents;
- visible or modelled plume location;
- solar irradiance (and turbidity of water); and
- physicochemical parameters of water quality.

The alternative approach is to construct a nearshore hydrodynamic model linked to a water-quality model predicting concentrations of faecal indicator organisms (Falconer *et al* 1998).

Both methods offer potential for real-time prediction of faecal pollution changes for protection of public health through timely management interventions. Therefore, some of these parameters could be considered for analysis at control points. In HACCP, control points are those points that can be monitored to provide information to management so that management actions can impact on risk.

5.5.5 Monitoring and auditing

This section should be read in conjunction with Section 2.6.2 on the design and implementation of monitoring programs for microbial hazards.

Monitoring and auditing include visual inspection of potential sources of contamination, water sampling and verification of control points. Examples of control points include measurement of rainfall in the catchment, municipal sewage discharge points, operation of treatment works, deliberate or accidental sewer overflows, and illegal connections to wastewater drains.

After initial classification, all recreational water environments should be subject to an annual sanitary inspection to determine whether pollution sources have changed.

For recreational water areas where no change to the sanitary inspection category of 'very low' or 'low' has occurred over several years, and the microbial water quality assessment is stable (based on at least 100 samples), sampling to ensure that no changes go unidentified can be reduced to a minimum of five samples per year. For waters where the sanitary inspection category is 'very high' (where swimming would be strongly discouraged), a similar situation applies if recreational use continues. For the intermediate categories ('moderate' and 'high'), a greater annual microbial sampling program is recommended, as is the demonstration of suitable surrogates for 'real-time' management.

Table 5.14 shows the recommended monitoring schedule.

Table 5.14 Recommended monitoring schedule

Risk category identified by sanitary inspection^a	Monitoring schedule	Frequency of sanitary inspection
Very low	Minimum of 5 samples per year, at regular intervals during recording period.	Annual
Low	Minimum of 5 samples per year, at regular intervals during recording period.	Annual
Moderate	20 samples at regular intervals (eg 1 sample from 4 locations on 5 occasions during swimming season). Annual verification of management effectiveness. Additional sampling if abnormal results obtained.	Annual
High	20 samples at regular intervals (eg 1 sample from 4 locations on 5 occasions during swimming season). Annual verification of management effectiveness. Additional sampling if abnormal results obtained.	Annual
Very high	Minimum of 5 samples per year, but nil if closed to use.	Annual

^a If there is effectively no body-contact use during event periods, such periods are not considered in the ranking of a recreational zone in this table or Table 5.13.

5.6 MANAGEMENT OF RISKS FROM MICROBIAL QUALITY

The two main considerations in relation to management actions are the classification of recreational water areas and short-term information about changes in conditions. Good-quality public information in near-real time about the recreational water environment, for example through public health advisories, is particularly important to enable the public to make informed choices about if and when to use recreational waters (see Section 5.6.1). Long-term management on the other hand, might also be aimed at encouraging pollution abatement and prevention (see Section 5.6.2).

5.6.1 Public health advisories and warnings

Recreational water managers may take steps to identify periods when water quality is poor, issue advisory notices warning the public of increased risk, and assess the impact of those advisories in discouraging water contact. This approach has the benefit of protecting public health and, in many circumstances, allows an area's classification to be improved through low-cost measures. It can also permit, for long periods, the safe use of areas that might otherwise be considered unsuitable.

Water quality will differ between locations, for example locations may:

- consistently have very poor water quality because they are near sewage discharges;
- intermittently have poor water quality because of pollution that may be infrequent or impossible to predict; and
- have episodic but possibly predictable deterioration in water quality, such as that driven by weather conditions, particularly rainfall.

In any of these circumstances, local public health agencies may wish to issue an advisory notice or other form of public notification.

The level at which an advisory might be issued depends on local circumstances, which include the levels and types of endemic illness prevalent in the population and outbreaks or epidemics of potentially serious illness that may be spread by recreational water exposure. Where an area is known to have consistently very poor microbial water quality, an appropriate management action may be to permanently discourage its recreational use, for example by fencing, signposting or changing the location of car parks, bus stops and toilets (Bartram and Rees 2000).

5.6.2 Pollution prevention

Recreational waters are often polluted by sewage and industrial discharges, sewer overflows, diffuse source pollution from agricultural areas and urban run-off. This section describes abatement and remediation measures available for water-quality improvement.

Direct point source pollution abatement

Effective outfalls are designed with sufficient length and depth of diffuser discharge to ensure a low probability of sewage reaching the designated recreational water environment. The aim is to separate the bather from the sewage. Secondary treatment is considered to be the minimum appropriate treatment level, other than for deep-water and cliff outfalls where primary treatment may be sufficient.

For nearshore discharges from large urban communities, where effluent may come into contact with recreational water users, tertiary treatment with disinfection will provide the greatest health benefits and produce a sanitary inspection category of 'very low' risk. However, public health risks will vary depending on the operation and reliability of the plant and the effectiveness of disinfection.

Intermittent pollution abatement

Pollution from run-off via drainage ditches, sewer overflows etc is predominantly 'event-driven' and may affect recreational water areas for relatively short periods after rainfall. Despite separation of sewage and stormwater in most Australian towns and cities, these effluents may 'combine' during significant rain events, and may present a greater health risk if water users are exposed to diluted but untreated sewage at stormwater outlets. Because of infiltration, all gravity sewers receive surface water during major rainfall events and overflows of 'uncombined' raw sewage (at pumping stations or designated overflow points) present a direct health risk.

Treatment is an option for stormwater or sewer overflows. However, during major events such control measures may not be able to cope with the quantity of the sewage, or the effectiveness of the treatment may be lowered because of a change in the 'quality' of the sewage. Therefore, relevant authorities need to be aware of the relative costs of effective management versus health and environmental gains.

Other pollution abatement alternatives to reduce sewage release into the environment include:

- relining sewers and stormwater pipes, fixing pumping stations and reducing sewer inputs to reduce the potential for overflows, such as by reusing wastewater;
- using retention tanks or tunnels that discharge during periods when water is not being used recreationally or that act as buffers during storms by retaining sewage for future treatment (these are costly and may be impractical for large urban areas, but examples exist, such as the Northside tunnel in Sydney);
- transporting sewage to locations distant from recreational areas via piped collection systems or effective outfalls; and
- disinfection (ozone, chlorine, peracetic acid or UVR), which may not be effective against all hazards.

Abatement methods for event-driven pollution episodes usually require major capital expenditure and may not be readily justifiable, especially in regional communities. An alternative is to develop and apply management programs that minimise recreational use during such events.

Reuse of wastewater for agricultural, groundwater injection, groundwater infiltration or other purposes may eliminate health risks for recreational water areas. However, during events such as heavy rainfall, recycled materials may be carried into waterways.

Catchment pollution abatement

Significant pollution sources that present a challenge to pollution abatement can include upstream diffuse pollution, point-source discharges, pathogen accumulation and remobilisation from stream sediments and riverine discharges to coastal recreational areas (Kay *et al* 1999). Major sources of pollution should be identified and a program for catchment-wide pollution abatement developed. Multiagency and interdisciplinary cooperation among health and environmental control agencies, local authorities, users, polluters and others will help in developing an effective program. The role of the agricultural sector in the generation and remediation of pollution loadings is often crucial.

6 CYANOBACTERIA AND ALGAE IN FRESH WATER

Guidelines

Fresh recreational water bodies should not contain:

- $\geq 10 \mu\text{g/L}$ total microcystins; or $\geq 50\,000$ cells/mL toxic *Microcystis aeruginosa*; or biovolume equivalent of $\geq 4 \text{ mm}^3/\text{L}$ for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume; or
- $\geq 10 \text{ mm}^3/\text{L}$ for total biovolume of all cyanobacterial material where known toxins are not present; or
- cyanobacterial scums consistently present.

6.1 OVERVIEW

Cyanobacteria (blue-green algae) are bacterial photosynthetic autotrophs⁶ that form a common and naturally occurring component of most aquatic ecosystems (Van den Hoek *et al* 1995). Cyanobacteria have some of the characteristics of bacteria and of algae. Their capacity to photosynthesise with the aid of green and blue-green pigments, and their size and tendency to occupy a similar habitat, make them look much like algae — hence the historical classification of the group as blue-green algae. They can occur singly or grouped in colonies (Whitton and Potts 2000) and can increase to such large numbers that they colour the water (a ‘bloom’) and form highly visible thick scums. The unicellular species range in size from $0.4 \mu\text{m}$ to more than $40 \mu\text{m}$ in diameter and some filamentous species have diameters over $100 \mu\text{m}$ (Whitton and Potts 2000).

The term ‘algae’ here often refers to microscopically small plants in fresh water. Algae can be single cells, or they can form colonies of many cells and reach sizes visible to the naked eye as small green particles. Algae are common in both aquatic and terrestrial habitats (soil etc). Like cyanobacteria, many species of freshwater algae can proliferate intensively in eutrophic waters⁷ to the extent that they cause visible discolouration. However, unlike cyanobacteria, algae have been implicated in only relatively minor health problems. Because algae do not usually form dense surface scums as some cyanobacteria do, their numbers do not accumulate to concentrations likely to become a hazard to recreational water users, except on the rare occasions when the cell concentration (i.e. cell count/unit volume) becomes so great that it obscures submerged hazards. This would occur only in highly eutrophic water that would also be suspected of other types of potentially hazardous contamination (eg effluent, animal waste or agricultural pollution), and that would therefore be restricted. There is some evidence of rare irritation and allergic effects caused by algae, but this chapter is principally concerned with the health implications of cyanobacteria.

Cyanobacteria are of public health concern because some types produce toxins that have harmful effects on tissues, cells or organisms (Carmichael 1992, NHMRC/NRMMC 2004). These toxins are a potential hazard in waters used for human and animal drinking-water supplies, aquaculture, agriculture and recreation (Ressom *et al* 1993). Furthermore, production of toxins is unpredictable, making it difficult to identify the toxicity of waters and define the restrictions that should be placed on their use (Falconer *et al* 1999). There appears to have been an increase in both the incidence and awareness of algal blooms in Australia since the recognition of the issue of toxicity in the late 1980s.

⁶ ‘Autotrophs’ are organisms that undergo photosynthesis (ie primary producers)

⁷ ‘Eutrophic waters’ are those in which there are high levels of nutrients

Australian responses to algal blooms have included a range of national and state agency activities and reactive management plans to deal with the causes and consequences of blooms. Guidelines are important in responsible management of cyanobacteria in water.

Toxic cyanobacteria are found worldwide in inland and coastal waters. At least 46 species have been shown to cause toxic effects in vertebrates (Sivonen and Jones 1999). Worldwide, about 60% of the cyanobacterial samples investigated have proven to contain toxins, and the toxicity of a single bloom may change in both time and space (Sivonen and Jones 1999). Toxic cyanobacteria in a water body do not necessarily pose an environmental or human hazard as long as the cells remain thinly dispersed. Mass developments, especially of surface scums, pose the largest risks.

The most common toxic cyanobacteria in Australia are:

- *Microcystis aeruginosa*, *Anabaena circinalis*, *Cylindrospermopsis raciborskii*, and *Aphanizomenon ovalisporum* in fresh water; and
- *Nodularia spumigena* and *Lyngbya majuscula* in estuarine and coastal marine water.

Other genera and species that may commonly be encountered in Australia may also be toxic. A comprehensive list of potentially toxic types of cyanobacteria and the toxins they produce is given in Table 6.1 (see also Sivonen and Jones 1999). Additional toxic species are likely to be found as research broadens and covers further regions around the world. Therefore, a toxic potential should be assumed in any cyanobacterial population until testing indicates otherwise.

6.2 HEALTH EFFECTS

The health problems associated with cyanobacteria are due to the cyanotoxins that they produce. The three main groups of cyanotoxins are:

- the cyclic peptides — microcystins and nodularin (Section 6.2.1);
- the alkaloids — such as neurotoxins and cylindrospermopsin (Section 6.2.2); and
- lipopolysaccharides (Section 6.2.3).

Table 6.1 lists the major target organs of these toxins and the cyanobacterial genera that produce them. Although the toxins listed are assumed to be the substances most significant for human health, it is unlikely that all cyanotoxins have been discovered.

Researchers are now identifying many compounds from cyanobacteria and marine phytoplankton that could be used medicinally (Carmichael 1997, Skulberg 2000).

Table 6.1 General features of the cyanotoxins

Toxin group ^a	Primary target organ in mammals	Cyanobacterial genera ^b
Cyclic peptides		
Microcystins	Liver	<i>Microcystis</i> , <i>Anabaena</i> , <i>Planktothrix</i> (<i>Oscillatoria</i>), <i>Nostoc</i> , <i>Hapalosiphon</i> , <i>Anabaenopsis</i>
Nodularin	Liver	<i>Nodularia</i> , <i>Anabaena</i> , <i>Planktothrix</i> (<i>Oscillatoria</i>), <i>Aphanizomenon</i>
Alkaloids		
Saxitoxins	Nerve axons	<i>Anabaena</i> , <i>Aphanizomenon</i> , <i>Lyngbya</i> , <i>Cylindrospermopsis</i>
Anatoxin-a	Nerve synapse	<i>Anabaena</i> , <i>Planktothrix</i> (<i>Oscillatoria</i>), <i>Aphanizomenon</i>
Anatoxin-a(s)	Nerve synapse	<i>Anabaena</i>
Aplysiatoxins	Skin	<i>Lyngbya</i> , <i>Schizothrix</i> , <i>Planktothrix</i> (<i>Oscillatoria</i>)
Cylindrospermopsin	Liver	<i>Cylindrospermopsis</i> , <i>Aphanizomenon</i> , <i>Umezakia</i> , <i>Raphidiopsis</i> , <i>Anabaena</i>
Lyngbyatoxin-a	Skin, gastrointestinal tract	<i>Lyngbya</i> , <i>Schizothrix</i> , <i>Planktothrix</i> (<i>Oscillatoria</i>)
Lipopolysaccharides (LPSs)	Potential irritant; affects any exposed tissue	All

a Many structural variants are known for each toxin group

b This is a compilation of worldwide information, and the toxins are not produced by all species of the particular genus

Source: Sivonen and Jones (1999)

6.2.1 Cyclic peptides (microcystins and nodularin)

Characteristics and occurrence

The cyclic peptides microcystin and nodularin produced by cyanobacteria contain a specific amino acid side chain Adda ((2S, 3S, 8S, 9S)-3-amino-9-methoxy-2, 6, 8-trimethyl-10-phenyldeca-4, 6-dienoic acid), which is the most unusual structure in this group of peptide toxins. Microcystins are the most frequently occurring and widespread cyanotoxins, with about 70 structural analogues identified so far (Rinehart *et al* 1994, Sivonen and Jones 1999). They vary with respect to methyl groups and two amino acids within the ring. This affects the tertiary structure of the molecule and results in pronounced differences in toxicity and in hydrophobic and hydrophilic properties.

Microcystins

Microcystins are found in most populations of *Microcystis spp*, which frequently form surface scums and in strains of some species of *Anabaena*, which may also form scums. Furthermore, high levels of microcystin have been observed in *Planktothrix* (syn *Oscillatoria*) *agardhii* and *P. rubescens* (Fastner *et al* 1999). However, *P. agardhii* never forms scums, and *P. rubescens* usually does not form scums during the swimming season, thus reducing the hazard to swimmers. Microcystins are the most significant public health issue associated with cyanobacterial blooms in southeastern Australia (NHMRC/NRMMC 2004).

Toxicity varies between different populations of *M. aeruginosa*. However, one extensive survey of toxicity across the Murray–Darling Basin indicated that 56% of field samples tested were hepatotoxic (Baker and Humpage 1994). A natural population may consist of a mixture of toxic and nontoxic strains, and this is believed to be the reason that population toxicity can vary over time and between samples (Chorus and Bartram 1999).

The toxicity of a strain depends on whether or not it contains the gene for microcystin production (Rouhiainen *et al* 1995, Dittmann *et al* 1996), and field populations are a mixture of genotypes that have or lack this gene (Kurmayer *et al* 2002). Culture of cyanobacteria shows that microcystin production is a fairly constant trait of a given strain or genotype and is only partly modified by environmental conditions (Chorus 2001).

Nodularin

Nodularin is produced by the cyanobacterium *Nodularia spumigena*, which is regarded as primarily a brackish-water species and is known to form blooms in estuarine lakes in Australia, New Zealand and Europe. It can also occur in brackish inland lakes in Australia (Wood 1975). In addition to these saline environments there are occasional blooms of toxic *N. spumigena* in freshwater lakes of the lower Murray River in South Australia (Baker and Humpage 1994). Blooms of *N. spumigena* in fresh water are relatively rare but are particularly important in the Murray because its water is used for potable supplies, irrigation and stock watering. Lake Alexandrina in South Australia was the site of the first scientifically documented animal poisoning by *N. spumigena*, and indeed by any cyanobacterium (Francis 1878). It is likely that these poisonings and the toxic effects described by Francis were due to nodularin. Low numbers of *N. spumigena* have also been recorded in the other (freshwater) river systems of the Murray–Darling Basin. Because of the limited geographic scope for blooms of this organism in fresh water in Australia, nodularin is a relatively minor public health threat in recreational water.

Toxic effects

Microcystins and nodularin bind covalently to protein phosphatases 1 and 2a (MacKintosh *et al* 1990); this binding is therefore very inhibitory and highly specific, and in the case of microcystin, it is irreversible. The chief pathway into cells for microcystins is the bile acid carrier, which is found in liver cells and, to a lesser extent, in intestinal epithelia (Falconer 1993). In vertebrates, a lethal dose of microcystin causes death by liver necrosis within hours to a few days. Evidence for the permeability of other cell membranes for microcystins is controversial. Possibly, hydrophobic structural analogues can penetrate into some types of cells even without the bile acid carrier (Codd 1995). In addition, Fitzgeorge *et al* (1994) published evidence for disruption of nasal tissues even by the common hydrophilic analogue microcystin-LR. Toxicity by oral uptake is generally at least an order of magnitude lower than toxicity by intraperitoneal injection. However, intranasal application in these experiments was as toxic as intraperitoneal injection, and membrane damage by microcystin enhanced the toxicity of anatoxin-a. This uptake route may be relevant for water sports such as waterskiing that lead to inhalation of spray and droplets.

Fitzgeorge *et al* (1994) demonstrated that microcystin toxicity is cumulative: a single oral dose showed no increase in liver weight (a measure of liver damage), whereas the same dose applied daily over 7 days caused an increase in liver weight of 84% and thus had the same effect as a single oral dose 16 times as large. This may be explained by the irreversible covalent bond between microcystin and the protein phosphatases, which leads to subsequent damage to cell structure (Falconer 1993). Healing of the liver probably requires growth of new liver cells. Subacute liver injury is likely to go unnoticed for two reasons:

- liver injury shows externally noticeable symptoms only when it is severe; and
- acute dose–response curves for microcystins are steep, so little acute liver damage may be observed up to levels close to severe acute toxicity.

The two potential mechanisms for chronic microcystin damage to the liver are progressive active liver injury (as described above) and the promotion of tumour growth. Tumour-promoting activity of microcystins is well documented in animals, although microcystins alone have not been demonstrated to be carcinogenic. Promotion of mouse skin tumours has been shown after initiation by topical exposure to a carcinogen (dimethylbenzanthracene) followed by ingestion of a *Microcystis aeruginosa* extract (Falconer and Buckley 1989, Falconer and Humpage 1996). In rat liver studies the appearance of preneoplastic liver foci and nodules was promoted by pure microcystin-LR in a protocol involving one intraperitoneal dose of diethylnitrosamine and intraperitoneal doses of microcystin-LR over several weeks (Nishiwaki-Matsushima *et al* 1992). Studies on the mechanism of cell toxicity showed that microcystin interferes with cell structure and mitosis, and this may help to explain the tumour-promoting activity (Falconer and Yeung 1992, Kaja 1995).

6.2.2 Alkaloids

Characteristics and occurrence

The alkaloid toxins produced by cyanobacteria include a range of neurotoxins, such as anatoxins and saxitoxins, and the hepatotoxic and cytotoxic alkaloid cylindrospermopsins (see Table 6.1). Saxitoxins and cylindrospermopsins have been found in cyanobacteria in Australia but the neurotoxins anatoxin.a or anatoxin.a (s) have not yet been found (NHMRC/NRMMC 2004).

A number of cyanobacterial genera can produce neurotoxins, including *Anabaena*, *Oscillatoria*, *Cylindrospermopsis*, *Cylindrospermum*, *Lyngbya* and *Aphanizomenon*. In Australia, neurotoxin production has only been detected from *Anabaena circinalis*, and the Australian isolates appear to produce only saxitoxins (Velzeboer *et al* 1998). Blooms of *Anabaena circinalis* have been recorded in many Australian rivers, lakes, reservoirs and dams, and it is the most common organism in riverine blooms in the Murray–Darling Basin (Baker and Humpage 1994). In temperate parts of Australia, blooms typically occur from late spring to early autumn. The first reported neurotoxic bloom of *A. circinalis* in Australia occurred in 1972 (May and McBarron 1973). The most publicised bloom occurred in late 1991 and extended over 1000 km of the Darling–Barwon river system in New South Wales (NSWBGATF 1992). A state of emergency was declared, with a focus on providing safe drinking water to towns, communities and landholders. Stock deaths were associated with the bloom but there was little evidence of effects on human health. A bloom of *A. circinalis* in a dam in New South Wales was shown to have caused sheep deaths (Negri *et al* 1995). Relatively low numbers of *A. circinalis* (less than 2000 cells/mL) can produce offensive tastes and odours in drinking water due to the production of odorous compounds, such as geosmin.

There are three analogues of cylindrospermopsin and this alkaloid toxin was originally isolated from *Cylindrospermopsis raciborskii* (Ohtani *et al* 1992). In Australia, cylindrospermopsin is produced by *Cylindrospermopsis raciborskii*, *Aphanizomenon ovalisporum* and *Lyngbya wollei* (NHMRC/NRMMC 2004; Shaw *et al* 1999; Siefert *et al* 2006). Both *C. raciborskii* and *A. ovalisporum* have a planktonic occurrence, ie are free in the water column, while *Lyngbya wollei* occurs as a benthic organism, ie is a sediment dwelling type.

C. raciborskii has historically been considered to be a tropical and subtropical species and it can be regarded as the major toxic cyanobacterium of concern in Queensland as it has been found in many water supply reservoirs in northern, central and southern Queensland. *A. ovalisporum* was also first reported and was shown to be toxic in Australia from Queensland (Shaw *et al* 1999). While both *C. raciborskii* and *A.*

ovalisporum are predominantly tropical and subtropical in their habitats, both species occur in the Murray–Darling system (Baker and Humpage 1994) and have been shown to develop blooms in lakes in Sydney, Adelaide and southwest Western Australia. Based on international biogeographic studies, it has been proposed that *C. raciborskii* may be invading temperate regions (Padisák 1997). Certainly, occasional blooms of *C. raciborskii* that contain cylindrospermopsin have been recorded in southeastern and Western Australia in recent years, and cylindrospermopsin may become a more relevant public health concern in temperate zones in future.

Toxic effects

While each of the neurotoxins has a different mode of action, all have the potential to be lethal at high doses by causing asphyxia through paralysis of respiratory muscles. However, no human deaths from exposure to neurotoxins associated with recreational use of water are known.

The saxitoxins are also produced by various marine dinoflagellates under the name of paralytic shellfish poisons (PSPs) and the human health effects caused by saxitoxins are well described from numerous reports of human toxicity associated with consumption of shellfish containing relatively high concentrations of PSPs (NHMRC/NRMMC 2004). There are no known chronic effects from exposure to saxitoxins but long-term animal studies are lacking.

Cylindrospermopsin is a general cytotoxin that blocks protein synthesis, with the acute clinical symptoms being kidney and liver failure. Clinical symptoms may appear only several days after exposure, so it will often be difficult to determine a cause–effect relationship. Results by Falconer and Humpage (2001) suggest that cylindrospermopsin may also act directly as a tumour initiator, which has implications for both short and long-term exposure.

Historically, cylindrospermopsin is believed to have been the causative agent in the Palm Island ‘mystery disease’ poisoning incident in Queensland in 1979, in which 148 people were hospitalised (Byth 1980). It was subsequently shown that the drinking water from Solomon Dam on Palm Island contained blooms of toxic *C. raciborskii* (Hawkins *et al* 1985). No reports of human poisoning attributable to cylindrospermopsin have appeared since the Palm Island incident. Recent cattle deaths in Queensland are attributed to this toxin (Saker *et al* 1999).

6.2.3 Lipopolysaccharides

Characteristics and occurrence

Lipopolysaccharides (LPS) are an integral component of the cell wall of all gram-negative bacteria, including cyanobacteria — in conjunction with peptidoglycan and proteins they determine and maintain the size and shape of the cell (Bertocchi *et al* 1990). Weise *et al* (1970) were the first to isolate LPS from the cyanobacterium *Anacystis nidulans* and numerous reports of endotoxins in cyanobacteria have followed.

Toxic effects

The universal presence of LPS in cyanobacteria has led to discussion of their significance (compared to the other toxins) as a potential issue of concern for exposure in recreational situations. LPS can elicit irritant and allergenic responses in human and animal tissues (Sivonen and Jones 1999). They are pyrogenic (fever-causing) and toxic (Weckesser and Drews 1979). An outbreak of gastroenteritis in Pennsylvania in

the United States may have been caused by cyanobacterial LPS (Lippy and Erb 1976). However, cyanobacterial LPS are considerably less potent than LPS from pathogenic gram-negative bacteria such as *Salmonella* (Keleti and Sykora 1982, Raziuddin *et al* 1983). A recent Australian review has suggested that although cyanobacterial LPS is widely cited as a putative toxin, most of the small number of formal research reports describe cyanobacterial LPS as weakly toxic compared to LPS from the Enterobacteriaceae. (Stewart *et al* 2006). They also conclude that there does not appear to be good evidence that cyanobacterial LPS are likely to initiate cutaneous reactions in healthy people exposed in recreational or occupational settings (Stewart *et al* 2006).

It is therefore possible that cyanobacterial lipopolysaccharides represent a relatively minor to low hazard to human health in water contaminated with cyanobacteria.

6.3 EXPOSURE

Observations of lethal poisoning of animals drinking from water with blooms of cyanobacteria are numerous. The first documented case of a lethal intoxication of livestock after drinking water from a lake heavily infested with cyanobacteria occurred in South Australia in 1878 (Francis 1878). Cases recorded since have included sheep, cattle, horses, pigs, dogs, fish, rodents, amphibians, waterfowl and bats (Codd *et al* 1989). Dogs have died after grooming accumulations of cyanobacteria out of their fur or after ingesting beached mats of benthic cyanobacteria. Box 6.1 presents a number of reported cases of human illness associated with exposure to cyanobacteria.

Box 6.1 Examples of cases of human illness attributed to cyanotoxins in recreational water

1959, Canada

Despite a kill of livestock and warnings against recreational use, people swam in a lake infested with cyanobacteria and 13 became ill (headaches, nausea, muscular pains, painful diarrhoea). Numerous cells of *Microcystis* spp and some trichomes of *Anabaena circinalis* were identified in the excreta of one patient (Dillenberg and Dehnel 1960).

1989, England

Ten out of twenty soldiers became ill after swimming and canoe training in water with a heavy bloom of *Microcystis* spp. Two of the ten developed severe pneumonia attributed to the inhalation of a *Microcystis* toxin and needed hospitalisation and intensive care (Turner *et al* 1990). Swimming skills and the amount of water ingested appear to have been related to the degree of illness.

1991, Australia

Two teenage girls suffered gastroenteritis and myalgia after swimming in the Darling River at Wilcannia during a cyanobacterial bloom containing *Anabaena* (Williamson and Corbett 1993).

1995, Australia

Epidemiological evidence of adverse health effects after recreational water contact from a prospective study involving 852 participants showed elevated incidence of diarrhoea, vomiting, flu symptoms, skin rashes, mouth ulcers, fevers, and eye or ear irritations within 2–7 days after exposure (Pilotto *et al* 1997). Symptoms increased significantly with duration of water contact and density of cyanobacterial cells, but were not related to the content of known cyanotoxins.

Human health risk from exposure to cyanobacteria and their toxins during recreational water use arises through three routes of exposure:

- direct contact of exposed parts of the body, including sensitive areas such as the ears, eyes, mouth and throat, and the areas covered by a bathing suit (which may collect cell material);
- accidental swallowing of water containing cells; and
- aspiration (inhalation) of water containing cells.

6.3.1 Dermal contact

Allergic reactions to cyanobacteria are reported anecdotally from eutrophic bathing waters but are rarely investigated in scientific studies or published in peer-reviewed journals. However, a number of laboratory studies have investigated the irritation effects of cyanobacteria.

Human studies

Heise (1951) observed allergic reactions in people given subcutaneous injections of glycerosaline extracts of dried *Microcystis* and *Oscillatoriaceae* species. Of 60 people tested, 10 reacted to both groups of cyanobacteria, but the remainder showed no reaction to any of the test organisms. The authors concluded that *Microcystis* and *Oscillatoriaceae* species contained similar antigens and that only certain individuals will show an allergic response.

McElhenny *et al* (1962) performed subcutaneous skin tests using four different green algae species on 140 children — 20 nonallergic and 120 having pollen and/or other inhalant sensitivities. None of the nonallergic group showed a reaction. Of the 120 allergic children, 98 showed positive reactions to one or more of the algal species, and 22 showed no reaction.

Mittal *et al* (1979), investigating the clinical aspects of respiratory allergy to a range of planktonic cyanobacteria and algae, performed 4000 intradermal skin tests on 400 people suffering from nasal-bronchial allergy and 300 skin tests on 30 healthy people. The species studied were 10 common phytoplankton isolated from the region around Delhi, India: *Lyngbya*, *Phormidium*, *Anabaena*, *Scytonema*, *Chlorella*, *Westiellopsis*, *Anabaenopsis*, *Oscillatoria*, *Nostoc* and *Chlorococcum*. Positive skin reactions ranged from 25.7% for *Lyngbya* to 1.7% for *Oscillatoria* in allergic volunteers. There were no positive skin reactions in nonallergic volunteers. Prausnitz-Küstner, bronchial provocation and conjunctival tests were negative in patients with negative skin reactions. However, in patients with positive skin reactions, Prausnitz-Küstner was positive for 70.9%, bronchial provocation for 50% and conjunctival outcomes for 48%. Levels of total immunoglobulin E in patients with nasobronchial allergy were higher, ranging from 1225 to 1550 international units (IU)/mL, while healthy volunteers had values less than 885 IU/mL.

Turner *et al* (1990) reported a possible link between pneumonia in two army recruits and reservoir water containing toxic *Microcystis aeruginosa* in which the recruits had been canoeing. El Saadi *et al* (1995) identified a possible increase in risks of gastrointestinal and dermatological symptoms in a population using the drinking water supplied from the Murray River during times of high cyanobacterial cell numbers.

In Australia, Pilotto *et al* (2004) looked at skin irritation effects in humans from cyanobacteria cell suspensions. The purpose of this work was to gather basic information on skin contact issues for development of guidelines for recreational exposure. Both cell suspensions and extracts of toxic cyanobacterial cultures of *Microcystis aeruginosa* (toxic and nontoxic strains), *Anabaena circinalis* (toxic), *Nodularia spumigena* (toxic), *Aphanocapsa incerta* (nontoxic) and *Cylindrospermopsis raciborskii* (toxic) were applied to the skin of 114 volunteers at cell concentrations of 5000–350 000 cells/mL using adhesive skin patches. Cell concentration and total cell volume were quantified to determine whether dose as biovolume (ie cyanobacterial biomass dose) were quantitatively related to irritation effects. Patches were removed after 24 hours and erythema was assessed by a dermatologist using direct observation.

Results showed that 22% of both atopic and of non-atopic individuals reacted to each of the six cyanobacterial species studied across the concentration range tested. This was reduced to 12% when those individuals who reacted to negative controls (culture medium) were removed. This was the case for both whole and lysed cells, with little difference in reaction rates between these two treatments. No difference in the irritant effect between the six species was observed. The study did not identify any consistent dose–response relationship for any of the cyanobacterial species tested nor did it find a difference in reaction between atopic and non-atopic individuals.

The demonstration of irritation in a small proportion of the population at low to moderate cell concentrations confirms that there is an adverse health hazard from exposure. Irritation in the affected individuals did not appear severe; it was self-limiting and was resolved within a short period (24–72 hours). The absence of both a dose-dependent response and a threshold make it difficult to develop a quantitative protective guideline based on this study.

Animal studies

Torokne *et al* (2000) carried out sensitisation tests on albino guinea pigs and intradermal reactivity and ocular irritation tests on albino rabbits. The study examined *Microcystis*, *Anabaena*, *Cylindrospermopsis* and *Aphanizomenon* bloom samples and axenic (pure) cultures of *Anabaena*, *Oscillatoria* and *Microcystis* and used freeze-dried algal suspensions in physiological salt solution. Slight skin irritation was recorded for *Anabaena*, *Microcystis* and *Aphanizomenon*, but no correlation was found between the toxin content and the allergenic character. None of the strain samples was found to be allergenic. Water-soluble and lipid-soluble fractions of a lysed *Aphanizomenon* bloom sample were made by water and chloroform extraction. A slight irritant effect was shown by the water-soluble fraction, but there was negligible reaction to the lipid-soluble fraction. The authors argued that the irritant effect was caused by lipopolysaccharides which, they suggested, originated from the bacteria present in the bloom samples and not from the cyanobacterial cell wall. This was supported by results that showed no irritant effects for axenic cultures (ie cultures containing no bacterial contamination). This conclusion must be regarded with caution, as there was no identification of any lipopolysaccharide from the cyanobacterial material in this work.

Epidemiological studies

Skin irritation symptoms were found frequently in an epidemiological study of 852 participants, 777 of whom had water contact (Pilotto *et al* 1997). The study looked at health effects after recreational exposure to cyanobacteria. The dominant cyanobacteria on the survey days across all sites were *Microcystis spp.*, *Anabaena spp.*, *Aphanizomenon spp.* and *Nodularia spumigena* were also identified. No significant differences in overall symptoms were found between the unexposed and the exposed after 2 days. At 7 days, there was a significant increase in symptom occurrence with duration of exposure ($P = 0.03$). There was also a significant increase in symptom occurrence with increasing cell count ($P = 0.04$). Participants exposed to cell concentrations greater than 5000 cells/mL for more than one hour had a significantly higher symptom occurrence rate than the unexposed. Symptoms were collated as vomiting or diarrhoea, cold and flu symptoms, mouth ulcers, eye irritation, ear irritation, skin rash and fever. Less than a quarter of the participants experienced one or more symptoms, the most common being cold and flu-like symptoms. For each symptom apart from eye irritation, there tended to be a higher rate of occurrence in the exposed participants. However, since the occurrence of each individual symptom was low, the presence of one or more symptoms was chosen as the outcome variable for comparative

analysis. These symptoms were not correlated with the presence of hepatotoxins. The authors concluded that symptom occurrence was associated with duration of contact (> 60 minutes) with water containing cyanobacteria, and with cyanobacterial concentration.

Stewart *et al* (2006) studied recreational exposure to freshwater cyanobacteria in southern Queensland, the Myall Lakes area in New South Wales and northeast and central Florida. The study design was a prospective cohort study that included 1331 individuals recruited before they engaged in various water recreation activities at freshwater and brackish lakes and reservoirs. On the day, participants were given a self-administered questionnaire that provided basic demographic information. This was followed up by a telephone interview after the third post-exposure day to determine symptom occurrence rate and severity. Water samples were collected on the recruitment day for cyanobacterial counts. The results were divided into people who were exposed to levels of cyanobacteria classified as follows:

- low (< 5000 cells/mL; cell surface area < 2.4 mm²/mL);
- medium (5000 – 100 000 cells/mL; 2.4–12.0 mm²/mL); and
- high (> 100 000 cells/mL; > 12.0 mm²/mL) levels of cyanobacteria.

These exposure categories were also expressed as biovolumes (mm³/L). The principal finding of the study was that individuals exposed to waters with high cyanobacterial cell concentration (where total cyanobacterial surface areas exceeded 12 mm²/mL), were more likely to report symptoms after exposure than those exposed to waters with low cell concentrations (total surface areas < 2.4 mm²/mL). Mild respiratory symptoms were the predominant symptom category. The relative odds ratio reported was that respiratory symptoms were 2.08 times more likely to be reported by subjects exposed to high levels of cyanobacteria than by those exposed to low levels. This work is important in considering exposure assessment for total cyanobacteria in recreational situations in terms of measures of total biomass, such as surface area and biovolumes.

Algae

While algae are not generally associated with skin irritation problems a number of cases have been reported. Naglitsch (1988) reported a case where *Staurostrum gracile*, the cell walls of which are covered with spine-like structures, caused irritative coughs in staff and patients of a physiotherapy unit. The unit was supplied with coarsely filtered surface water containing the algae and used this water for underwater massage treatment. Chorus (1993) reported skin reactions in response to a bloom of *Uroglena spp* in a small number of swimmers. These reactions were especially pronounced under bathing suits, where cells accumulated and were partially disrupted during swimming. Divers frequently complain of dermal reactions to algal material accumulating under their wetsuits, which tend to act as a strainer that lets out water but collects algae between skin and suit. Pressure and friction between fabric and skin lead to cell disruption, liberation of cell contents and intensified dermal exposure to both algal cell wall material and to substances otherwise largely confined within the cells.

Another report involved the algal species *Gonyostomum semen*, which may develop high population concentrations in slightly acidic waters and emits a slimy substance causing skin irritation and allergic reactions. In Sweden, occurrence of this species has led to closure of a number of freshwater recreational sites (Cronberg *et al* 1988).

Although these incidents are rare, they highlight the need for managers to be aware of possible skin irritation problems associated with algae.

6.3.2 Ingestion or aspiration

In contrast to dermal contact most of the reported cases of human illnesses caused by algae in recreational situations (see Box 6.1) have been due to uptake by ingestion or aspiration of cyanobacterial cells. The uptake of cyanobacteria involves a risk of intoxication by the cyanotoxins listed in Table 6.1. Acute mechanisms of toxicity are well known for a range of hepatotoxins and neurotoxins, and some information is available to estimate risks from repeated or chronic exposure.

Most documented cases of human injury through cyanotoxins have involved exposure through drinking water and they demonstrate that humans have become ill — in some cases seriously — through ingestion or aspiration of toxic cyanobacteria. The low number of reported cases might be due to lack of knowledge about the toxicity of cyanobacteria, leading to patients and doctors failing to associate symptoms with this cause. This hazard, and the range of toxicological information, has been taken into account in the most recent revision of the *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004), which now contain a guideline for one class of cyanotoxins (total microcystins). However, because adequate data are lacking, no guideline values have been set for concentrations of nodularin, saxitoxins or cylindrospermopsin.

In addition to uptake of cyanotoxins by ingestion, a single animal study has considered the effects of uptake by aspiration. Fitzgeorge *et al* (1994) investigated the response of mice to administration of microcystin-LR and anatoxin-a by different routes. For microcystin-LR, intraperitoneal administration gave an LD₅₀ value (the dose needed to kill 50% of mice) of 250 µg/kg, whereas gastric intubation gave an LD₅₀ value of 3000 µg/kg and intranasal application gave an LD₅₀ value of 250 µg/kg. Aerosol inhalation of microcystin-LR gave no deaths at 0.0005 µg/kg. The authors argued that this was due to the small aerosol size, 3–5 µm, but in the natural environment larger particle sizes (> 10 µm) could be expected from waves, water sports and swimming. This would be more likely to impact on mucosal surfaces and could give a response similar to intranasal application. For anatoxin-a, administration by intraperitoneal, gastric intubation and intranasal application produced LD₅₀ values of 350 µg/kg, > 5000 µg/kg and 2000 µg/kg, respectively.

6.4 GUIDELINES FOR FRESHWATER BODIES

6.4.1 Derivation of guideline

WHO guideline

WHO recently reviewed the health significance of algae and cyanobacteria in fresh water to develop a guideline for recreational water environments (WHO 2003). The organisation recommended that the approach to developing guidelines for cyanobacteria in fresh water should consider:

- the occurrence of cyanobacteria in general (in addition to known toxins) as part of the hazard, because it is not clear that all known toxic components have been identified and irritation symptoms reported may be caused by these unknown substances;
- the particular hazard caused by the well-known microcystin toxins; and
- the hazard associated with the characteristic tendency of many cyanobacterial populations in freshwater towards a heterogeneous distribution, which can result in the potential for scum formation.

WHO considered health effects to be in two classes:

- chiefly irritative symptoms caused by unknown cyanobacterial substances; and
- the potentially more severe hazard of exposure to high concentrations of known cyanotoxins, particularly microcystins.

Because of the two classes of effect, WHO found that a single guideline value was not appropriate. Rather, the organisation defined a series of guideline values associated with incremental severity and probability of health effects at three levels.

WHO Level 1: Relatively low probability of adverse health effects

The lowest level of 20 000 cyanobacterial cells/mL is recommended for ‘protection from health outcomes not due to cyanotoxin toxicity, but rather to the irritative or allergenic effects of other cyanobacterial compounds’.

WHO Level 2: Moderate probability of adverse health effects

This level is based on ‘data used for the drinking-water provisional guideline value for microcystin-LR’ (WHO 1998). The level of ‘100 000 cyanobacterial cells/mL represents a guideline value for a moderate health alert in recreational waters. At this level, a concentration of 20 µg microcystin/litre is likely if the bloom consists of *Microcystis* and has an average toxin content of 0.2 pg/cell.’ They indicate that ‘with very high cellular microcystin content, 50–100 µg microcystin/litre would be possible’ at this cell density.

The data further indicated that ‘the level of 20 µg microcystin/litre is equivalent to 20 times the WHO provisional guideline value concentration for microcystin-LR in drinking water (WHO 1998) and would result in consumption of an amount close to the tolerable daily intake (TDI) for a 60 kg adult consuming 100 mL of water while swimming (rather than 2 litres of drinking water). However, a 15 kg child consuming 250 mL of water during extensive playing could be exposed to 10 times the TDI’.

WHO Level 3: High probability of adverse health effects

The highest level was defined by the presence of scums. The data indicate that scums represent ‘a readily detected indicator of a risk of potentially severe adverse health effects for those who come into contact with the scums’. The recommendation at this level is for ‘immediate action to control scum contact’.

The justification for selection of this upper level is as follows: ‘Abundant evidence exists for potentially severe health outcomes associated with scums caused by toxic cyanobacteria. No human fatalities have been unequivocally associated with cyanotoxin ingestion during recreational water activities, although numerous animals have been killed by consuming water with cyanobacterial scum material. Calculations suggest that a child playing in *Microcystis* scums for a protracted period and ingesting a significant volume could receive a lethal dose, although no reports indicate that this has occurred. Based on evidence that a lethal oral dose of microcystin-LR in mice is 5000–11 600 mg/kg body weight and sensitivity between individuals may vary approximately 10-fold, the ingestion of 5–50 mg of microcystin could be expected to cause acute liver injury in a 10 kg child’.

Australian guideline

This document proposes a two-level guideline for Australia for exposure to cyanobacteria in recreational water, based on:

- **Level 1** — the probability of adverse health effects from ingestion of known toxins, in this case based on the toxicity of microcystins.
- **Level 2** — the probability of increased likelihood of nonspecific adverse health outcomes, principally respiratory, irritation and allergy symptoms, from exposure to very high cell densities of cyanobacterial material irrespective of the presence of toxicity or known toxins.

The difference between this two-level guideline and the three levels suggested by WHO is that the lowest level recommended by WHO (of 20 000 cyanobacterial cells/mL) for ‘protection from health outcomes due to the irritative or allergenic effects’ is here not considered sufficiently significant to warrant a specific warning. This decision is based on the study by Pilotto *et al* (2004) described above, which indicated that human skin contact with cyanobacteria across a wide cell density range results in a somewhat idiosyncratic response. The study showed that there were relatively low-severity adverse skin irritation reactions in a small proportion of the volunteers over a range of cell densities from 5000 to > 200 000 cells/mL, and that there was no dose–response across the concentration range for any of the cyanobacterial species tested. The interpretation derived from the study is that these mild skin irritative effects, which are readily resolved without medical treatment, do not warrant consideration in the setting of a quantitative guideline for recreational exposure.

Level 1 of the Australian guideline is therefore based on risk of exposure to microcystin toxins via ingestion. This is similar in principle to the WHO Level 2 guideline, which is based on that organisation’s drinking water guideline, although a different derivation process and an alternative animal model study are employed here. The health risk associated with ingestion is estimated from basic animal toxicological data. Although acute mechanisms of toxicity are well known for the neurotoxins and microcystins, the information presented here estimates the risk for short-term repeated exposure, which is regarded as being relevant for recreational situations. Animal toxicity data for microcystin toxins and conventional toxicological calculations are used to derive a guideline for short-term (14-day) exposure to microcystins via ingestion for both children and adults based on typical bodyweights (Box 6.2). The guideline is derived using the lowest observed adverse effect level (LOAEL) from the 44-day pig study of Kuiper-Goodman *et al* (1999) as the most suitable for deriving a shorter term exposure LOAEL (ie 14 days) that is representative of a period of repeated daily exposure for an uninterrupted period of up to 2 weeks. Two weeks is regarded as a likely, albeit rather intensive, continuous exposure for swimming and aquatic recreation in a summer holiday season.

The child exposure guideline for microcystins (measured as total microcystins and expressed as microcystin-LR toxicity equivalents as per NHMRC/NRMMC 2004), is recommended as the Level 1 guideline in a typical recreational situation. The microcystin concentration is converted to an equivalent worst-case cell density of *Microcystis aeruginosa*, based on cell toxin data (NHMRC/NRMMC 2004). This guideline on equivalent cell density can also be translated into an equivalent biovolume of total cyanobacterial material to gauge the potential hazard of other cyanobacteria in the first instance, irrespective of whether toxic status is known (Box 6.2).

Box 6.2 Derivation of a guideline for short-term cyanobacterial exposure for recreational activities

The guideline values for cyanobacterial exposure in recreational water is based on the LOAEL for microcystin LR of 100 µg/kg body weight per day derived from a 44 day study in pigs (Kuiper Goodman *et al* 1999)

$$\text{Child} = \frac{100 \text{ µg/kg bodyweight per day} \times 15 \times 10}{0.32 \times 5000} = 9.4 \text{ µg/L rounded here to } 10 \text{ µg/L total microcystins}$$

Where:

- 100 µg/kg body weight per day is the LOAEL based on a 44 day study using pigs (Kuiper Goodman *et al* 1999)
- 15 is the average weight of a child (in kg)
- 10 is the conversion from the amount of water accidentally swallowed per day (approximately 100 mL) to litres
- 0.32 is the conversion from 44 days exposure in the pig study, to a realistic recreational water exposure period of 14 days per year
- 5000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variation, 10 for intraspecies variation, 10 for concerns with carcinogenicity, and 5 because an LOAEL was used instead of an NOAEL^a)

$$\text{Adult} = \frac{100 \text{ µg/kg body weight per day} \times 70 \times 10}{0.32 \times 5000} = 44 \text{ µg/L total microcystins}$$

Where:

- 100 µg/kg body weight per day is the LOAEL based on a 44 day study using pigs (Kuiper Goodman *et al* 1999)
- 70 is the average weight of an adult (in kg)
- 10 is the conversion from the amount of water accidentally swallowed per day (approximately 100 mL) to litres
- 0.32 is the conversion from 44 days exposure in the pig study, to a realistic recreational water exposure period of 14 days per year
- 5000 is the safety factor in using the results of an animal study as a basis for human exposure (10 for interspecies variation, 10 for intraspecies variation, 10 for concerns with carcinogenicity, and 5 because an LOAEL was used instead of an NOAEL^a)

To derive a cell number that is equivalent to this toxin hazard, a toxin cell quota of 2×10^{-7} µg total microcystins/cell is assumed (NHMRC/NRMMC 2004).

Therefore the equivalent concentrations of toxic cells for *Microcystis aeruginosa* that are tolerable for a small child and an adult during recreational activities are:

$$\text{Child} = \frac{10 \text{ µg/L} \times 10^{-3}}{2 \times 10^{-7}} = 50\,000 \text{ cells/mL}$$

Where:

- 10 µg/L is the guideline value for cyanobacterial exposure in children
- 10^{-3} is the conversion from litres to millilitres
- 2×10^{-7} is the toxin cell quota for total microcystins/cell.

$$\text{Adult} = \frac{44 \text{ µg/L} \times 10^{-3}}{2 \times 10^{-7}} = 220\,000 \text{ cells/mL}$$

Where:

- 44 µg/L is the guideline value for cyanobacterial exposure in adults
- 10^{-3} is the conversion from litres to millilitres
- 2×10^{-7} is the toxin cell quota for total microcystins/cell

For the assessment of hazard posed by cyanobacteria other than by toxic *Microcystis aeruginosa* (ie containing microcystins), the approximate biovolume equivalent of 4 mm³/L for the combined total of all cyanobacteria is recommended. This is the approximate biovolume equivalent to 50 000 cells/mL of *M. aeruginosa*.

LOAEL = lowest observed adverse effect level; NOAEL = no observed adverse effect level

^a A value of 10 was considered inappropriate due to the low incidence of effects in the lowest dose group and the deduced shape of the dose–response curve.

It is recommended that this biovolume of $\geq 4 \text{ mm}^3/\text{L}$ be applied as an 'equivalent' guideline for populations of known potentially toxic cyanobacteria other than *Microcystis aeruginosa* (ie toxic *Anabaena circinalis*, *Cylindrospermopsis raciborskii*, and *Aphanizomenon ovalisporum*), and also in the first instance to cyanobacteria other than these known toxin producers. The rationale is that the hazard from toxicity is unlikely to exceed the worst case for an equivalent biovolume of highly toxic *M. aeruginosa* containing microcystin. This should allow protection from significant risk while a further health risk assessment is made.

There is insufficient evidence at this time to derive a quantitative guideline for ingestion of other cyanotoxins commonly encountered in Australia (ie saxitoxins and cylindrospermopsin).

A second guideline level is also required for circumstances where high cell densities or scums of 'nontoxic' cyanobacteria are present — that is, where the cyanobacterial population has been tested and shown not to contain known toxins (microcystin, nodularin, cylindrospermopsin or saxitoxins). Where the microcystin-related biovolume guideline is exceeded and no microcystin or other toxins are present, it is appropriate to issue warnings if either the total biovolume of all cyanobacterial material exceeds $10 \text{ mm}^3/\text{L}$ or scums are consistently present (ie scums are seen at some time each day at the recreational site). This guideline recommendation is based upon the work of Stewart *et al* (2006), where it was shown that there was an increase in the likelihood of symptom reporting in bathers above a cyanobacterial cell surface area equivalent to this approximate biovolume. The potential symptoms reported above this cell surface area are primarily mild respiratory symptoms. The biovolume represents a conversion from the surface area units given by Stewart *et al* (2006), where total surface area of $12.0 \text{ mm}^2/\text{mL}$ is given as being equivalent to a total biovolume of approximately $12.5 \text{ mm}^3/\text{L}$. This value is rounded here to a more conservative value of $10 \text{ mm}^3/\text{L}$ (two significant figures) to account for the uncertainties associated with sampling cyanobacterial populations in normal water bodies (see Section 6.6) and with estimating cell densities by cell counting, which is subsequently used to derive biovolumes or surface areas. The biovolume unit is also chosen to be consistent with the practice of measurement or derivation of biovolumes in algal/water quality monitoring laboratories in Australia, which is discussed in detail in NRMMC (2007, in review).

The Level 2 guideline accounts for protection from health hazards associated with the occurrence of cyanobacteria at high levels in general, demonstrated in particular by the consistent presence of scums (ie where scums occur daily at a number of sites in a water body). This is consistent with the WHO Level 3 guideline for occurrence of scums (WHO 2003).

The rationale for using cell counts and biovolumes rather than toxin concentrations to prompt management actions is that, for most practical purposes, cell counting is still primarily used by most authorities to detect algae-related water quality problems. This is because the testing is widely available and provides relatively rapid and cost-effective information. By contrast toxin testing is not widely available and has a slow turnaround time for results. Cell counts (and biovolumes) must, however, be regarded as an indicator or 'surrogate' for a potential toxin hazard. The counts should be used to prompt actions, such as toxin monitoring, that are outlined in the alert levels framework described in Section 6.4.2.

6.4.2 Interpretation and application of the guideline

The framework used in these guidelines uses a risk assessment of the surface waters to determine their suitability for recreational use (Figure 6.1). This is done with a combination of recreational water environment grading based on an assessment of prior data for cyanobacteria, and on historical information on physicochemical conditions that are used to identify risk factors for the water body assessment. Figure 6.1 outlines the framework for application of the guidelines. The interpretation of the cyanobacterial alert levels is described in Box 6.3.

Figure 6.1 Framework for assessment of cyanobacterial quality of recreational water

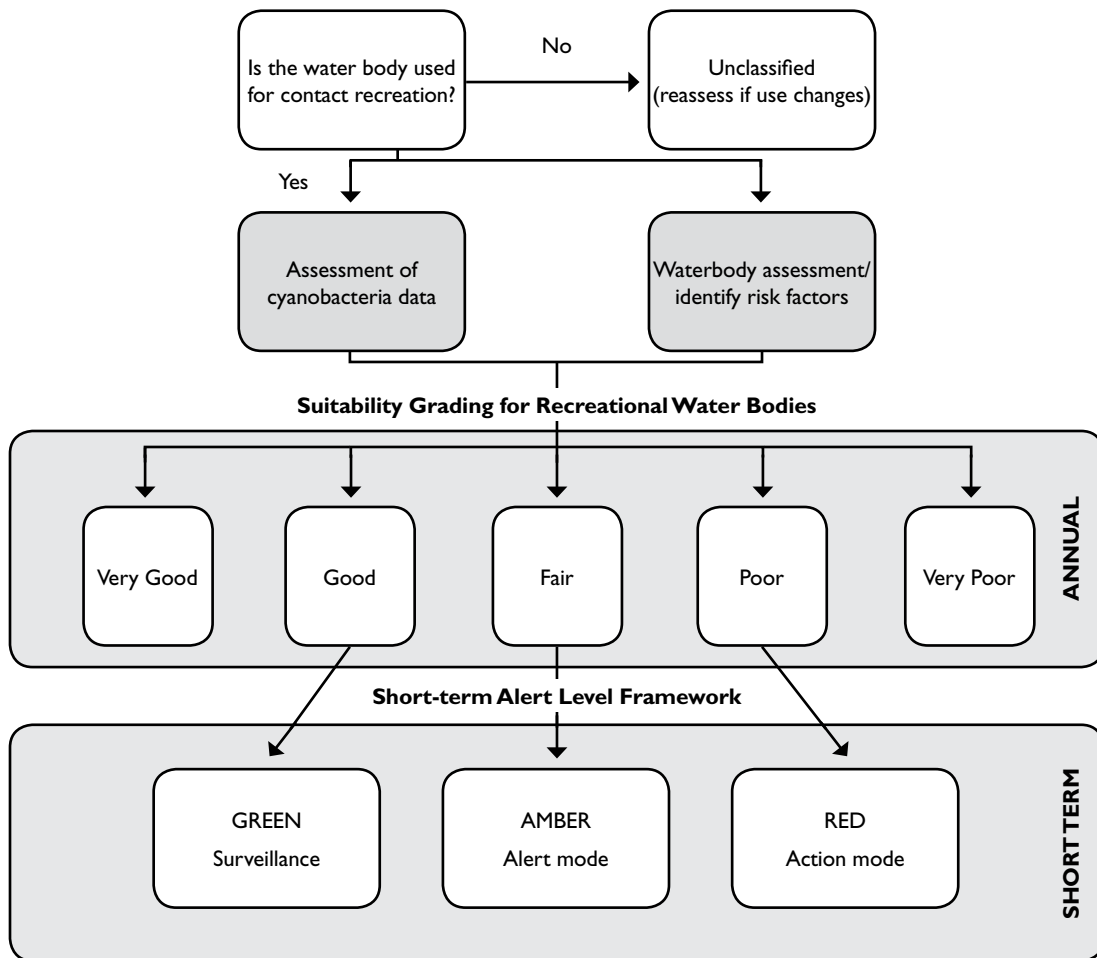


Table 6.2 Interpretation of cyanobacterial alert levels for recreational water

Green level Surveillance mode	Amber level Alert mode	Red level Action mode
≥500 to <5000 cells/mL <i>M. aeruginosa</i> or biovolume equivalent of >0.04 to <0.4 mm ³ /L for the combined total of all cyanobacteria.	≥5000 to <50 000 cells/mL <i>M. aeruginosa</i> or biovolume equivalent of ≥0.4 to <4 mm ³ /L for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume ^a . or ^b ≥0.4 to <10 mm ³ /L for the combined total of all cyanobacteria where known toxin producers are not present.	Level 1 guideline: ≥10 µg/L total microcystins or ≥50 000 cells/mL toxic <i>M. aeruginosa</i> or biovolume equivalent of ≥4 mm ³ /L for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume. or ^b Level 2 guideline: ≥10 mm ³ /L for total biovolume of all cyanobacterial material where known toxins are not present. or cyanobacterial scums are consistently present ^c .

- a The definition of 'dominant' is where the known toxin producer comprises 75% or more of the total biovolume of cyanobacteria in a representative sample.
- b This applies where high cell densities or scums of 'nontoxic' cyanobacteria are present, ie where the cyanobacterial population has been tested and shown not to contain known toxins (microcystin, nodularin, cylindrospermopsin or saxitoxins).
- c This refers to the situation where scums occur at the recreation site each day when conditions are calm, particularly in the morning. Note that it is not likely that scums are always present and visible when there is a high population, as the cells may mix down with wind and turbulence and then reform later when conditions become stable.

The grading is intended to provide an indication of the susceptibility of the water body to cyanobacterial growth. For a grading of 'very good', the water body will almost always comply with the guideline values for recreation. Water bodies graded as 'very poor' will be highly susceptible to cyanobacterial growth and may rarely pass the quantitative guidelines and their use for recreational activities is not recommended. For the remaining gradings ('good', 'fair' and 'poor'), it is recommended that a monitoring program be introduced.

The monitoring program that is then implemented is based on a three-tier alert levels framework, which is a monitoring and management action sequence that operators and regulators can use for a graduated response to the onset and progress of a cyanobacterial bloom in the water body. A similar system has been in use for management of cyanobacteria in drinking water sources for many years. The alert levels recommended for a recreational water monitoring program are summarised in Table 6.3, and discussed in more detail in Section 6.5.2.

Table 6.3 Monitoring program associated with cyanobacterial alert levels

Cyanobacterial alert level	Monitoring requirement
<i>Surveillance mode</i> (Green level)	Routine sampling to measure cyanobacterial levels.
<i>Alert mode</i> (Amber level)	Investigations into the causes of the elevated levels and increased sampling to enable the risks to recreational users to be more accurately assessed.
<i>Action mode</i> (Red level)	Local authority and health authorities to warn the public that the water body is considered to be unsuitable for primary contact recreation.

6.5 APPLICATION OF THE CYANOBACTERIAL GUIDELINES

The framework in these guidelines involves using a water body grading to decide to initiate and establish a monitoring program if one is not already in place, and applying the quantitative guideline values within the monitoring program. The water body grading provides the initial procedure to assess suitability for recreation and the requirement for monitoring. This uses a combination of pre-existing knowledge of the characteristics of the water body and any prior monitoring data on cyanobacterial incidence.

6.5.1 Grading a water body

There are two components to grading water bodies according to their cyanobacterial contamination:

- the **susceptibility category** (see Table 6.4 and Appendix 1), which generates a measure of the susceptibility of a water body to cyanobacterial contamination; and
- historical cyanobacterial monitoring results, which generate a **cyanobacterial history** category (see Table 6.4) — this is a measure of the prior incidence of cyanobacteria.

Table 6.4 Susceptibility to cyanobacterial contamination category

Environmental factors (singly or in combination)				
History of cyanobacterial blooms	Water temperature (°C)	Nutrients: total phosphorus (µg/L)	Thermal stratification	Susceptibility category
No	< 15	< 10	Never present	Very low (good)
Yes	15–20	< 10	Infrequent	Low
Yes	20–25	10–25	Occasional	Moderate
Yes	> 25	25–100	Frequent and persistent	High
Yes	> 25	> 100	Frequent and persistent/strong	Very high (poor)

The susceptibility category and the cyanobacterial history are combined to give an overall **suitability for recreation** (Table 6.5), which describes the suitability of a site, based upon both an assessment of risk of cyanobacteria occurring (ie susceptibility), and category of cyanobacteria counts from historical monitoring data. Environmental factors that contribute to cyanobacterial growth are complex. However, some basic conditions have been identified (Table 6.3) which can indicate the likelihood of a cyanobacterial bloom occurring in a water body.

In the process of matching up the environmental factors and historical data, combinations may arise where there appears to be mismatched information (identified in Table 6.5 as 'Further assessment required'). Examples of this situation include apparent absence or low densities of cyanobacteria where conditions should be favourable for growth (eg Category A) and vice versa (eg Category D), with other combinations occurring in between in each category (eg Categories B and C). The advice in these cases is to follow up with further monitoring, data collection and review to refine the suitability assessment. These exceptions may be due to factors such as inadequate or unrepresentative monitoring data for either the cyanobacteria or the environmental factors. In such cases it is appropriate to ensure that a monitoring program aims to refine data quality or information gaps for this site.

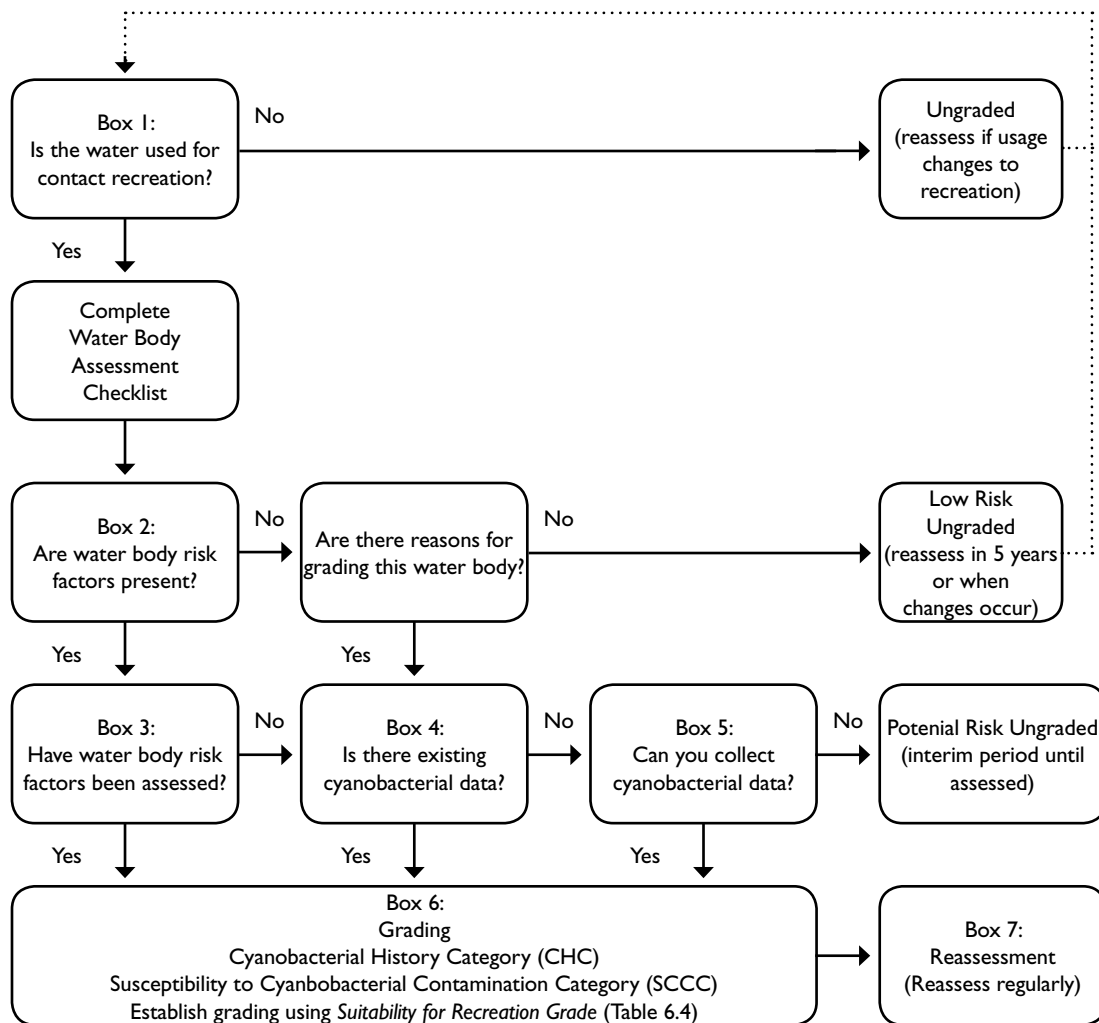
Table 6.5 Suitability for recreation

		Cyanobacterial history category				Exceptional circumstances
		A <500 cells/mL	B ≥ 500–< 5000 cells/ mL <i>M. aeruginosa</i> or biovolume equivalent of > 0.04–< 0.4 mm³/L for the combined total of all cyanobacteria	C ≥ 5000– < 50 000 cells/ mL <i>M. aeruginosa</i> or biovolume equivalent of ≥ 0.4–< 4 mm³/L for the combined total of all cyanobacteria	D ≥ 50 000 cells/mL <i>M. aeruginosa</i> or biovolume equivalent of ≥ 4 mm³/L for the combined total of all cyanobacteria	
Susceptibility to cyanobacterial contamination category	Very low	Very good	Good	Fair	Further assessment required	
	Low	Good	Fair	Further assessment required	Further assessment required	
	Moderate	Fair	Further assessment required	Poor	Very poor	
	High	Further assessment required	Poor	Very poor	Very poor	
	Very high	Further assessment required	Very poor	Very poor	Very poor	
Exceptional circumstances						

It is expected that all water bodies that may be used for recreational activity will

have to go through this process initially. The recreational water-quality decision tree (Figure 6.2) outlines the process that will lead to grading of a recreational water body.

Figure 6.2 Decision tree to determine recreational water quality



The purpose of the decision tree is to provide a logical course that allows the responsible authority to make defensible decisions on whether or not to grade a particular water body. Box 6.3, which should be read in conjunction with Figure 6.2, describes the process and decisions required to complete each step.

Box 6.3 Processes and decisions required to complete the assessment of suitability

This process is outlined in Figure 6.2

Box 1 — Is the water body used for contact recreation? This should be decided on a site specific basis by the appropriate authorities depending on the extent of use of the site.

Box 2 — Are water body risk factors present? The risk factors here refer to activities in the surrounding area or the water body itself, and other environmental conditions that may result in increased algal levels. A 'yes' means that there are environmental conditions that could support the growth of phytoplankton to hazardous levels.

As much information about the site as is feasible should be collected to make the assessment of risk factors as complete as possible. Sources of information will vary from region to region. Gathering this information may involve consultation with a range of agencies (health, water and sewage authorities, local government and councils). These agencies may collect or have access to different information for the same water body and its catchment. Relevant information includes drainage plans, site maps, water quality monitoring results (this could include physical, chemical and biological data) and catchment use.

Risk factors that may influence the formation of harmful algal blooms include:

- history of hazardous algal blooms (ie the presence of a seed source);
- environmental conditions conducive to bloom formation (stable weather patterns, inputs of fresh water); and
- high input of nutrients from anthropogenic or other sources.

Box 3 — Have water body risk factors been assessed? Identification of risk factors will alert the policing authority to the possible risk of a phytoplankton bloom and to the fact that a monitoring program should be initiated.

Box 4 — Are there existing algal or cyanobacterial data? Existing data will allow assessment of the possible risk of harmful algal blooms and will help in the development and implementation of a monitoring program. The more data the better to make the assessment of the risk as accurate as possible.

Box 5 — Can you collect algal or cyanobacterial data? If such data is required, a sampling program should be established.

Box 6 — Grading and monitoring — collected information and data should be assessed and a monitoring protocol should be developed if a need is identified.

Box 7 — Reassess on a 5 yearly basis or sooner if significant change occurs. This applies to all three grades. Examples of significant change would be:

- altered land use;
- significantly higher or lower algae/cyanobacteria levels;
- major infrastructure works affecting water quality parameters (eg new coastal developments, new sources of effluent or stormwater inputs); and
- changes in environmental conditions.

6.5.2 Monitored water bodies: surveillance, alert and action modes

This section should be read in conjunction with Section 2.6.3 on the design and implementation of monitoring programs for cyanobacterial and algal hazards.

The decision tree shown in Figure 6.1 allows for a staged response to the presence of cyanobacteria in recreational waters, as it links the results from the monitoring program with associated actions in three stages linked to the different alert levels. The alert levels signal the potential for hazard and appropriate actions, such as additional sampling and eventual warnings to users when the guideline is exceeded. The rationale for choosing each level is discussed below. Table 6.6 below lists recommended monitoring and management actions at each alert level.

Table 6.6 Recommended actions at different alert levels

Level	Recommended actions
Surveillance mode (green level)	Regular monitoring: - Weekly sampling and cell counts at representative locations in the water body where known toxigenic species are present (ie <i>Microcystis aeruginosa</i>, <i>Anabaena circinalis</i>, <i>Cylindrospermopsis raciborskii</i>, <i>Aphanizomenon ovalisporum</i>, <i>Nodularia spumigena</i>); or - Fortnightly for other types including regular visual inspection of water surface for scums.
Alert mode (amber level)	- Notify agencies as appropriate. - Increase sampling frequency to twice weekly at representative locations in the water body where toxigenic species (above) are dominant within the alert level definition (ie total biovolume) to establish population growth and spatial variability in the water body. - Monitor weekly or fortnightly where other types are dominant. - Make regular visual inspections of water surface for scums. - Decide on requirement for toxicity assessment or toxin monitoring.
Action mode (red level)	- Continue monitoring as for alert mode. - Immediately notify health authorities for advice on health risk. - Make toxicity assessment or toxin measurement of water if this has not already been done. - Health authorities warn of risk to public health (ie the authorities make a health risk assessment considering toxin monitoring data, sample type and variability).

Surveillance mode — green level

Green level (surveillance mode) is triggered when cyanobacteria are first detected at low levels in water samples, signalling the early stages of possible bloom development. The indicative cell numbers for *Microcystis aeruginosa* ($\geq 500 - < 5000$ cells/mL) and the biovolume equivalent of $\geq 0.04 - < 0.4$ mm³/L for the combined total of all cyanobacteria are somewhat arbitrary. A cell count of 500 cells/mL is the approximate detection limit for cyanobacteria.

There are some important points to note in relation to sampling and cell counts for these level definitions. Firstly the cell numbers that define the levels apply to samples of the recommended type (ie composite 50 cm hose-pipes) that are taken at a representative location(s) in the water body (ie the likely or designated recreational areas).

In relation to cell counts the actual or real value for the cell concentration in the 500 to 5000 cells/mL range can vary from the measured value. This is due to inherent errors in the cell counting methods. There is a likely minimum precision of $\pm 50\%$ for counting colonial cyanobacteria such as *Microcystis aeruginosa* at such low cell densities. For counting filamentous cyanobacteria such as *Anabaena circinalis* the precision is likely to be better at these cell densities ($\sim \pm 20\%$). Also the biovolume equivalents given in the level definitions are calculated using the equivalent cell numbers of *Microcystis aeruginosa*⁸.

⁸ The biovolume is based upon a single cell of *Microcystis aeruginosa* with a volume of 87 μm^3 .
Therefore 5000 cells/mL $\times 87 \mu\text{m}^3 = 4.35 \times 10^5 \mu\text{m}^3/\text{mL} \div 1 \times 10^9 = 4.35 \times 10^{-4} \text{ mm}^3/\text{mL} \times 1000 = 0.435 \text{ mm}^3/\text{L}$.
This is rounded to a biovolume of 0.4 mm³/L.

Sampling and cell counts should be undertaken weekly at representative locations in the water body where the known toxigenic species (ie *Microcystis aeruginosa*, *Anabaena circinalis*, *Cylindrospermopsis raciborskii*, *Aphanizomenon ovalisporum*, or *Nodularia spumigena*) are present. Fortnightly sampling frequency may be appropriate for surveillance mode where other types are present and the risk is perceived to be lower. A single site that is representative of the recreational area may be acceptable but multiple sites are warranted if the area is large.

Cyanobacteria can still form surface scums at low population densities and it is good practice for the managers to visually inspect waters regularly under calm conditions even though the risk is low.

Alert mode — amber level

Amber level (alert mode) is triggered when cell counts in representative samples are >5000 cells/mL for *Microcystis aeruginosa* or a biovolume equivalent of ≥ 0.4 - < 4 mm³/L for the combined total of all cyanobacteria *where a known toxin producer is dominant in the total biovolume*. There is also a second definition for Amber level to consider cyanobacterial hazard where known toxin producers are not present. In this case the Amber level biovolume range is ≥ 0.4 - < 10 mm³/L for the combined total of all cyanobacteria. This accommodates the transition to the Level 2 guideline (ie ≥ 10 mm³/L biovolume, see action mode) The definition of 'dominant' is where the type or species of interest (ie known toxin producer) comprises 75% or more of the total biovolume.

This level indicates an established cyanobacterial population, with the potential for localised high numbers that could pose a potential hazard. Cell numbers greater than 5000 cells/mL have been identified as a level at which skin irritation (Pilotto *et al* 2004) and other health problems (Pilotto *et al* 1997) can occur in a small percentage of the population.

The Amber level requires notification and consultation with health authorities and other agencies for ongoing assessment of the status of the bloom. This consultation should start as early as possible and continue after the results of toxicity testing or toxin analysis become available. The requirement for information on toxicity will depend on advice and discussion with health authorities, and on circumstances such as whether the cyanobacteria are known toxigenic species or whether there is a past history of toxicity.

In alert mode it is recommended that sampling frequency should be increased to twice weekly where the known toxigenic species is dominant in the total cyanobacterial biovolume, however only up to the biovolume of 4 mm³/L. Note that when biovolume exceeds 4 mm³/L with dominance by toxigenic cyanobacteria the level increases to the action mode-red level. The recommendation to increase sampling frequency to twice weekly depends to some extent upon the sensitivity and usage of the area. For example, twice-weekly sampling may be justified where there is a pressing need to issue advice for ongoing use if the site is being used heavily by recreational users, or a special event is coming up. In most circumstances weekly sampling provides sufficient information to assess the rate of change of algal populations, and to judge the population growth rate and spatial variability and therefore the hazard.

The bloom population should be sampled to establish the extent of its spread and spatial variability. Multiple sites should be sampled at representative locations in the water body. The number of samples depends on factors such as the size of the water body and the degree of use of different recreational sites. Where toxicity testing or toxin analysis is required, it is advisable to collect special samples by sampling concentrated scums or taking grab samples in parts of the site that are most likely to contain cyanobacteria.

Action mode — red level

Red level (action mode) is defined by exceedance of the NHMRC guideline for cyanobacteria in freshwater defined in section 6.4.1 (see Table 6.2). This is the two level guideline triggered when representative samples exceed either:

Level 1 guideline: the toxin level of $\geq 10 \mu\text{g/L}$ total microcystins, $\geq 50\,000$ cells/mL of *Microcystis aeruginosa*, or a biovolume equivalent of $\geq 4 \text{ mm}^3/\text{L}$ for the combined total of all cyanobacteria where a known toxin producer is dominant in the total biovolume

or

Level 2 guideline: $\geq 10 \text{ mm}^3/\text{L}$ for total biovolume of all cyanobacterial material where known toxins are not present

or

Cyanobacterial scums are consistently present.

In action mode the local authority and health authorities warn the public of the existence of potential health risks; for example, through the media and the erection of signs by the local authority.

To reiterate the definition of the potential health risks the Level 1 guideline is developed to protect against short-term health effects of exposure to cyanobacterial toxins ingested during recreational activity, whereas the Level 2 guideline applies to the circumstance where there is a probability of increased likelihood of non-specific adverse health outcomes, principally respiratory, irritation and allergy symptoms, from exposure to very high cell densities of cyanobacterial material irrespective of the presence of toxicity or known toxins.

In practical terms the biovolume definition component of the Level 1 guideline (ie total cyanobacterial biovolume of known toxigenic cyanobacteria $\geq 4 \text{ mm}^3/\text{L}$) may be used to initially trigger the action mode (red level) before toxicity or toxin analysis is available. If this is the case and the subsequent toxin analysis is negative, the mode may revert to alert mode (amber level) in the biovolume range $\geq 0.4 - < 10 \text{ mm}^3/\text{L}$. If cell numbers continue to increase, the Level 2 guideline definition applies if either the total biovolume of all cyanobacterial material exceeds $10 \text{ mm}^3/\text{L}$ or cyanobacterial scums are consistently present.

As indicated in Section 6.4.1, the Level 2 guideline is applied in circumstances where toxicity testing and toxin monitoring has been carried out and the dominant cyanobacterium is identified as being 'nontoxic' — that is, where the population has been tested and shown not to contain known toxins (microcystin, nodularin, cylindrospermopsin or saxitoxins). In action mode, the monitoring of the bloom should continue as for alert mode to determine when the bloom is in decline so that normal recreational use can resume.

Changes in alert levels over time

It is recommended that the alert mode not be changed from a higher to a lower level (eg from red to amber) until two successive lower results from representative samples have been recorded. Toxicity testing is usually only warranted at 7–10 day intervals or less often. Experience suggests that the toxicity of a cyanobacterial population can change, but it is unlikely to become completely nontoxic or to decline in a period of a few days.

The sequence during the alert mode (amber level) follows through to deactivation of an emergency with media releases to confirm this. It is possible that the collapse of a bloom or other control measures could lead to a rapid decline from alert mode to surveillance mode. Similarly, a rapid escalation from the surveillance mode to the alert and action modes is possible. Therefore, adequate monitoring and early warning information is important.

6.6 SAMPLING

In any sampling program it is important that the cyanobacterial cell counts measured are representative of the whole area. The *National Protocol for Monitoring of Cyanobacteria and their Toxins in Surface Waters* (NRMMC 2007, in review) provides a detailed procedure for sampling of cyanobacteria for various types of study (eg drinking waters, recreational waters, ecological studies). The protocol also provides information on estimating cyanobacterial abundance and detecting and quantifying cyanotoxins.

Under the protocol, the monitoring class for recreational waters is defined as ‘public health surveillance of recreational water bodies and nonpotable domestic supplies’. The sample-collection and sample-handling process for this group is divided into the following categories:

- access point for sample collection;
- method used to collect a sample;
- number of samples collected at any one time; and
- frequency of sampling.

Access points for sample collection can include open water by boat, shoreline and bridge or weir. The national protocol gives examples of sampling sites.

The recommended sampling method for recreational water assessment for cyanobacteria is to collect a single composite or pooled sample to determine the cell density for each defined recreational site (eg beach entry point, paddling area). This composite sample comprises five 50-cm depth-integrated column (hosepipe) subsamples collected relatively randomly along an approximately 20–30 m transect and mixed into a single container (eg a bucket), from which the composite sample is then taken for the cell count. The rationale for this sample type is that the 50-cm integrated column or tube covers the surface exposure zone for the hazard of ingestion while swimming or paddling. The sampling of this shallow 0–50 cm zone also covers the accumulation of some buoyant cyanobacteria near the surface under calm conditions. The recommendation for five pooled subsamples accounts for spatial variability within a single site.

The definitions used in the alert levels framework are intended to be based on cell counts from these composite 50-cm integrated-depth samples. Where wading or boat access is not available, it is also possible to collect a pooled surface-grab (ie dipped-bucket samples) with little loss of information.

Additional individual, noncomposite samples may also be collected where scums or obvious discoloured water are encountered. These individual ‘grab’ samples represent the maximum hazard at the time of inspection and may assist in the overall health risk assessment.

Integrated samples can be collected using a flexible or rigid plastic hosepipe (instructions are given in the NRMMC National Protocol). The inner diameter of the pipe should be at least 2.5 cm; a rigid polyvinylchloride (PVC) or acrylic plastic pipe is probably more practical than a flexible pipe.

It may be necessary to collect special concentrated samples for toxin analysis or toxicity screening. This is because a normal hosepipe may contain insufficient cell material to allow extraction of toxins. Samples for qualitative toxin analysis can be collected from dense accumulations of scum along shorelines or by using a phytoplankton net to concentrate dispersed cells.

The number and frequency of samples collected at any one time are dictated by the alert level framework (Table 6.6). Time and financial considerations will also influence the number of samples collected. The NRMMC National Protocol also gives advice on transport and storage of samples, physical and chemical indicators that can be used to identify areas that may be at risk of cyanobacterial blooms, the keeping of field data records, staff training and quality control.

Caveats

Compliance with the guidelines does not guarantee that a water body is safe. Other problems, such as microbiological, chemical and physical quality, may pose a health risk. It is important that water managers use these guidelines judiciously and consider carefully how the guidelines can best be applied.

6.7 MANAGEMENT

Providing adequate information to the public on the cyanobacterial risk associated with using a particular recreational water area is important. It allows the public to avoid the hazard and to understand symptoms potentially caused by exposure and identify their cause. Warnings to the public may be provided through local news media, by posting warning notices or by other means. Warnings may be supplemented with additional information on other recreational water-quality parameters regularly monitored by the authorities, and with further information on cyanobacteria.

Media releases and warning notices should differentiate between the degrees of water contact in different types of water sports. Information on the frequently transient nature and very variable local distribution of scums is important. Such information conveys the message that restrictions on recreational activities are only temporary and often only very local; it can also be used to inform the public of where acceptable water quality may be found nearby, for example at another site on the same lake.

The following advice should be considered for inclusion in information provided to the public.

- Avoid areas with visible cyanobacterial or algal concentrations or scums in the water or on shore. Direct contact with and swallowing of appreciable amounts pose the highest chances of a health risk.
- Where no scums are visible but the water shows strong greenish discolouration and turbidity, it may also be advisable to avoid bathing.
- Where scums and discoloured water are both present avoid waterskiing because of the potential for substantial exposure to sprays containing algae and cyanobacteria.

- Wetsuits for water sports may result in a greater risk of rashes, because cyanobacterial or algal material in the water trapped inside the wetsuit will be in contact with the skin for long periods.
- Sailing and sailboarding may involve swallowing considerable amounts of water, particularly for beginners or in stormy weather.
- After coming ashore shower or wash yourself down to remove any cyanobacterial or algal material.
- Wash and dry all clothing and equipment with clean water after any contact with cyanobacterial or algal blooms and scum.
- If you experience any health effects, whatever the nature of your exposure, seek medical advice promptly and inform the public authorities responsible for the site.

7 CYANOBACTERIA AND ALGAE IN COASTAL AND ESTUARINE WATER

7.1 OVERVIEW

Chapter 6 provides background information on algae and cyanobacteria.

Guidelines

Coastal and estuarine recreational water bodies should not contain:

- ≥ 10 cells/mL *Karenia brevis* and/or have *Lyngbya majuscula* and/or *Pfiesteria* present in high numbers
-

In coastal and estuarine waters, algae range from single-celled forms to the seaweeds that form a common and naturally occurring component of most marine and estuarine ecosystems. Algal blooms in the sea are a natural phenomenon and have occurred throughout recorded history but over recent decades their frequency, intensity and geographic distribution appear to have increased (Smayda 1989a, Hallegraeff 1993). They have become a recurring phenomenon in several areas including the Baltic and North Seas, the Adriatic Sea, Japanese coastal waters and the Gulf of Mexico. This increased occurrence has been accompanied by nutrient enrichment of coastal waters on a global scale (Smayda 1989b).

Four explanations for this increase have been suggested:

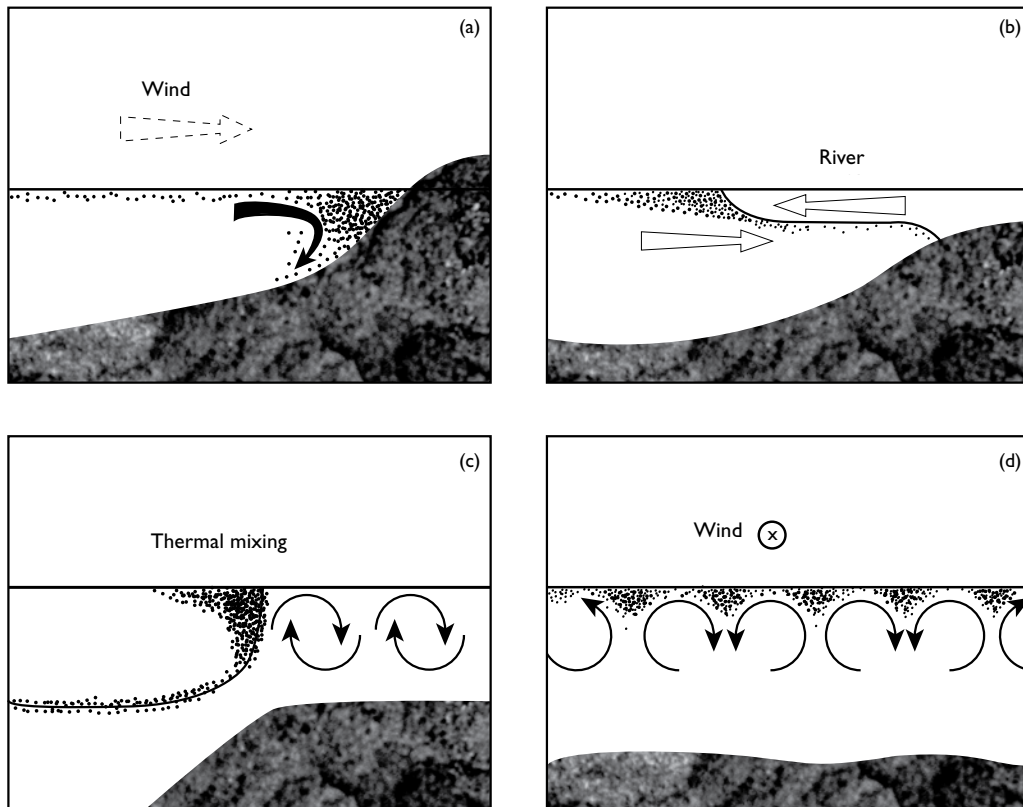
- increased scientific awareness of toxic species;
- increased use of coastal waters for aquaculture;
- stimulation of plankton blooms by cultural eutrophication and/or unusual climatological conditions; and
- transport of resting dinoflagellate cysts, either in ships' ballast water or with shellfish stocks moved from one area to another (Hallegraeff 1993).

Factors associated with the formation of harmful algal and cyanobacterial blooms in marine and estuarine waters include:

- history of hazardous algal blooms;
- environmental conditions conducive to bloom formation;
- high input of nutrients from anthropogenic or other sources; and
- introduction of exotic species into waterways via ballast water containing algae, cysts or spores that can remain dormant but viable in sediments for long periods.

Formation of high concentrations of marine algae and cyanobacteria is a natural phenomenon caused by various environmental conditions. Taylor (1987) describes various situations in which low concentrations of dinoflagellates (eg *Pfiesteria*, *Karenia*) can be transformed into blooms through horizontal aggregation (Figure 7.1b) rather than through local growth. Furthermore, blooms can be transported from the area of origin into other areas by currents.

Figure 7.1 Formation of algal blooms or accumulations of cells by physical concentration mechanisms



- (a) An onshore wind with downwelling
- (b) Aggregation at the boundary of a river, or other low-density flow, the more dense water containing the dinoflagellate
- (c) Aggregation at the boundary between stratified (left) and mixed water, such as that found at the edge of a shelf region with strong tidal mixing (similar conditions may occur between sheltered, stratified and open, turbulent coastal waters)
- (d) 'Langmuir cells' produced by wind (perpendicular to the page) of moderate strength, with buoyant or upwardly migrating cells aggregated at the convergences (there is spiral downwind transport within rotating Langmuir cells).

Source: Taylor (1987)

The processes influencing bloom formation of cyanobacteria such as *Nodularia spumigena* are slightly different from those influencing dinoflagellate blooms. For example, the filamentous cyanobacterium *Lyngbya majuscula* grows on the bottom in mats and concentrates at the surface of a water body through the accumulation of gas bubbles, which cause the mats to rise to the surface. These mats can then concentrate further through wind and wave action moving them onto the shore. Appendix 1 describes in detail how cyanobacteria can concentrate to high levels.

Another important influence on marine phytoplankton growth is eutrophication of coastal areas with nitrogen and phosphorus, which can lead to increased local production of algae and an increased risk of algae blooms as a result. Local kills of benthic organisms caused by oxygen deficiency or toxic algae may facilitate algal blooms by suppressing grazing of algae (Anderson 1996).

Although formation of a bloom has been identified as a health risk, some algal species (eg *Karenia brevis*) may pose a problem even at relatively low numbers.

7.2 HEALTH EFFECTS

Marine algal toxins become a problem primarily because they bioaccumulate in shellfish and fish that are subsequently eaten by humans. Several human diseases have been reported in association with many toxic species of dinoflagellates, diatoms, nanoflagellates and cyanobacteria that occur in the marine environment; these diseases are summarised in Table 7.1.

These guidelines, however, are concerned only with risks that may be associated with recreational activities in or near coastal and estuarine waters. This includes exposure through dermal contact, inhalation of sea-spray aerosols and possible ingestion of water or algal scums, but does not include dietary exposure to marine algal toxins.

The effects of these algae on humans are due to some of their constituents, principally algal toxins. The algae and cyanobacteria that cause problems for human health can be divided into two categories according to the pathway of exposure by which the adverse health outcomes occur:

- organisms causing adverse effects through dermal contact and inhalation; and
- organisms causing adverse effects through ingestion.

The characteristics, occurrence and health effects of these two categories of algae and cyanobacteria are discussed below (Sections 7.3.1 and 7.3.2 respectively).

Table 7.1 Toxic syndromes associated with marine algal toxins affecting humans

Syndrome	Causative organisms	Primary vector	Toxin	Pharmacologic target	Reference
Paralytic shellfish poisoning	<i>Alexandrium</i> sp <i>Gymnodinium</i> sp <i>Pyrodinium</i> sp <i>Karenia</i> sp	Shellfish	Saxitoxins	Binds to site 1 on the voltage-dependent sodium channel, affecting the nervous system.	Andrinolo <i>et al</i> 2002 Azanza <i>et al</i> 2001 Yoshida <i>et al</i> 2000 Compagnon <i>et al</i> 1998
Neurotoxic shellfish poisoning	<i>Karenia</i> sp <i>Gymnodinium</i> sp	Shellfish, aerosol	Brevetoxins	Binds to site 5 on the voltage-dependent sodium channel, affecting the nervous system. Aerosol linked to respiratory problems.	Chang <i>et al</i> 2001 Poli <i>et al</i> 1986 Trainer <i>et al</i> 1994 Dechraoui <i>et al</i> 1999
Ciguatera fish poisoning	<i>Gambierdiscus</i> sp	Reef fish	Ciguatoxins	Binds to site 5 on the voltage-dependent sodium channel, affecting the nervous system.	Lehane 2000, Holmes 1998, Lewis 2001 Dechraoui <i>et al</i> 1999 Hokama and Yoshikawa-Ebesu 2001
Amnesic shellfish poisoning	<i>Pseudo-nitzschia</i> sp	Shellfish	Domoic acid	Binds to subtypes of the glutamate receptor, resulting in both gastrointestinal and neurologic effects.	Mos 2001 Amzil <i>et al</i> 2001 Bates 2000

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Syndrome	Causative organisms	Primary vector	Toxin	Pharmacologic target	Reference
Diarrhoeic shellfish poisoning	<i>Dinophysis</i> spp <i>Prorocentrum</i> sp	Shellfish	Dinophysistoxins Okadaic acid	Inhibit <i>ser/thr</i> protein phosphatases 1, 2A and at high concentrations 2B, resulting in diarrhoea, impaired balance and loss of fluids. Tumour promoters	Ten-Hage <i>et al</i> 2000 Dahl and Johannessen 2001 Bravo <i>et al</i> 2001 Burgess and Shaw 2001 Marasigan <i>et al</i> 2001
Hepatotoxicity	<i>Nodularia spumigena</i>	Water	Nodularin	Inhibition of protein phosphatases 1 and 2A, breakdown of hepatic structure liver function with liver failure at high levels. Long-term exposure could promote liver cancer.	Kuiper-Goodman <i>et al</i> 1999
Estuary syndrome	<i>Pfiesteria</i> sp	Water	Unknown	Unknown target. Causes memory loss, confusion and respiratory, skin and gastrointestinal problems.	Morris 2001 Samet <i>et al</i> 2001
Swimmers itch — skin irritation	<i>Lyngbya majuscula</i> ^a <i>Oscillatoria nigroviridis</i> ^a <i>Schizothrix calcicola</i> ^a	Water	Debromoaplysiatoxin Lyngbyatoxin A	Protein kinase C. Causes dermatitis. Unknown target Unknown target	Hashimoto <i>et al</i> 1976 Osborne <i>et al</i> 2001 Mynderse <i>et al</i> 1977
Skin irritation	<i>Trichodesmium</i> spp <i>Heterosigma akashiwo</i>	Water	Unknown	Unknown target causing dermatitis.	WHO 2003

^a *Lyngbya majuscula* is known to produce debromoaplysiatoxin and lyngbyatoxin A, and *Oscillatoria nigroviridis* and *Schizothrix calcicola* are known to produce debromoaplysiatoxin.

7.3 OCCURRENCE, EXPOSURE AND EFFECTS

7.3.1 Organisms causing adverse effects through dermal contact or inhalation

Lyngbya majuscula

Lyngbya majuscula is a toxic marine cyanobacterium found mainly in tropical waters. Outbreaks have been reported from Japan, Hawaii and Australia (Grauer and Arnold 1961, Hashimoto *et al* 1976, WHO 1984, Yasumoto and Murata 1993, Dennison *et al* 1999). In Australia, large blooms have recently been reported in Moreton Bay near Brisbane in Queensland (Dennison *et al* 1999).

Lyngbya majuscula has been shown to produce more than 70 biologically active compounds, many of which have been shown to be toxic and which include debromoaplysiatoxin and lyngbyatoxin (Osborne *et al* 2001). These toxins are highly inflammatory and are potent promoters of skin tumours, using mechanisms similar to phorbol esters through the activation of protein kinase C (Gorham and Carmichael 1988, Fujiki *et al* 1990).

Osborne *et al* (2001) described cases of eye and respiratory irritations reported by people:

- walking on the beach at Okinawa, Japan where *L. majuscula* was present in the water;
- driving on the beach covered by *L. majuscula* on Fraser Island, Australia; and
- cleaning fishing nets and crab pots in Moreton Bay, Australia and in Hawaii.

Severe blistering may also result if *L. majuscula* is trapped under the clothing of swimmers.

The Queensland Environmental Protection Agency has identified *L. majuscula* growing attached to seagrass, seaweed, and rocks in clumps or mats of fine, dark cotton wool like strands 10 to 30 cm long. Mats of *L. majuscula* can accumulate gas bubbles and rise to the surface to form large floating mats, and these can wash up on beaches, often mixed with seagrass.

In view of its potential to cause severe irritation people should avoid areas affected by *L. majuscula* if possible. People should also avoid direct contact with material washed up onto the beach. This includes swimming or wading in areas where *L. majuscula* is growing or floating in the water. Where *L. majuscula* has washed onto beaches it should be cleared immediately by local councils. In these circumstances it is important to take precautions to minimise contact with *Lyngbya* during collection, transit and disposal operations. It is further recommended that people with any of the symptoms listed above, who have been in an area affected by the algae, should consult a doctor.

Pfiesteria piscicida

Pfiesteria piscicida was discovered inadvertently when cultured *Tilapia* fish died after exposure to water collected from the Pamlico River in North Carolina in the late 1980s. The organism was first identified in the wild from water of the Albemarle–Pamlico estuary in 1991 (Fleming *et al* 1999). In its May 2002 newsletter, the Australian Research Network for Algal Toxins reported that *Pfiesteria* had been identified in Tasmania and Queensland. However, this occurrence was believed to be *P. shumwayae*. The current occurrence of *Pfiesteria spp* is believed to be rare and at low concentrations and therefore does not pose a risk to humans or fish. However, caution is required if these organisms are identified in a marine or estuarine area.

Samet *et al* (2001) and Swinker *et al* (2002) in their reviews of *Pfiesteria*, described the symptoms reported by people exposed to *P. piscicida*, including dizziness, eye irritation and headache. Gastrointestinal complaints of diarrhoea and abdominal pain were common, as were respiratory complaints of wheezing, coughing and shortness of breath. Dermatological symptoms were also frequent. Complaints of cognitive deficits were described, including memory impairments that developed within hours after exposure. The cognitive deficits and memory impairments have been reported to subside spontaneously in some cases but were aggravated by strenuous exercise in others. At the time of writing, dose–response relationships for cell material or active components and any of these symptoms have not been established.

The biology and toxicology of this organism remain a topic of debate and research (Swinker *et al* 2002). Samet *et al* (2001) identify the following knowledge gaps for human exposure to *Pfiesteria*:

- very limited understanding of *Pfiesteria* toxin, which has not yet been isolated, and the action mechanism which has not been identified;
- incomplete description of the effects of exposure on humans; and
- lack of knowledge of the nature and extent of exposure that puts people at risk.

Karenia brevis

Inhalation of sea-spray aerosol containing fragments of the marine dinoflagellate *Karenia brevis* (also known as *Gymnodinium breve* and *Ptychodiscus brevis*) has been associated with severe irritation of conjunctiva and mucous membranes (particularly of the nose), followed by persistent coughing and sneezing and tingling of the lips (Baden *et al* 1984, Scoging 1991, Backer *et al* 2002, Baden *et al* 2002). The sea-spray aerosol contains cells, fragments of cells and/or toxins (brevetoxins) released into the surf from the lysed algae. The asthma-like effects are not usually observed more than a few kilometres inland (Pierce 1986).

Brevetoxins, which are produced by *K. brevis*, can accumulate in seafood and cause neurotoxic shellfish poisoning (Steidinger 1993). These toxins can also kill fish, invertebrates and seabirds, and possibly lead to mortalities in manatees and dolphins (Abbott *et al* 1975, Forrester *et al* 1977, O'Shea *et al* 1991).

For many years *K. brevis* blooms were only reported from the southeast United States and eastern Mexico (Steidinger 1993). In 1993, neurotoxic shellfish poisoning was detected in New Zealand (Fernandez and Cembella 1995); in the summer of 1998 massive fish kills and human respiratory illnesses along the east coast of the North Island were attributed to blooms of the organism (Chang *et al* 2001).

Table 7.2 identifies the possible health risks of different levels of *K. brevis*. The levels are based on levels used when closing shellfish harvesting (5 cells/mL) and also on anecdotal evidence of respiratory irritation because epidemiological and toxicological evidence are lacking.

Table 7.2 Possible health risks at different levels of *Karenia brevis*

Key for results	<i>Karenia brevis</i> cells/mL	Possible effects
Present	Normal levels of 1 cell or less	None
Very low	> 1–< 5	Possible respiratory irritation
Low	5–10	Possible respiratory irritation and shellfish harvesting closure
Medium	> 10–< 100	Respiratory irritation and possible fish kills
High	100–< 1000	Respiratory irritation and probable fish kills
Very high	> 1000	As above plus discolouration of water

Source: Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, 100 Eighth Avenue SE, St. Petersburg, Florida, USA (http://research.myfwc.com/features/view_article.asp?id=12373)

Trichodesmium spp

The marine cyanobacteria *Trichodesmium spp* are found worldwide in surface waters of tropical and subtropical oceans and are well known to form blooms around the tropical Australian coast from Western Australia to Queensland (A. Negri, Australian Institute of Marine Science, pers comm, July 2004). The blooms of *Trichodesmium* can look like oil slicks or foamy pollution and vary in colour from red, pink, green to brown, and even to white when in decay. They have historically been known to sailors as 'sea sawdust' and were first described in Australian waters by Captain Cook in the 1700s.

The health significance of *Trichodesmium* is unclear, although some strains have been reported to cause skin irritation in swimmers (WHO 2003). In addition, *T. thiebautii* contains a type of neurotoxin (Codd 1994) and has been reported to cause respiratory difficulties ('*Trichodesmium fever*', Sato *et al* 1963).

Given that *Trichodesmium spp* form such common and occasionally extensive blooms in coastal waters and also have potential to cause irritation, it is recommended that if possible people avoid areas that are visibly affected. This includes avoiding swimming or wading in areas where *Trichodesmium* is visible in the water and avoiding direct contact with material washed up onto the beach.

7.3.2 Organisms causing adverse effects through ingestion of water or scum

Nodularia spumigena

Nodularia spumigena, the first cyanobacterium recognised to cause animal deaths (Francis 1878) can be a problem in both freshwater and estuarine environments. Chapter 6 (Section 6.1) discusses *N. spumigena* and guidelines that apply to it in recreational waters.

Other organisms

There have been no records of, or other information on, adverse health effects from either ingestion or contact, during bathing or recreation, with marine waters containing the algal species that produce the toxins causing paralytic shellfish poisoning, neurotoxic shellfish poisoning, amnesic shellfish poisoning and diarrhoeal shellfish poisoning (as listed in Table 7.1).

7.4 GUIDELINES FOR COASTAL AND ESTUARINE WATERS

These guidelines use a risk assessment of the surface waters to determine their suitability for recreational use (Figure 7.2). The assessment combines recreational water environment grading based on long-term analysis of data with a water body assessment.

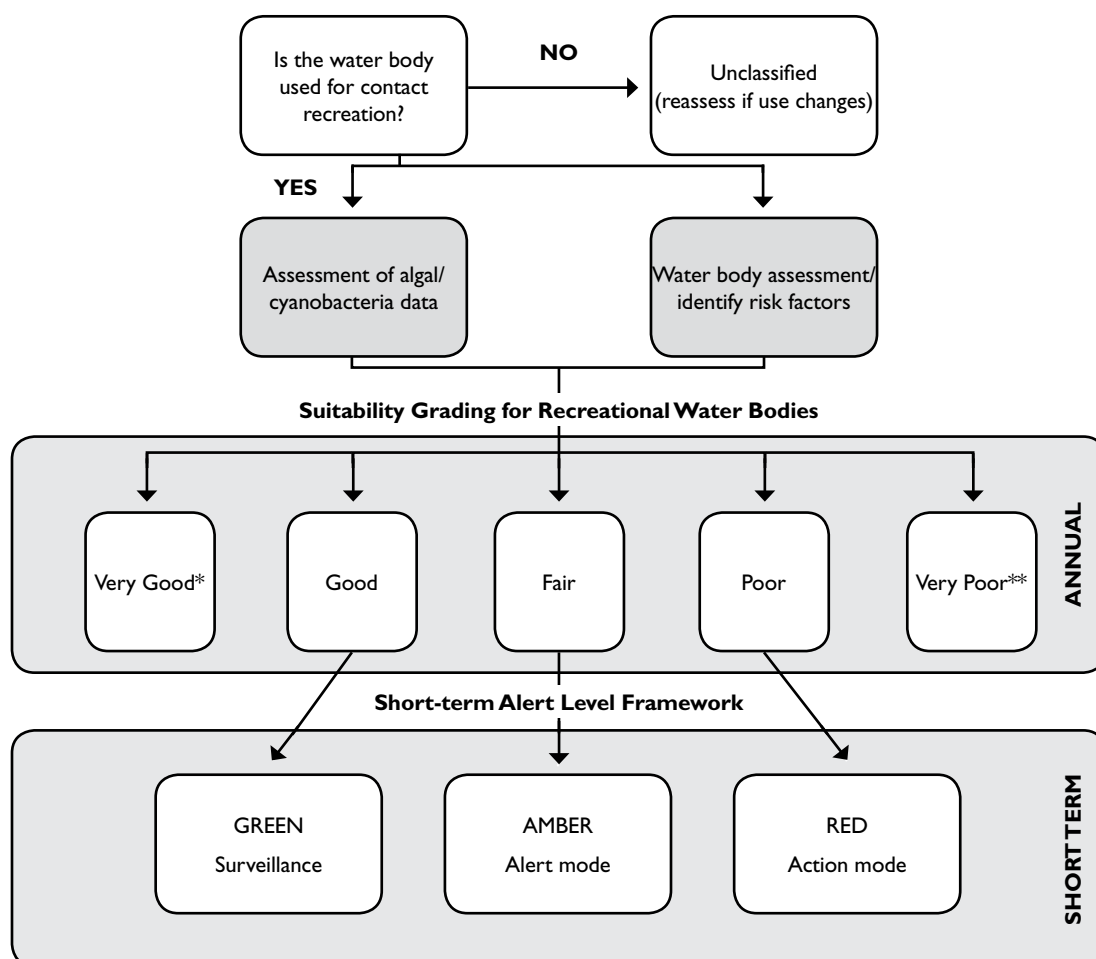
The grading gives an indication of the general condition of the recreational water body. Those rated 'very good' will almost always comply with the guideline values for recreation, whereas water bodies graded as 'very poor' rarely pass the guidelines, and their use for recreational activities is not recommended. For the remaining gradings ('good', 'fair' and 'poor') it is recommended that a monitoring program be introduced.

The monitoring program is based on a three tier system:

- **Surveillance mode (green level)** — this level involves routine sampling to measure contaminants (eg physical, microbial, cyanobacterial and algal).
- **Alert mode (amber level)** — requiring investigations into the causes of the elevated levels and increased sampling, which enables a more accurate assessment of the risks to recreational users.
- **Action mode (red level)** — requiring the local authority and health authorities to warn the public that the water body is considered to be unsuitable for primary and secondary recreational use.

The episodic and patchy nature of marine algal blooms makes them difficult to predict in terms of physical, chemical and biological properties of a water body. Prediction of algal blooms requires observations to identify links between marine algal distributions and changes in environmental factors. These factors include tides, freshwater outflows, wind and topography, all of which can influence mass accumulations of populations into blooms (Hallegraeff *et al* 1995). Observations range from visual detection of discoloured water and analysis of water samples to autonomous measurements from moorings and remote sensing. Autonomous measurements and remote sensing are beyond the scope of these guidelines, however, a detailed description of those techniques is available in Anderson *et al* (2001).

Figure 7.2 Framework for assessment of algal and cyanobacterial quality of coastal and estuarine recreational water



* No Alert required

** This water body should be closed for recreational purposes

Table 7.3 Interpretation of algal and cyanobacterial alert levels for coastal and estuarine recreational water

	Green level Surveillance mode	Amber level Alert mode	Red level Action mode
<i>Karenia brevis</i>	≤ 1 cell/mL	> 1 – < 10 cells/mL	≥ 10 cells/mL
<i>Lyngbya majuscula</i> <i>Pfiesteria spp</i>	History but no current presence of organism	Present in low numbers	Present in high numbers ^a
<i>Nodularia spumigena</i>	See Chapter 6 (Cyanobacteria and algae in fresh water) for detail		

^a For *Lyngbya majuscula* this involves the relatively widespread visible presence of dislodged algal filaments in the water and washed up onto the beach.

7.5 APPLICATION OF THE ALGAE AND CYANOBACTERIA GUIDELINES

The framework in these guidelines uses both water body grading and guideline values. Water body grades provide the basic means to assess safety status over time using knowledge of the water body and coastal and catchment characteristics, combined with information on algae and cyanobacteria gathered over previous years. Guideline values are used to help water managers determine when intervention is required.

Note that the cyanobacterium *Nodularia spumigena* occurs in freshwater and in estuarine environments. It is dealt with in detail in Chapter 6 (Cyanobacteria and algae in fresh water) but reference will be made to it below for continuity.

7.5.1 Grading a water body

There are two components to grading water bodies according to algal/cyanobacterial contamination:

- the susceptibility category (see Table 7.4), which generates a measure of the susceptibility of a water body to algal contamination; and
- historical cyanobacterial monitoring results, which generate an algal history category (see Table 7.5) — this is a measure of the concentrations that have occurred during typical prior incidences of algae and cyanobacteria.

The two are combined to give an overall suitability for recreational use, which describes the suitability of a site based on an assessment of risk and the category of algae and cyanobacteria counts. Of course, this is influenced by the combination of input data and it is appropriate to select data that are indicative of the peak of the recreational season where such data are available.

Table 7.4 Susceptibility to algal contamination

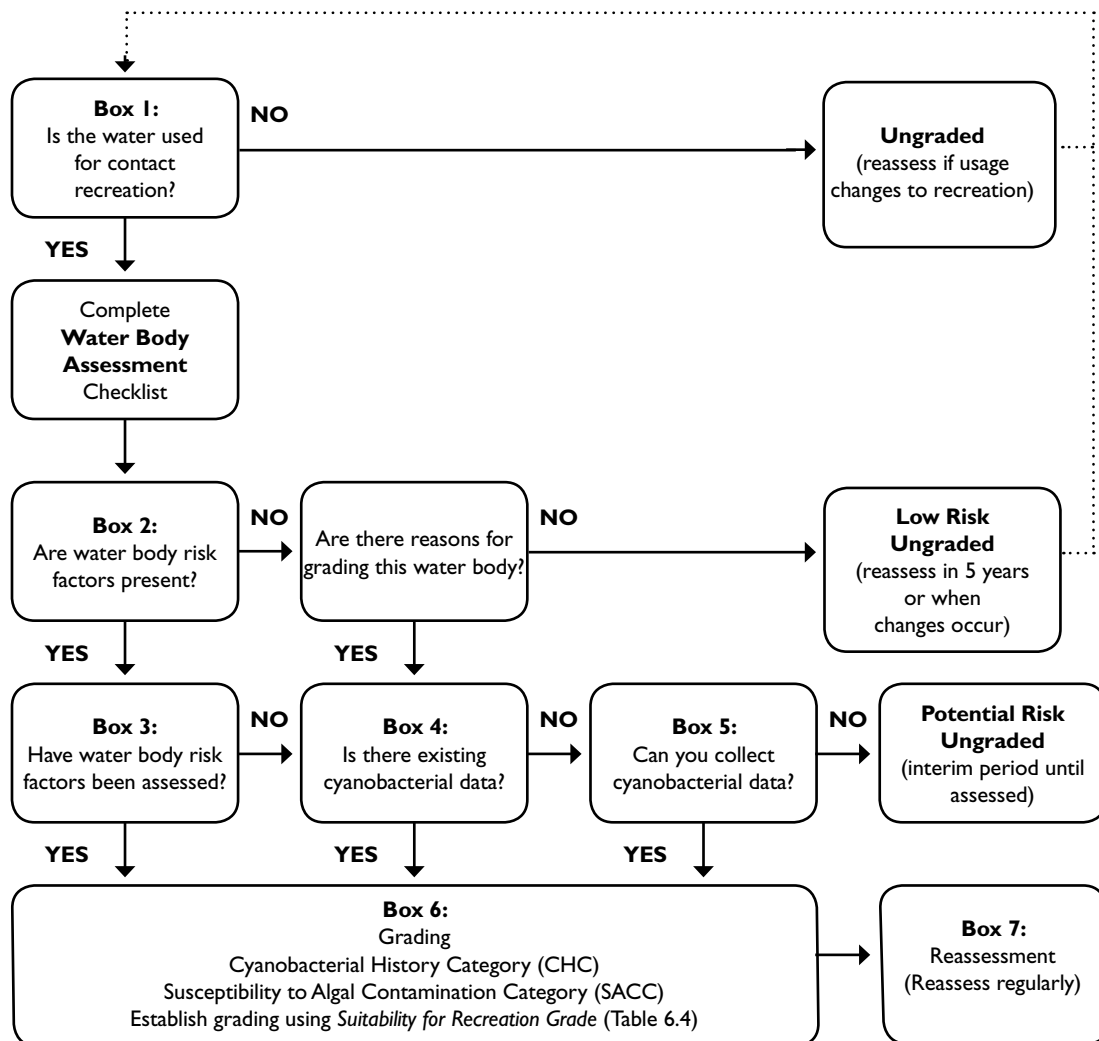
Water body inspection category	Environmental factors		
	History of algal or cyanobacterial blooms	Nutrient inputs: anthropogenic or other sources (eg upwelling)	Concentration or accumulation processes can occur
Low	No	No	No
Moderate	Yes	Low–moderate	Yes
High	Long history	High	Yes

Table 7.5 Suitability for recreation

	Algal species	Algal history category (AHC)			
		A	B	C	D
	<i>Karenia brevis</i>	0	1 cell/mL	> 1–10 cells/ mL	> 10 cells/mL
	<i>Nodularia spumigena</i>	See Chapter 6 (Cyanobacteria and algae in fresh water)			
	<i>Lyngbya majuscula</i> and <i>Pfiesteria spp</i>	Absent	History but no current presence of organism	Present in low biomass	Present in high biomass
Susceptibility to algal contamination category	High (good)	Very good	Good	Fair	Poor
	Moderate	Good	Fair	Poor	Very poor
	Low (poor)	Fair	Poor	Very poor	Very poor
Exceptional circumstances					

It is expected that, initially, this process will be applied to all water bodies that may be used for recreational activity. The decision tree to determine recreational water quality (Figure 7.3) outlines the process that leads to grading of a recreational water body. The grading should be established using the suitability for recreation shown in Table 7.5.

The purpose of the decision tree is to provide a logical course that allows the responsible authority to make defensible decisions on whether or not to grade a particular water body. Box 7.1 describes the process and the decisions required to complete each step.

Figure 7.3 Decision tree to determine recreational water quality

Box 7.1 Processes and decisions required to complete decision tree to determine recreational water quality

This process is outlined in Figure 7.3.

Box 1 — Is the water body used for contact recreation? This should be decided on a site specific basis by the local authorities, depending on the extent of use of the site.

Box 2 — Are water body risk factors present? The risk factors here refer to activities in the surrounding area and the water body itself, and to other environmental conditions that may result in increased algal levels. A 'yes' means that there are environmental conditions that could support the growth of phytoplankton to hazardous levels.

As much information about the site as is feasible should be collected to assess risk factors as completely as possible. Sources of information will vary from region to region. Gathering this information may involve consultation with a range of agencies (health, water and sewage authorities, local government and councils). These agencies may collect or have access to different information for the same water body. Relevant information includes drainage plans, site maps, water quality monitoring results (this could include physical, chemical and biological data) and catchment use.

Risk factors that may influence the formation of harmful algal blooms include:

- history of hazardous algal blooms — this may indicate the presence of a seed source, which can also be investigated by surveying locally for cysts or resting spores in sediments;
- environmental conditions conducive to bloom formation (stable weather patterns, inputs of fresh water); and
- high input of nutrients from anthropogenic or other sources.

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Box 3 — Have water body risk factors been assessed? Identification of risk factors will alert the managing authority to the possible risk of a phytoplankton bloom and that a monitoring program should be initiated.

Box 4 — Is there existing algal/cyanobacterial data? Existing data will allow assessment of the possible risk of harmful algal blooms and help in the development and implementation of a monitoring program. The more data available the better, as this makes the assessment of the risk as robust as possible.

Box 5 — Can you collect algal/cyanobacterial data? If algal/cyanobacterial data is required, a sampling program should be established as described in Hallegraeff *et al* (1995).

Box 6 — Grading and monitoring — To obtain a 'suitability for recreation', both the susceptibility category (see Table 7.4) and algal history category (see Table 7.5) must be determined. To find the appropriate grading for the recreational water body, locate the box in Table 7.4 that coincides with both the susceptibility category and the algal history category for the water body.

Box 7 — Reassess on a 5 yearly basis, or sooner if significant change occurs. Such changes will be reflected in new information identified in the water body assessment checklist. Examples of significant change would be:

- altered coastal or estuary catchment land use;
 - significantly higher or lower algae/cyanobacteria levels;
 - major infrastructure works affecting water quality parameters (eg new coastal developments, new sources of effluent or stormwater); and
 - changes in environmental conditions.
-

7.5.2 Monitored water bodies: surveillance, alert and action modes

The situation assessment and alert levels framework for the management of algae and cyanobacteria in recreational water bodies allows for a staged response to the presence and development of blooms.

The framework assesses the development of a bloom through a monitoring program, with actions in three stages linked to different alert levels. The levels use algal and cyanobacterial numbers as indicators to define the potential for hazard and to recommend appropriate actions, such as additional sampling and eventual warning of users should the guideline be exceeded. The health effects of individual species on which the alert levels are based are discussed in Section 7.2 above.

Surveillance mode — green level

In green level (surveillance mode) conditions the water body has the potential for phytoplankton growth and regular sampling and monitoring should be carried out.

Alert mode — amber level

The amber level (alert mode) is triggered when representative water samples exceed the trigger values or ranges for each species shown in Table 7.6.

At the amber level, the problem species and types are detected in moderate numbers. It is necessary to increase vigilance and expand monitoring to collect information for informed risk assessment. This may involve an increase in sampling frequency to twice weekly, but this will depend on resources and analytical capacity (for cell counts etc) and, importantly, on the sensitivity and usage of the recreational water area. For example, in a highly used area in peak season it may be important to make rapid judgments about local variability of a developing bloom and rates of change of the population, to inform and anticipate the decision-making process for issuing warnings. In most circumstances weekly sampling is adequate to capture rates of change in natural algal populations and inform management decisions.

Action mode — red level

The red level (action mode) is triggered when samples exceed the guideline values for each species, as shown in Table 7.6.

At red level, the local authority and health authorities warn the public through the media that the water body is unsuitable for recreation, and arrange for the local management authority to erect signs warning the public of the potential for adverse health effects.

Table 7.6 Surveillance, alert and action modes

Level	Recommended actions
Surveillance mode (green level)	Regular monitoring Weekly sampling and cell counts Regular visual inspection of water surface for visible discolouration or scums
Alert mode (amber level)	Notify agencies as appropriate Increase sampling frequency to twice weekly if warranted at representative locations to establish population growth and spatial variability in the waterbody ^a Decide on requirement for toxicity assessment or toxin monitoring
Action mode (red level)	Continue monitoring as for amber level Immediately notify health authorities for advice on health risk Carry out toxicity assessment or toxin measurement of water if not already performed Health authorities advise public of risk to health (ie authorities assess health risk by considering toxin monitoring data, sample type and variability)

- ^a The recommendation to increase sampling frequency to twice weekly depends on the sensitivity and usage of the area; for example whether there is a pressing need to issue advice for usage of a site if the site is being used heavily by recreational users. In most circumstances weekly sampling provides adequate information to assess the rate of change of algal populations and judge the population growth rate and spatial variability.

7.6 MANAGEMENT

Regional councils, local government authorities and health authorities may all be involved in the management of recreational water. Overlaps in responsibility can create uncertainty about agency responsibilities. The most important course of action is the implementation of a management program. This involves the identification of a possible risk area, followed by the implementation of a monitoring program. The management process can be divided into short-term and long-term measures, discussed below.

7.6.1 Short-term measures

Once an area has been identified as at risk from toxic phytoplankton blooms, it is appropriate to provide general practitioners and medical clinics with information about the health problems associated with blooms and the diagnosis and treatment of poisonings.

The evidence suggests that the risk to human health from toxic marine and estuarine phytoplankton during recreational activities is limited to a few species and geographical areas; and knowledge about exposure levels and health risks is limited. However, the local authority and health authorities should warn the public through the media that the water body is potentially unsafe, as identified by the alert levels framework, and arrange for the local authority to erect signs warning the public of a health danger. These authorities should also make the public aware of the following precautions which are recommended for individuals during any bloom.

- Avoid areas with visible algal concentrations or algal scums, in the sea as well as on the shore. Direct contact or swallowing appreciable amounts of such material pose the greatest health risk.
- While on the beach, avoid sitting downwind of any algal material drying on the shore that could form a dust or aerosol and be inhaled.
- Use of wetsuits for water sports may increase the risk of rashes, because algal material in the water trapped inside the wetsuit will be in contact with the skin for long periods.
- After coming ashore, shower or wash yourself down to remove any algal material.
- Wash and dry all clothing and equipment after any contact with algal blooms or scum.
- If you experience any health effects, whatever the nature of your exposure, you should seek prompt medical advice.
- Note that sailing and sailboarding may involve swallowing considerable amounts of water, particularly for beginners or in stormy weather.

7.6.2 Long-term measures

Algal blooms result from a complex interaction between hydrographic, meteorological, biological and chemical conditions, of which only a few can be controlled. Excessive input of nutrients from land and fresh water is one of the strongest factors promoting bloom development. Implementation and enforcement of comprehensive and integrated coastal management plans to control nutrient discharges at point sources (rivers, pipes and drains) and from diffuse sources will reduce the potential for algal growth and formation of blooms.

It is now well recognised that it is important to control and manage the transport of exotic toxic phytoplankton species via ship ballast water.

7.7 SAMPLING

Chapter 6 has detailed information on sampling for algae and cyanobacteria.

8 DANGEROUS AQUATIC ORGANISMS

Guideline

Direct contact with venomous or dangerous aquatic organisms should be avoided. Recreational water bodies should be reasonably free of venomous organisms (eg box jellyfish and bluebottles). Where risks associated with dangerous aquatic organisms are known, appropriate warning signs should be clearly displayed.

8.1 OVERVIEW

A wide range of potentially dangerous organisms are found in Australian recreational waters. Such organisms are generally of local or regional importance. The risk associated with them during recreational activity varies widely with the type of activity and when and where it takes place.

8.2 ASSESSMENT OF RISKS ASSOCIATED WITH DANGEROUS AQUATIC ORGANISMS

8.2.1 Types of injury

Injuries from encounters with dangerous aquatic organisms are generally sustained in one of the following ways (WHO 2003):

- accidentally brushing past a venomous sessile or floating organism when bathing (eg box jellyfish, bluebottle);
- inadvertently treading on a dangerous organism (eg stonefish);
- unnecessarily handling venomous organisms (eg blue-ringed octopus, cone shell) during seashore exploration;
- invading the territorial waters of large animals (eg shark, crocodile) when swimming or at the waterside;
- swimming in waters used as hunting grounds by large predators (eg shark);
- intentionally interfering with or provoking dangerous aquatic organisms; and
- being exposed to free-living microorganisms (eg the protozoan *Naegleria fowleri* in warm fresh waters).

8.2.2 Organisms known to pose a risk to health

Because of the wide variety of organisms that may be encountered this chapter summarises only those organisms known to have caused significant ill health, injury or death to recreational water users; these organisms are listed in Table 8.1.

Table 8.1 Dangerous aquatic organisms in Australian waters

Organism	Discomfort	Require further medical attention	May require emergency medical attention
Nonvenomous organisms			
Sharks			
White pointer (<i>Carcharodon carcharias</i>)		X	XX
Whaler sharks		X	XX
Tiger shark (<i>Galeocerdo cuvier</i>)		X	XX
Oceanic whitetip (<i>Carcharhinus longimanus</i>)		X	XX
Bull shark (<i>Carcharhinus leucas</i>)		X	XX
Hammerhead (<i>Sphyrna lewini</i>)		X	XX
Crocodiles			
Saltwater (<i>Crocodylus porosus</i>)		X	XX
Freshwater (<i>Crocodylus johnstoni</i>)		X	XX
Seals			
Elephant seal (<i>Mirounga leonina</i>)		X	XX
Sea lion (<i>Neophoca cinerea</i>)		X	XX
Leopard seal (<i>Hydrurga leptonyx</i>)		X	XX
Eels			
Moray eel (<i>Gymnothorax spp</i>)		X	
Conger eel (<i>Conger spp</i>)		X	
Venomous invertebrates			
Box jellyfish (<i>Chironex fleckeri</i>)		X	XX
Sea wasp (<i>Chironpsalmus quadrigatus</i>)		X	
Irukandji jellyfish (<i>Carukia barnesi</i>)		X	XX
Siphonophores			
Bluebottle (<i>Physalia utriculus</i>)	X	X	
Portuguese man-of-war (<i>Physalia physalis</i>)	X	X	XX
Hair jellyfish (<i>Cyanea</i>)	X	X	
Blubber jellyfish (<i>Catostylus</i>)	X	X	
Jimble (<i>Caryddea rastoni</i>)	X	X	
Blue-ringed octopus			
<i>Hapalochlaena maculosa</i> , in the south		X	XX
<i>Hapalochlaena lunulata</i> , in the north		X	XX
Cone shells (<i>Conus spp</i>)		X	XX
Crown-of-thorns starfish (<i>Acanthaster planci</i>)	X	X	
Bristle worms (<i>Polychaeta</i>)	X	X	
Fire coral (<i>Milleporidae</i>)	X		
Venomous vertebrates			
Stonefish (<i>Synanceia verrucosa</i>)		X	X(X)
Stingrays		X	XX
Catfish	X	X	
Bullrout (<i>Notesthes robusta</i>)	X	X	

Organism	Discomfort	Require further medical attention	May require emergency medical attention
Free-living microorganisms			
<i>Aeromonas hydrophila</i>		X	
<i>Mycobacterium marinum</i>		X	
<i>Naegleria fowleri</i>		X	XX
<i>Vibrio cholerae</i>		X	

XX = associated with fatalities

X(X) = probably associated with fatalities

Source: Adapted from WHO (2003)

The distribution, habitat and factors influencing contact with dangerous aquatic organisms are summarised in Table 8.2 (Nonvenomous organisms), Table 8.3 (Venomous invertebrates), Table 8.4 (Venomous vertebrates) and Table 8.5 (Free-living microorganisms).

Table 8.2 Distribution, habitat and factors influencing the risk of contact with nonvenomous organisms

Organisms	Distribution	Habitat	Risk prevalence	Greatest risk
Sharks: White pointer (<i>Carcharodon carcharias</i>) Tiger shark (<i>Galeocerdo cuvier</i>) Oceanic whitetip (<i>Carcharhinus longimanus</i>) Bull shark (<i>Carcharhinus leucas</i>) Hammerhead (<i>Sphyrna lewini</i>)	Tropical to temperate	Ocean, estuaries, reefs, rivers	Near-shore steep drop-offs Turbid waters Waste outlets	After dusk During whale migration, seal breeding season Proximity to waste outlets, fish wastes Proximity to seal colonies, whales
Crocodiles	Tropical	Rivers, ocean, mangroves, billabongs (up to 200 km inland), swamps, coast	Murky water, tropical rivers, swamps	During wet season, after dusk Proximity to watering holes
Seals Elephant seals Sea lions	Temperate	Coastal islands, southern Australia	On land	During summer breeding season
Moray and conger eels	Tropical to temperate	Reefs, estuaries	Fish territory	All year

Table 8.3 Venomous Invertebrates – Distribution, habitat and factors influencing the risk of envenomation

Organisms	Distribution	Habitat	Risk prevalence	Greatest risk
Box jellyfish (<i>Chironex fleckeri</i>)	Tropical	Near shore, estuaries	Rising tide (calm weather), after rain	Wet season (Oct–April) in north Qld and WA All year in NT
Sea wasp (<i>Chironpsalmus quadrigatus</i>)	Tropical	Near shore, estuaries	Rising tide (calm weather), after rain	Wet season (Oct–April) in north Qld and WA All year in NT
Irukandji jellyfish (<i>Carukia barnesi</i>)	Tropical	Near shore, shallow water	Mild northerly winds, periods of low rainfall, hot days and onshore winds	Summer months Presence of discoid medusae (jelly buttons)
Siphonophores Bluebottle (<i>Physalia utriculus</i>) Portuguese man-of-war (<i>Physalia physalis</i>) Hair jellyfish (<i>Cyanea</i>) Blubber jellyfish (<i>Catostylus</i>) Jimble (<i>Caryddea rastoni</i>)	Tropical to temperate	Near shore	Mild northerly winds, periods of low rainfall, hot days and onshore winds	Summer months
Blue-ringed octopus	Tropical to temperate	Reefs, rocks, estuaries	Rock pools,	All year
Cone shells	Tropical	Reefs, shallow waters Ponds, rubble	Warm waters Sandy bottom	All year
Crown-of-thorns starfish	Tropical	Reefs, shallow waters		All year
Bristle worms	Tropical and subtropical (east coast)	Reefs, rocks		All year

NT = Northern Territory; Qld = Queensland; WA = Western Australia

Table 8.4 Venomous Vertebrates – Distribution, habitat and factors influencing the risk of envenomation

Organisms	Distribution	Habitat	Risk prevalence	Greatest risk
Stonefish (<i>Synanceia verrucosa</i>)	Tropical	Rubble or coral bottoms, reefs, rocks, estuaries (sand and mud)	Murky waters, reef, clear water rubble bottoms	All year
Stingrays	Tropical to temperate	Reefs, estuaries	Murky waters, muddy or sandy, seabed	All year
Catfish	Tropical to temperate	Estuaries, rivers, freshwater lakes, tidal lagoons, mudflats, reef	Fish territory, murky waters	All year

Table 8.5 Distribution, habitat and factors influencing the risk of infection by *Naegleria fowleri* (free-living microorganisms)

Organisms	Distribution	Risk prevalence	Greatest risk
<i>Naegleria fowleri</i>	Indigenous to warm fresh water; density may increase rapidly if temperature exceeds 35°C for prolonged periods	High health significance to recreational freshwater users, although fortunately the risk of infection is very low	Primary amoebic meningoencephalitis, an almost invariably fatal condition

8.2.3 Nonvenomous organisms

Sharks

In Australia four species of shark are responsible for most attacks on humans: the great white shark or white pointer (*Carcharodon carcharias*); the tiger shark (*Galeocerdo cuvier*); the oceanic whitetip shark (*Carcharhinus longimanus*); and the bull shark (*Carcharhinus leucas*). In the tropical region of Australia, the hammerhead shark (*Sphyrna lewini*) also poses a risk in recreational waters.

The great white shark is most prolific along the Southern Ocean coast and in the Great Australian Bight, particularly where seals are abundant. An increase in use of these waters by wetsuited surfers and divers has been accompanied by an increase in shark attacks in Tasmania and South Australia. In Western Australia, bull sharks have been sighted in the Swan River estuary. In Queensland, a man was savaged in a coastal lake near houses by a bull shark in February 2003, showing that potentially dangerous sharks may be found in rivers during summer when freshwater flows are low.

Attacks by sharks on swimmers, surfers and divers are rare and most are not fatal. Most attacks occur in waters near the shore, typically inshore of a sandbar or between sandbars where sharks feed and can become trapped at low tide. Areas with steep drop-offs are also likely sites.

Attacks are more frequent during warm weather, particularly at dusk, near deep channels, in turbid waters in estuaries or where animal products are dumped. The probability of being attacked increases when diving at depths greater than 30 metres.

Crocodiles

There are two types of crocodile in Australia: the freshwater crocodile (*Crocodylus johnstoni*); and the estuarine or saltwater crocodile (*Crocodylus porosus*). The range of both is limited to the tropical region of Australia: northern Queensland (north of the Tropic of Capricorn); the Northern Territory; and northern Western Australia.

The saltwater crocodile is found primarily in brackish water along mangrove-lined tidal rivers up to 200 km from the coast, and in flood-plain billabongs, creeks and freshwater swamps up to 100 km inland. Freshwater crocodiles occur in inland freshwater rivers, billabongs and swamps. They migrate between areas during the wet season (November–April) and in the dry season. Both species of crocodile can be found in the marine and freshwater environments.

Crocodiles congregate around pools, lakes and rivers where animals gather to drink. Most attacks by estuarine crocodiles occur in the wet season when the crocodiles do most of their feeding and growing. Females make nests seasonally in the form of mounds of rotting vegetation 1–2 m in diameter. The nests are close to water and the females remain nearby to defend them aggressively. It is risky to pass close to the nests during this time.

Sea lions, elephant seals and leopard seals

The Australian sea lion (*Neophoca cinerea*) is considered the most dangerous seal in Australia. Bulls can exceed 2 metres and weigh about 300 kg. *Neophoca cinerea* has permanent breeding grounds in South Australia on Kangaroo Island and at Point Labatt on the west of the Eyre Peninsula. Other sites are on islets off Western Australia and South Australia. Elephant seals (*Mirounga leonina*) can exceed 4 metres and weigh up to 4 tonnes, and breed on Tasmania's northwest coast and on Bass Strait Islands. Leopard seals (*Hydrurga leptonyx*) can travel north as far as southwest Western Australia and northern New South Wales, and are found in waters off all southern states. They can reach 3.5 metres and weigh up to 450 kg.

Seals and sea lions are not aggressive towards humans under normal circumstances. During the mating season, however, or when with pups, bulls and females may become aggressive and attack intruders.

Moray eels and conger eels

Moray eels (*Gymnothorax spp*) and conger eels (*Conger spp*) grow up to 3 metres long and 30 cm in diameter. Moray eels are common in tropical and subtropical waters and usually live in crevices and corners. However, they are not restricted to reefs. Conger eels are common around rocky reefs in cooler regions along the southern mainland and Tasmanian coast.

Most eels are harmless, although they may attack and inflict fairly deep puncture wounds when provoked.

8.2.4 Venomous invertebrates

The effects of invertebrate venoms on humans range from mild irritation to sudden death. This section discusses the important venomous invertebrate species in Australia, including description and occurrence, and risks to humans. Treatment and preventive actions to avoid envenomation are covered in Section 8.3.

Box jellyfish

The box jellyfish (*Chironex fleckeri*) is a large, transparent, pale blue jellyfish, weighing up to 6 kg and measuring about 200–300 mm across the bell. The tentacles may stretch up to 2 metres. It has four bundles of tentacles, each containing up to 60 individual tentacles. Each tentacle contains many millions of nematocysts (stinging cells) that discharge venom through the skin on contact.

Box jellyfish range from Gladstone in Queensland, across northern Australian waters to Broome in Western Australia. They have been found around inshore reefs of the Great Barrier Reef and in the far north. They frequent Melville and Bathurst Islands near Darwin and the islands of the Gulf of Carpentaria.

Across the northern coastline, the *Chironex* season begins with the wet season, usually around October, and lasts until April. Further south along the Queensland and Western Australian coasts the season is shorter, usually from November to March. Box jellyfish are primarily an estuarine and inshore species, though they may sometimes be blown offshore by winds.

In the Northern Territory, stings have occurred in every month, with deaths in almost all months. Box jellyfish may occur only in December and January at the southern extreme of their recorded range (Fenner and Williamson 1996). Their stings have historically been an important cause of mortality and morbidity in coastal tropical Australia (O'Reilley *et al* 2001), and the cause of the most common sting presentations to the Royal Darwin Hospital.

If a swimmer makes contact with enough tentacular material over a wide body surface area, massive envenomation can result in death within five minutes. The pain is such that many die from drowning after shock. However, fatalities are relatively rare considering the number of people stung every year.

Sea wasps

The sea wasp (*Chironpsalmus quadrigatus*) is a close relative of *Chironex*. It is similar to but smaller than the box jellyfish (Fenner and Williamson 1996). The bell measures up to 70 mm and the number of tentacles on each of the pedalia (fleshy arms) seldom exceeds nine. The tentacles are shorter and finer than those of *Chironex fleckeri*.

The venom of the sea wasp contains lethal, dermatonecrotic and haemolytic properties in approximately the same proportions as *Chironex* venom, but the venom output of *Chironpsalmus* is much less. Stinging results in severe pain and shock, but the illness is less severe than that from the box jellyfish. No deaths from the sting of this genus have been reported in Australia, although there have been reported deaths overseas (Fenner and Williamson 1996).

Irukandji jellyfish

The irukandji jellyfish (*Carukia barnesi*) is a box jellyfish with a bell approximately 20 mm long and 25 mm in diameter with tentacles less than 600 mm long. They occur in swarms, infesting northern beaches for brief period in summer. In Queensland their movement is influenced by currents forced by northerly winds.

Irukandji envenomations occur on hotter days, typically with lower than average rainfall in the past seven days, and with northerly winds, but less than average wind speeds (Little and Mulcahy 1998). Irukandji envenomation is most common in waters north of Cairns in Queensland. The sting is only moderately painful at first, but becomes intensely painful over about 30 minutes, and symptoms may include the following which are known as 'irukandji syndrome': severe backache; muscle pains; chest and abdominal pain, nausea and vomiting; headache; sweating; and (rarely) pulmonary oedema (Little and Mulcahy 1998).

Siphonophores

The bluebottle (*Physalia utriculus*) and the Portuguese man-of-war (*Physalia physalis*) are siphonophores (colonies of individual organisms) occurring in all Australian coastal waters.

Physalia venom injected into human skin causes severe pain and blisters may form. Headache, vomiting or abdominal pains are most uncommon. Children, asthmatics and people with allergies can be badly affected and many cases of respiratory distress have been reported in Australia (Fenner and Williamson 1996). Death has been reported overseas (Edmonds 1984, Burnett and Gable 1989).

Blue-ringed octopus

Two species of blue-ringed octopus occur in Australian waters: *Hapalochlaena maculosa* in the south and *Hapalochlaena lunulata* in the north. The first does not exceed 120 mm in length, the latter 200 mm. The limits of their distributions, which overlap on the east coast, are not clear. The blue-ringed octopus is found in tidal rock pools and can be extremely attractive to children and tourists who risk envenomation if they pick up the animal.

The blue-ringed octopus secretes a salivary venom that includes tetrodotoxin, the paralysing poison also found in the tissue of puffer fish. The toxin causes a blockade of sodium channels and thus neurological problems such as weakness, numbness or paraesthesia, breathing difficulties and paralysis. The patient may be completely paralysed and unable to respond, sometimes with fixed, dilated pupils, but is often fully conscious of events. Envenomation is uncommon, but two fatalities have been reported (Fenner and Williamson 1996).

Blue-ringed octopuses are more often seen in summer, although they are a significant risk all year, especially in the tropics. Lower temperatures do not affect their activity or the potency of their venom.

Cone shells

Cone shells are predatory gastropods that live in shallow reef waters and kill their prey with venom that they inject via radula teeth like small harpoons. About 70 species of the genus *Conus* in Australian waters have venomous darts. However, only the geographer cone shell (*Conus geographus*) has been lethal to humans.

The cone shell inhabits shallow water, reefs, ponds and rubble. Because it often burrows under the sand, the siphon that it uses to suck in water for respiration may be the only part visible. Around the Australian coastline, cone shells are found throughout the tropical regions and on the eastern and western coasts, south to about latitude 30°S.

Cone shells should be left alone. No part of the shell can be handled safely as the snout can reach any part of it. It can also sting through clothing.

Crown-of-thorns starfish

The crown-of-thorns starfish (*Acanthaster planci*) occurs over a wide range, through the tropical waters of the Pacific and Indian oceans and as far south as the central coast of New South Wales. It prefers to live in more sheltered areas such as lagoons and in deeper water along reef fronts. It generally avoids shallow water on the tops of reefs where water conditions are likely to be more turbulent. The starfish may occasionally feed in these areas, particularly when the weather is calm.

Each of the hundreds of spines of the crown-of-thorns starfish is encased in a sheath containing venom cells with toxic saponins, a group of natural steroids. Multiple stinging can cause excruciating pain (which may last several hours), fainting, nausea and vomiting. Frequently, the area around the puncture turns a dark blue and begins to swell. The swelling may persist for a number of days. Where the victim has suffered multiple wounds, the whole limb may stiffen and swell. In such cases, the patient may experience a numbness around the wounds and the swollen area may become extremely itchy. Repeated envenomation over days or weeks can lead to much more severe responses to successive stinging in some individuals.

Fire corals

Fire corals (Milleporidae) sting by releasing toxins from nematocysts. The severity of the sting depends on the area of exposure and on the delicateness of the skin surface. The pain is usually localised, but nausea and vomiting have been reported for severe stings (Edmonds 1984).

Bristle worms

Bristle worms (*Polychaeta spp*) lie under rocks or in corals and can be found anywhere down the east coast into New South Wales. Many species may reach 200 mm in length, but the tropical species *Eunice aphroditois* may grow to 1.5 m.

Bristle worms cause injury by penetration of their bristles or by biting. *Eunice aphroditois* can inflict more severe biting wounds. Local burning sensations followed by secondary infection are common. Some cardiovascular reactions have also been reported with *Eurythoe complanata* (Edmonds 1984).

8.2.5 Venomous vertebrates

Venomous marine vertebrates deliver their venom either via spines, as in many fish species, or through fangs, as in sea snakes. Injuries caused by venomous marine vertebrates are common, especially among people who frequently come into contact with these animals. Potent vertebrate toxins usually cause great pain to the victim, who may also experience tissue damage.

The effects of vertebrate venoms range from mild irritation to death. This section discusses the important venomous vertebrate species in Australia, including description and occurrence and risks to humans. Treatment and preventive actions to avoid envenomation are discussed in Section 8.3.

Stonefish

Stonefish (*Synanceja trachynis* or *Synaneichthyes verrucosa*) are usually greenish-brown, grow to about 30 cm in length and have stonelike appendages that provide almost perfect camouflage in their preferred habitat. The stonefish can mainly be found north of the Tropic of Capricorn on coral reefs, near or about rocks, or dormant in the sand or mud.

Along the back of the fish are 13 grooved spines that, when stepped on, penetrate the skin of the victim, injecting venom that causes intense pain. The spines are capable of piercing a sandshoe.

Stingrays

Stingrays are widespread in tropical and temperate seas. A flat fish up to 2 metres wide and 4.3 metres long, the stingray buries itself in the seabed of sheltered bays and estuaries and between coral reefs. The stingray usually has one venomous spine (the sting) halfway along the tail. The sting can inflict a severe or potentially fatal wound. The stingray swings its tail upwards and drives the spine into the body of the victim, releasing venom — a protein that is heat labile and water soluble (Edmonds 1984). The spine can penetrate most protective material, including rubber boots.

Low concentrations of the venom cause bradycardia (abnormally slow pulse) and intense pain. Large amounts of venom may lead to cardiac ischaemia (blockage of blood flow to the heart muscle), respiratory depression and convulsions. Deaths have been reported when the spine perforated the pericardial, peritoneal or pleural cavities.

Swimmers in shallow recreational waters are not usually in danger, as they usually cause too much disturbance for stingrays to remain nearby.

Catfish

More than 30 species of catfish are found in and around mainland Australia and Tasmania. They are commonly netted in estuaries but their other habitats include rivers, freshwater lakes, tidal lagoons, mudflats and rocky or coral reefs. Both fresh and saltwater catfish are dangerous to handle because of their retroussé barbs (ie with the tip turned up), which can cause significant damage on entry and can be difficult to remove (Ashford *et al* 1998).

Virulent bacteria may be introduced through the puncture wound. The injury usually manifests acutely as immediate throbbing pain, which may spread to involve the whole limb. A variety of organisms not otherwise commonly encountered have been implicated in acute and chronic infection after catfish wounds (Murphey *et al* 1992). Late presentations have been reported, especially with *Mycobacterium* and *Klebsiella* species.

Bullrout

The bullrout (*Notesthes robusta*) has variable colouration from pale yellowish to dark brown and can grow up to 30 cm in length. The fish has a large head with seven spines on the covering of the gills. The bullrout lives in tidal estuaries and slow-flowing freshwater streams. It can be found in estuaries from northern Queensland to southern New South Wales and has infrequently been caught at sea.

The bullrout should be handled with extreme care as the dorsal, anal and pelvic spines all have venom glands. A puncture wound from one of these spines can be excruciatingly painful. Envenomation takes place when the spines puncture flesh, when the fish is stepped on or when anglers attempt to disengage it from nets or lines.

8.2.6 Free-living microorganisms

Recreational waters may contain free-living (indigenous) pathogens or opportunistic pathogens (eg the protozoan *Naegleria fowleri* in warm fresh waters, and certain bacterial strains of *Aeromonas hydrophila*, *Vibrio cholerae* and *Mycobacterium marinum*). Whereas *N. fowleri* is largely a risk following head immersion in warm fresh waters (causing primary amoebic meningoencephalitis) (Dorsch *et al* 1983), both *A. hydrophila* in eutrophied waters (Dorsch *et al* 1994) and *M. marinum* largely

in sea water (Iredell *et al* 1992, Ang *et al* 2000) pose risks because breaks in the skin can lead to infected wounds. It is also important to note that most *V. cholerae* occurring naturally in some Australian tropical fresh waters are non-epidemic strains (Mallard and Desmarchelier 1995).

8.3 MANAGEMENT OF RISKS ASSOCIATED WITH DANGEROUS AQUATIC ORGANISMS

Many serious incidents can be avoided through public education and awareness. It is therefore important to identify and assess the hazards posed by various aquatic organisms in a given region and bring the results to public attention. Awareness raising should be targeted at groups at particular risk, which may include local and visiting populations. In addition, at locations where hazards involving dangerous aquatic organisms have been identified, procedures should be developed for treating any injury sustained.

8.3.1 Nonvenomous organisms

Although attacks by nonvenomous organisms, such as sharks, usually attract a lot of public and media attention, the organisms are endemic only to certain regions and their real public health significance is varied. Individuals can take the following preventive measures.

- Treat all animals with respect and keep at a distance whenever possible.
- Avoid swimming in murky, brackish inlets, river mouths and mangrove swamps inhabited by crocodiles.
- Obtain information from local authorities about the risk from hazardous organisms and ask for their guidance on risk prevention.

8.3.2 Venomous invertebrates

Treatment for venomous invertebrates

Box jellyfish

If envenomation (stinging) occurs medical attention should be sought immediately and, if resuscitation is not needed, vinegar should be poured onto the affected area for a minimum of 30 seconds to inactivate undischarged nematocysts (stinging cells). Antivenom may be administered by lifesaving or other paramedical personnel at the scene via the intramuscular route, although intravenous administration is preferable if appropriately skilled personnel are available. Where antivenom is unavailable pressure immobilisation may be used on limbs after inactivation of nematocysts while the patient is being transported to the nearest medical centre.

Sea wasp

If envenomation (stinging) occurs medical attention should be sought immediately and vinegar poured onto the area for a minimum of 30 seconds to inactivate undischarged nematocysts (stinging cells). Antivenom may be administered by lifesaving or other paramedical personnel at the scene via the intramuscular route, although intravenous administration is preferable if appropriately skilled personnel are available.

Irukandji jellyfish

If a person is stung by an irukandji jellyfish medical attention should be sought immediately. Analgesia is usually required and may need to be given intravenously when pain is severe. First aid consists of analgesia and reassurance. The role of vinegar to inactivate undischarged nematocysts remains uncertain, with initial work proving inconclusive. No definitive treatment is currently available for irukandji syndrome.

Siphonophores

First aid for a person stung by a siphonophore consists of removing the tentacles, preferably with forceps, or washing off adherent tentacles with salt water and then applying a cold pack over a tissue or cloth, or ice wrapped in a wet cloth, over the sting site for 10–20 minutes. Analgesia may be required, although most stings respond to ice packs and/or topical anaesthetic agents. Vinegar is not recommended.

Blue-ringed octopus

Victims of the blue-ringed octopus may require supportive treatment, including mechanical ventilation, until the effects of the venom wear off. No antivenom is available in Australia.

Cone shells

For a person stung by a cone shell pressure immobilisation first aid should be applied and left in place until resuscitation facilities are available as assisted ventilation may be required. There is currently no antivenom for cone shell stings. The wound should be regarded as potentially contaminated and tetanus immunisation should be updated if required.

Fire corals

Vinegar has been recommended for first aid for fire corals.

Preventive measures for venomous invertebrates

The effects of invertebrates on humans range from mild irritation to sudden death. Individuals can take the following preventive measures.

- Always wear suitable footwear when exploring the intertidal area or wading in shallow water.
- Avoid handling sponges, cnidarians, cone shells, blue-ringed octopuses and bristle worms.
- Avoid brushing against hydroids, true coral and anemones.
- Avoid swimming in waters where jellyfish are concentrated (often indicated by specimens along the beach).
- If swimming where jellyfish are prevalent wear a wetsuit or other form of protective clothing, such as the full-length stretch-fitting stinger suits used by divers in tropical waters.

8.3.3 Venomous vertebrates

Treatment for venomous vertebrates

Stonefish

The venom of stonefish is heat labile and bathing in hot water will inactivate it but medical attention should be sought immediately.

Catfish

After initial management of a catfish wound, the wound should be vigorously cleansed, irrigated, explored and debrided. A hand wound should be left open. Most cases present early and symptoms resolve within 3 months.

Bullrout

Recommended treatments for injury caused by bullrout include the application of heat and administration of local anaesthetics and analgesics. Some victims require complete sedation in hospital (Sutherland 1983).

Preventive measures for venomous vertebrates

Preventive measures that can be undertaken by the individual include the following.

- Always shuffle the feet when walking along sandy lagoons or shallow waters, particularly in areas frequented by stingrays.
- In catfish waters, fishermen should be extremely careful when handling and sorting their catch.

9 CHEMICAL HAZARDS

Guideline

Waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes. Recreational water should have a pH in the range 6.5–8.5 (a pH range of 5–9 is acceptable in recreational waters with a very low buffering capacity) and a dissolved oxygen content greater than 80%.

9.1 OVERVIEW

Chemical contaminants can enter recreational water or be deposited on shore from both natural and anthropogenic sources. These may be either point sources, such as an industrial outfall or a natural spring or nonpoint (diffuse) sources, such as run-off from land. In most cases and depending on circumstances, there will be significant dilution or attenuation of contaminants. In all cases, chemical and physical contaminants must be assessed on a local basis (WHO 2003).

9.2 ASSESSMENT OF EXPOSURE TO CHEMICALS

In general, the potential risks from chemical contamination of recreational waters will be very much smaller than the potential risk from other hazards, outlined in earlier chapters (WHO 2004), apart from toxins produced by marine and freshwater cyanobacteria and algae (see Chapters 6 and 7) or other exceptional circumstances. Recreational water users are unlikely to come into contact with sufficiently high concentrations of most contaminants to suffer adverse effects from a single exposure. Even repeated (chronic) exposure is unlikely to result in adverse effects at the concentrations of contaminants typically found in water and with the exposure patterns of most recreational water users. However, it remains important to ensure that chemical hazards and any potential human health risks associated with them are recognised and controlled and that users can be reassured about their personal safety (WHO 2003).

For recreational water users, the dangers of chemical contamination will depend on the particular circumstances of the local area. For example, fast-flowing upland rivers will be unlikely to suffer significant chemical contamination, whereas slow-flowing lowland rivers, lakes and coastal waters may be subject to continuous or intermittent discharges which could result in contaminated sediments. Where motorboats are used extensively, fuel or fuel additives may be cause for concern. Where a water body used for recreational purposes receives significant wastewater discharges, its chemical composition and dilution or dispersion should be taken into consideration.

The potential for chemical contamination of groundwater in large urban areas and subsequently impacting on recreational waterways should be considered when investigating the sources or risks of chemical hazards occurring in recreational waters.

Exposure is a key issue in determining the risk of toxic effects from chemicals in recreational waters and this varies with different recreational activities. The frequency, extent and likelihood of exposure are crucial parts of assessing the risk from a contaminant. Routes of exposure are outlined in Table 9.1.

Table 9.1 Routes of exposure to chemicals in recreational water

Route of exposure	Comments
Direct surface contact	The most frequent routes are absorption through skin, eyes and mucous membranes. Wetsuits, used for long periods in the water, trap water against the skin and create a microenvironment that enhances the absorption of chemicals through the skin and the development of skin irritation or allergy.
Inhalation	Inhalation is important in circumstances where there is a significant amount of spray, such as in waterskiing.
Ingestion	Ingestion is likely during immersion or partial immersion activities. Very young children are likely to ingest proportionally greater amounts of water than adults when bathing, swimming or playing in the water. However, data on the quantities of water ingested during water sports are difficult to obtain.

Many substances of concern have low solubility in water and may accumulate in sediments. This is of concern if the sediment is disturbed and resuspended or if recreational users are in close contact with the sediment. However, in general, this is likely to make only a minor contribution to overall exposure.

9.3 ASSESSMENT OF CHEMICAL HAZARDS IN RECREATIONAL WATER

9.3.1 Qualitative assessment

An inspection of the recreational water area will reveal any obvious sources of chemical contamination, such as outfalls. These are a problem if they are easily accessible or if the effluent does not receive immediate and significant dilution. Intelligence on past industrial activity in the area and upstream will indicate the likely presence of contaminated sediments; it will also identify possible contamination. Those responsible for assessment need to know what upstream industry is present and whether direct or indirect discharges are made to the water.

Site inspection of industrial facilities may be another way to monitor discharges. Issues to be noted in a site inspection are:

- amounts of chemicals used and their uses in industrial processes;
- water use and the quantity used;
- sanitary conditions of the facility, especially the condition of the floor; and
- effectiveness of wastewater treatment processes.

Some of this information may be available in statistics and reports (eg the National Pollution Inventory⁹). Industrial and environmental departments of local or regional governments often have good information or may be able to suggest other sources of information. Information can also be gathered from water supply and wastewater agencies, municipal authorities and environmental agencies. Useful sources of information on chemicals likely to be present within a catchment are outlined in Table 9.2.

⁹ Available online at <http://www.npi.gov.au>

Table 9.2 Sources of information on chemical usage in local areas

Source of chemical	Information sources
Agriculture	• Farmers' associations • State/territory agricultural authorities • Local government authorities • University extension services • State and Territory Environmental Authorities • Natural Resource Management Agencies
Extractive industries	• State/territory resource management agencies • Local government authorities • University geology departments • Specialist research institutes associated with the mining industry • State and Territory Environmental Authorities • Natural Resource Management Agencies
Manufacturing and processing industries	• State/territory environmental protection authorities and industry departments • Local government authorities • Industry associations (eg chambers of commerce) • State and Territory Environmental Authorities • Natural Resource Management Agencies
Contamination from former industrial sites	• State/territory environmental protection agencies • Local government authorities • Historical societies • State and Territory Environmental Authorities • Natural Resource Management Agencies
Natural environment	• Australian Geological Survey Organisation • State/territory departments of natural resources • Geology departments of universities • Local government authorities • Mining companies • State and Territory Environmental Authorities • Natural Resource Management Agencies

In general, significant contamination by naturally occurring contaminants is less likely than contamination by industrial, agricultural and municipal pollution but there may be circumstances where small recreational water bodies containing water from mineral-rich strata could contain high concentrations of some substances. Such waters, however, are more likely to contain metals, such as iron, that may give rise to aesthetic degradation of the water (WHO 2003).

The pattern and type of recreational use of the water need to be carefully considered to determine the degree of recreational users' contact with the water and whether there is a significant risk of ingestion.

9.3.2 Quantitative assessment

If it is probable that contamination is occurring and there is significant exposure of users, chemical analysis will be required to support a quantitative risk assessment. Care should be taken in designing the sampling program to account for variation in time and water movement. If resources are limited and the situation complex, samples should first be taken at the point considered to give rise to the worst case; only if this sampling gives rise to concern is there a need for wider sampling.

The quantitative risk assessment should consider the expected exposure in terms both of dose (ie ‘Is there significant ingestion?’) and of frequency of exposure. The *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004) provide a point of reference for exposure through ingestion but with a few exceptions these relate to significant lifetime exposure.

Mance *et al* (1984) suggested that environmental quality standards for chemicals in recreational waters should be based on the assumption that recreational water makes only a relatively minor contribution to intake. They assumed a contribution for swimming of an equivalent to 10% of drinking water consumption. Since most authorities (including WHO) assume consumption of 2 litres of drinking water per day, this would result in an intake of 200 mL per day from recreational contact with water (WHO 2003). This provides for a simple screening approach in which a substance occurring in recreational water at a concentration of 10 times that stipulated in the drinking water guidelines may merit further consideration.

It is important that the basis for any guideline or standard considered necessary is transparent. Otherwise there is a danger that even occasional or trivial exceedances could unnecessarily undermine users’ confidence.

9.4 MANAGEMENT OF CHEMICALS

When potential sources of contamination are known to exist upstream of the recreational area, further tests should be required and a quantitative risk assessment implemented (NSWEPA 2002). Management strategies should focus on catchment protection. For example, planning should address:

- the prevention or reduction of existing or future nitrogen pollution from agricultural sources through safer storage and spreading of animal manure and fertilisers, to prevent eutrophication in seas, rivers and lakes; and
- improved protection of soils against erosion through codes of good practice and action programs.

The *Australian Drinking Water Guidelines* (NHMRC/NRMMC 2004***Under review*) provide a guide to those chemicals that may be present in Australian recreational waters. While this list should not be considered definitive, it is extremely unlikely that all of these chemical contaminants will be present in a recreational water body at any one time.

The guideline values provided in Table 9.3 are directly applicable to drinking water quality and should only be regarded as an initial guide to the quality of recreational water. Local circumstances should be taken into consideration in determining state/territory or local standards appropriate for recreational water, or in assessing priorities for action, including monitoring. The *Australian Drinking Water Guidelines* give more detailed information about individual chemicals that may be useful in making such decisions.

Table 9.3 Sources of chemicals in recreational water

Chemical	Drinking water guideline values ^a (mg/L)		Potential sources of contamination			
	Health	Aesthetic	Naturally occurring	Agricultural activities	Human settlements	Industry
Acephate	0.01			X		
Acrylamide	0.0002					x
Aldicarb	0.001			X		x
Aldrin/dieldrin	0.0003			X		x
Ametryn	0.05			X		
Amitrole	0.01			X	x	
Ammonia		0.5	X	X		X
Antimony	0.003		x			x
Arsenic	0.007		X			x
Asbestos	b					X
Asulam	0.05			X		
Atrazine	0.04			X	x	X
Azinphos-methyl	0.003			X	x	
Barium	0.7		X			X
Benomyl	0.1			X		
Bentazone	0.03			X		X
Benzene	0.001				X	X
Benzo[a]pyrene	0.00001				x	x
Beryllium	b		x			x
Bioresmethrin	0.1			X	x	
Boron	4		X		X	X
Bromacil	0.3			X		
Bromate	0.02					x
Bromochloroacetonitrile	b					x
Bromophos-ethyl	0.01			X		
Bromoxynil	0.03			X	x	
Cadmium	0.002		x			X
Carbaryl	0.03			X		
Carbendazin	0.1			X		
Carbofuran	0.01	0.005		X		x
Carbon tetrachloride	0.003				X	X
Carbophenothion	0.0005			X		
Carboxin	0.3			X		
Chloral hydrate	0.02			X		
Chlordane	0.001			X		x
Chlorfenvinphos	0.005			X		
Chloride		250	X		X	X
Chlorite	0.3				X	X
Chloroacetic acid	0.15					x

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Chemical	Drinking water guideline values ^a (mg/L)		Potential sources of contamination			
	Health	Aesthetic	Naturally occurring	Agricultural activities	Human settlements	Industry
Chlorobenzene	0.3					X
2-Chlorophenol	0.3	0.0001		X		x
Chlorothalonil	0.03			X		
Chloroxuron	0.01			X		
Chlorpyrifos	0.01			X	X	
Chlorsulfuron	0.1			X		
Chromium	0.05		X			X
Clopyralid	1			X		
Copper	2	1	x		x	x
Cyanide	0.08		x			X
Cyanogen chloride (as CN)	0.08					x
D 2,4-	0.03			X		x
DDT	0.02			X		x
Dialkyltins	b					X
Diazinon	0.003			X	x	
Dibromoacetonitrile	b					x
Dicamba	0.1				X	
Dichlobenil	0.01				x	X
Dichloroacetic acid	0.1					X
Dichloroacetonitrile	b					X
1,2-dichlorobenzene	1.5	0.001				X
1,3-dichlorobenzene	c	0.02				X
1,4-dichlorobenzene	0.04	0.0003				X
1,1-dichloroethane	c					X
1,2-dichloroethane	0.003					X
1,1-dichloroethene	0.03					X
1,2-dichloroethene	0.06					X
Dichloromethane	0.004				x	X
2,4-Dichlorophenol	0.2	0.0003				x
Dichlorvos	0.001				X	
Dicofol	0.003				X	
Dicofop-methyl	0.005			X		
Difenzoquat	0.1			X		
Dimethoate	0.05			X		x
Diphemamid	0.3			X		
Dioxin (2,3,7,8-TCDD)						
Diquat	0.005			X		x
Disulfoton	0.003			X		
Diuron	0.03			X		
2,2-DPA	0.5			X	x	
EDB	0.001			X		

Chemical	Drinking water guideline values ^a (mg/L)		Potential sources of contamination			
	Health	Aesthetic	Naturally occurring	Agricultural activities	Human settlements	Industry
Endosulfan	0.03			X		x
Endothal	0.1			X		
Epichlorohydrin	0.0005					X
EPTC	0.03			X		
Ethion	0.003			X		
Ethoprophos	0.001			X		
Ethylbenzene	0.3	0.003			X	X
Ethylenediamine tetraacetic acid (EDTA)	0.25				X	X
Etridiazole	0.1			X		
Fenamiphos	0.0003			x	X	
Fenarimol	0.03			x	X	
Fenchlorphos	0.03			X		
Fenitrothion	0.01			X		x
Fenoprop	0.01			X		x
Fensulfothion	0.01			X		
Fenvalerate	0.05			X		
Flamprop-methyl	0.003			X		
Fluometuron	0.05			X		
Fluoride	1.5		X			x
Formothion	0.05			X		
Fosamine	0.03			X		
Glyphosate	1			X	x	
Heptachlor and Heptachlor epoxide	0.0003			X		x
Hexachlorobutadiene	0.0007					x
Hexaflurate	0.03			X		
Hexazinone	0.3			X		
Hydrogen sulfide	b	0.05	X			
Iodide	0.1		X		x	
Iron	b	0.3	X			
Lead	0.01		x		x	x
Lindane	0.02			X		x
Maldison	0.05			X	x	
Manganese	0.5	0.1	X			x
Mercury (total)	0.001		x			X
Methidathion	0.03			X		
Methiocarb	0.005			X		
Methomyl	0.03			X		
Methoxychlor	0.3			X		x
Metolachlor	0.3			X		x
Metribuzin	0.05			X		

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Chemical	Drinking water guideline values ^a (mg/L)		Potential sources of contamination			
	Health	Aesthetic	Naturally occurring	Agricultural activities	Human settlements	Industry
Metsulfuron-methyl	0.03			X		
Mevinphos	0.005			X		
Molinate	0.005			X		x
Molybdenum	0.05		x	x		X
Monochloramine	3	0.5			X	x
Monochlorobenzene		0.01				X
Monocrotophos	0.001			X	x	
Napropamide	1			X		
Nickel	0.02		x		x	x
Nitralin	0.5			X		
Nitrate (as NO ₃ -)	50			X	X	
Nitrilotriacetic acid	0.2				x	X
Nitrite (as NO ₂ -)	3			X	X	
Norflurazon	0.05			X		
Oryzalin	0.3			X		
Oxamyl	0.1			X		
Paraquat	0.03			X		
Parathion	0.01			X		
Parathion-methyl	0.1			X		
Pebulate	0.03			X		
Pendimethalin	0.3			X		x
Pentachlorophenol	0.01			x		X
Permethrin	0.1			X		x
Picloram	0.3			X		
Piperonyl butoxide	0.1			x	X	
Pirimicarb	0.005			X		
Pirimiphos-ethyl	0.0005			X	x	
Pirimiphos-methyl	0.05			X		
Profenofos	0.0003			X		
Promecarb	0.03			X		
Propachlor	0.05			X		
Propanil	0.5			X		
Propargite	0.05			X		
Propazine	0.05			X		
Propiconazole	0.1			X		
Propyzamide	0.3			X	x	
Pyrazophos	0.03			X		
Quintozene	0.03			X		
Selenium	0.01		X			x
Simazine	0.02			X		x
Sodium		180	X			X
Styrene	0.03	0.004			x	X
Sulfate	500	250	X			X

Chemical	Drinking water guideline values ^a (mg/L)		Potential sources of contamination			
	Health	Aesthetic	Naturally occurring	Agricultural activities	Human settlements	Industry
Sulprofos	0.01			X		
Synthetic detergents					X	X
2,4,5-T	0.1			X		x
Temephos	0.3			X		
Terbacil	0.03			X		
Terbufos	0.0005			X		
Terbutryn	0.3					
Tetrachloroethene	0.05				x	X
Tetrachlorvinphos	0.1			X		
Thiobencarb	0.03			X		
Thiometon	0.003			X		
Thiophanate	0.005			X	x	
Thiram	0.003			X	x	
Toluene	0.8	0.025			x	X
Triadimefon	0.002			X		
Tributyltin oxide	0.001				X	x
Trichlorfon	0.005			X		
Trichloroacetaldehyde	0.02					x
Trichloroacetic acid	0.1					x
Trichloroacetonitrile	b					x
Trichlorobenzenes (total)	0.03	0.005				X
1,1,1-trichloroethane	b					X
Trichloroethylene	b			X		
2,4,6-trichlorophenol	0.02	0.002				x
Triclopyr	0.01			X	x	
Trifluralin	0.05			X		x
Uranium	0.02		X			x
Vernolate	0.03			X		
Vinyl chloride	0.0003					X
Xylene	0.6	0.02			x	X
Zinc		3	X			X

X Primary source of chemical in recreational water.

x Secondary sources of chemical in recreational water. Secondary sources must be considered as part of the assessment of priority chemicals.

a All guideline values listed in Table 9.1 are applicable to drinking water quality and are based on the daily consumption of 2 L. These values should only be used as a guide to deriving chemical values applicable to recreational water bodies. Using a consumption factor of 2 L will result in very conservative health guideline values in recreational water. When applying these values to recreational water exposure, consumption of 100–200 mL per day should be taken into consideration.

b Insufficient data to set a guideline value based on health considerations.

c The guideline value is below the limit of determination. Improved analytical procedures are required for this compound.

Note: Routine monitoring for pesticides is not required unless potential exists for contamination of the recreational water body.

9.5 MONITORING OF CHEMICALS

This section should be read in conjunction with Section 2.6.4 on the design and implementation of monitoring programs for chemical hazards.

Monitoring for chemicals should focus only on those of concern in the water body. While regular monitoring for a large number of chemical contaminants may not be justified, there may be instances where local knowledge or accidental spills justify increased surveillance (ANZECC/ARMCANZ 2000).

In areas where pesticides are used, monitoring should take into consideration those chemicals being used to ensure that management practices address all potential chemical contaminants in recreational water. Sediments often concentrate chemical contaminants; they should be included in the monitoring process because contact in shallow water is likely.

Monitoring of priority chemicals or indicators of chemical contamination (see Table 9.4) should be more frequent for water from unprotected or partially protected catchments, or water that may be contaminated with industrial discharges or effluent, compared to water from protected catchments. The analyses required will be determined by knowledge of the potential contaminants.

Table 9.4 Other measures of chemical quality of recreational waters

Indicator	Nature and purpose of measure	Comments
pH	Defines a water's ability to dissolve minerals from rocks and soil. To identify potential influences on the water body, eg acid mine drainage.	Low pH increases the probability that inorganic substances will occur naturally. Whenever the pH is less than 5.5 (eg water influenced by acid mine drainage), any water in contact with mineral deposits will require investigation. Both alkaline and acidic waters may cause eye and skin irritation and may affect the taste of water. Waters used for primary recreation should be in the pH range 6.5–8.5. If the water has a very low buffering capacity, the pH range may be extended to 5.0–9.0.
Oxygen concentration (dissolved oxygen)	Defines the aerobic or anaerobic condition of water. When considered with colour and transparency, an indicator of the extent of eutrophication.	Monitoring changes in oxygen levels may help to assess whether estuarine and coastal waters are receiving too many nutrients which may affect cyanobacterial growth. Low oxygen concentrations allow the growth of nuisance organisms, causing taste and odour problems, including the formation of undesirable amounts of hydrogen sulfide. Oxygen concentration greater than 80% saturation should prevent such problems.
Redox potential	Water is reducing in nature.	Low oxygen concentration and low redox potential can indicate the presence of hydrogen sulphide, causing odour problems, or dissolved iron and manganese. In a highly oxidised environment with available oxygen, a high redox reading would occur.

For persistent contaminants, monitoring should be based on knowledge of the individual system. A detailed initial monitoring program should be carried out to determine the optimal sampling frequency for each recreational water body. However, conditions and therefore sampling frequency can vary with local circumstances.

The minimum required in any monitoring program for physical and chemical characteristics is to collect representative samples routinely from a location within the bathing area.

Using a fixed sampling point (or points) will enable meaningful comparisons to be made over time. A more intensive investigation may be needed for a short period to establish that water quality at the chosen sampling point is representative of the water quality in the system or to establish the correlation between rainfall events and chemical agent concentrations.

If complaints are received, more frequent sampling should be carried out to determine the cause. Once the problem has been remedied routine sampling can be resumed. Most areas will only require quarterly sampling of physical parameters but local knowledge and experience may dictate a different monitoring program.

10 AESTHETIC ASPECTS OF RECREATIONAL WATER

Guideline

Recreational water bodies should be aesthetically acceptable to recreational users. The water should be free from visible materials that may settle to form objectionable deposits; floating debris, oil, scum and other matter; substances producing objectionable colour, odour, taste or turbidity; and substances and conditions that produce undesirable aquatic life.

10.1 OVERVIEW

Aesthetic issues play an important role in the public's perception of a recreational water area. The principal aesthetic concern is that obvious pollution of the water body, turbidity, scums or odour (which may relate to inadequate levels of dissolved oxygen) will cause people to feel revulsion. Pollution may cause nuisance for local residents and tourists, environmental problems and may lessen the psychological benefits of tourism (WHO 1980).

This chapter describes the aesthetic parameters that affect the acceptability of a recreational water area and the economic consequences. It also provides information on guideline values, management and monitoring of aesthetic aspects.

10.2 AESTHETIC PARAMETERS

The general aesthetic acceptability of recreational water can be expressed in terms of criteria for transparency, odour and colour. It has been suggested that values for light penetration, colour and turbidity should not be significantly increased over natural background values. The aesthetic value of recreational water areas implies freedom from visible materials that will settle to form objectionable deposits; floating debris, oil, scum and other matter; substances producing objectionable colour, odour, taste or turbidity; and substances and conditions that produce undesirable aquatic life (Department of National Health and Welfare, Canada, 1992).

10.2.1 Transparency and colour

Safety hazards from turbid or unclear water depend on the intrinsic nature of the water body. Ideally, water at swimming areas should be clear enough for users to estimate the depth, to see subsurface hazards easily and to detect the submerged bodies of other swimmers or divers who may be difficult to see (WHO 2003). Aside from the safety factor, clear water fosters enjoyment of the aquatic environment — the clearer the water, the more desirable the swimming area (National Academy of Sciences 1973).

The main factors affecting the depth of light penetration in natural waters include suspended microscopic algae and animals, suspended mineral particles, stains that impart colour (eg iron may impart a reddish colour to water while natural tannins may impart a tea colour), detergent foams, dense mats of floating and suspended debris or combinations of these factors.

There are two measures of colour in water: true and apparent. The true colour of natural water is the colour of water from which turbidity has been removed (ie filtered water). Natural minerals give true colour to water, for example, calcium carbonate in limestone regions gives a greenish colour and ferric hydroxide gives a red colour. Organic substances, tannin, lignin and humic acids from decaying vegetation also give true colour to water (Reid and Wood 1976). Apparent colour is an aesthetic quality, usually resulting from the presence of coloured particulates, the interplay of light on suspended particles and such factors as reflection of the bottom or sky. Abundance of (living) blue-green algae (cyanobacteria) may impart a dark green hue; diatoms give a yellow or yellow-brown colour; and some algae impart a red colour. Zooplankton, particularly microcrustaceans, may occasionally tint the water red (Reid and Wood 1976).

The causes of colour in marine waters are not thoroughly understood but dissolved substances are one of the contributory factors. The blue of the sea is a result of the scattering of light by water molecules, as in inland waters. Suspended detritus and living organisms give colours ranging from brown through red and green. Estuarine waters have a colour different from that of the open sea; the darker colours result from the high turbidity usually found in such situations (Reid and Wood 1976). This characteristic colour can also affect coastal recreational waters receiving estuarine input, leading to public perceptions that the colour change signals some form of pollution.

Some regulatory authorities have recommended absolute values for transparency/colour and turbidity in recreational waters. This approach can be difficult to apply at local level because many waters may have naturally high levels of turbidity and colour. It is therefore more common that changes from the normal situation are used to indicate potential water pollution.

10.2.2 Oil, grease and detergents

Even very small quantities of oily substances make water aesthetically unattractive (Environment Canada 1981). Oils can form films on the surface and some oil-derived substances, such as xylenes and ethylbenzene which are volatile, may also give rise to odours or tastes, even though they are of low toxicity. In common with some other countries, Canada has reasoned that oil or petrochemicals should not:

- be present in concentrations that can be detected as a visible film, sheen or discolouration on the surface;
- be detected by odour; and
- form deposits on shorelines and bottom sediments that are detectable by sight or odour (International Joint Commission 1977; Department of National Health and Welfare, Canada 1992).

It is difficult to establish criteria for oil and grease as the mixtures falling under this category are very complex. Tar may also present a problem on the shore; this can be removed by mechanical cleaning of the sand.

Detergents can give rise to aesthetic problems if foaming occurs, particularly since this can be confused with foam caused by the byproducts of algal growth (see Chapters 6 and 7, and Bartram and Rees 2000).

10.2.3 Litter

Beach litter is derived from four main sources: marine; riverine (including torrents); stormwater run-off and material discarded by beach users. Visitor enjoyment of any beach is likely to be marred by litter, although litter perception varies with many parameters such as age, socioeconomic status and gender. Although not litter, large accumulations of seaweed and algae are likely to be an aesthetic problem (both in visual impact and odour). If associated with flying or biting insects such accumulations may also be a nuisance. The variety of litter found in recreational water or washed up on the beach is considerable, including:

- flotsam and jetsam, including wooden crates;
- cardboard cartons and newspaper;
- steel drums;
- plastic containers and foam products;
- rubber goods, such as vehicle tyres;
- bottles and bottle tops, cans;
- dead animals or animal bones;
- human hair;
- discarded clothing;
- hypodermic syringes, needles and other medical wastes;
- cigarette butts and packets, matchsticks; and
- fish netting, fishing line and rope ends.

Litter counts have been considered as possible proxy indicators of the likelihood of gastrointestinal effects associated with swimming. For example, high incidence rates of self-reported gastrointestinal illness after bathing in sewage-polluted water have been associated with public perceptions of different items affecting the aesthetic appearance of recreational water and beaches (University of Surrey 1987). The presence of the following items was positively correlated with the likelihood of self-reported gastrointestinal symptoms: discarded food/wrapping; bottles/cans; broken bottles; paper litter; dead fish; dead birds; chemicals; oil slicks; human/animal excrement (particularly from dogs, cats, cattle or birds); discarded condoms and discarded sanitary towels.

The reliability and validity of litter counts as measures of health protection need to be tested among different populations and in different exposure situations (Philipp *et al* 1997). Beach surveys for the extent of littering are, however, useful as indicators of the need for behavioural change (WHO 1994). To be worthwhile in research litter counts, as measures of aesthetic quality and as potential indicators of the likelihood of illness associated with the use of the recreational water area, must be able to:

- classify different levels of beach and water quality, and the density of different litter and waste items before and after any environmental improvements or cleansing operations;
- be useful when compared with conventional microbial and chemical indicators of recreational water and beach quality;
- differentiate between the density of different pollutants deposited by the public on beaches from pollutants that originated elsewhere and were then washed ashore;

- show consistent findings when used in studies of similar population groups exposed to the same pollutant patterns; and
- show a correlation with variations in the human population density of recreational water and beaches (Philipp 1992, IEHO 1993, Philipp *et al* 1997).

10.2.4 Odour

Recreational water and beach users can be deterred by objectionable smells associated with sewage effluent, decaying organic matter such as vegetation, dead animals or fish, and discharged diesel oil or petrol. Odour thresholds and their association with concentrations of different pollutants in the recreational water environment have not been determined.

The presence of dissolved oxygen in the water body will be important in preventing the formation of undesirable amounts of odorous hydrogen sulfide.

10.2.5 Noise

Traffic on nearby roads, trade hawkers and indiscriminate use of beach buggies, motorbikes, portable radios and hi-fi equipment, motorboats and jet-skis can all disturb tranquillity for the beach and water user; at the same time, some people enjoy noisy activities (Velimirovic 1990). Mindful of the need for mutual respect, authorities often zone areas for different activities (WHO 1989).

10.3 ECONOMIC CONSEQUENCES

The public often perceives the quality of recreational water to be very different from its actual microbial or chemical quality (Philipp 1994). Some studies have shown that rivers of good microbial or chemical quality have been perceived as poor by the public because of aesthetic pollution (Dinius 1981, House 1993). Poor aesthetic recreational water and beach quality may, however, also imply poor microbial or chemical water quality.

The economic aspects associated with cleaning the coastline have been reviewed by Bartram and Rees (2000). Local economies may depend on the aesthetic quality of recreational water areas and many fear that environmental degradation of beaches could lead to loss of income from tourism (WHO 1990, Godlee and Walker 1991, Philipp 1992). At resort beaches litter may have an economic effect on the region. During 1987 and 1988, beach closures in New York and New Jersey in the United States caused by litter accumulation, together with the public's perception of degraded beach and water quality, cost the local economy several billion dollars (Valle-Levinson and Swanson 1991). The economic effects attributed to the loss of use of the environment for tourists and other economic purposes were:

- loss of tourist days;
- damage to the local tourist infrastructure (loss of income for hotels, restaurants, bathing resorts, other amenities etc);
- damage to tourist-dependent activities (loss of income for clothing manufacture, the food industry, general commerce etc);
- damage to fisheries (reduction in fish catch, depreciation of the price of seafood);

- damage to fisheries-dependent activities (fishing equipment production and sales, fisheries products etc); and
- damage to the image of the recreational area at both the national and international levels (WHO 1990, Philipp 1992).

A further economic factor that should be taken into consideration is the health-care cost associated with beach litter, in particular hospital waste washed up on beaches (Philipp 1991, Walker 1991, Anon 1994). The direct health-care costs arising from discarded hypodermic syringe needles have been studied and found to be considerable (Philipp 1993).

10.4 GUIDELINE VALUES AND MANAGEMENT

As guidelines are aimed at protecting public health no guideline values have been established for aesthetic aspects. Aesthetic aspects, however, are important in maximising the benefit of recreational water use.

Questions about aesthetic factors raised frequently for local managerial consideration include the following (Philipp 1993):

- Are wastes there?
- If present, where are the wastes coming from?
- Are they causing aesthetic problems?
- Could the aesthetic problems be responsible for economic losses in the local community?
- Can the effects (if any) be stopped?
- Who should control the problems?
- What will it cost and can any loss of environmental opportunity be measured?

Mechanical beach cleaning usually involves motorised equipment using a sieve that is dragged through the top layer of the sand. The sieve retains the litter but cigarette butts and other small items usually pass through. Resort beaches use such equipment because it is fast and provides an aesthetically clean recreational area for visitors. In areas with, for example, medical waste, sewage-related debris or other potentially harmful items, mechanical cleaning reduces health risks for those cleaning the beach, because no manual picking up of material is involved. The use of mechanical cleaning at rural beaches has been questioned because such cleaning affects local ecology (Llewellyn and Shackley 1996).

Other strategies for keeping recreational water areas free of litter include:

- providing waste bins and emptying them frequently;
- suggesting that recreational water users take their litter home with them;
- using people to manually pick up litter; and
- inhibiting litter creation at its source.

Examples are the banning of smoking on beaches, as recently employed by Sydney's Manly Council, and public education campaigns such as 'The Drain is Just for Rain' and 'Don't be a Tosser'.

10.5 MONITORING

This section should be read in conjunction with Section 2.6.5 on the design and implementation of monitoring programs for aesthetic aspects of recreational water.

A monitoring program should be implemented to provide the public with information on the aesthetic aspects of recreational water bodies in combination with data on microbial water quality. Microbial water quality monitoring should be conducted at prescribed intervals, with aesthetic aspects assessed more frequently (eg daily). Data should be collected on the presence and amount of:

- plastics;
- sanitary items;
- algae;
- tar;
- oil;
- litter;
- abnormal water colour;
- grease balls, which may also harbour microbial contaminants; and
- anything else that may cause aesthetic revulsion (eg shopping trolleys, car bodies).

The aesthetic data should be processed alongside the microbial water-quality data to give a combined classification for the recreational area. Aesthetic aspects are considered so important that an 'excellent' microbial classification may be reduced to 'good' or even 'poor' if the beach looks bad. Relevant regulatory agencies should inform local municipalities, tourist information offices, local newspapers, TV and radio of the weekly results. Local municipalities should also receive a report outlining raw microbial data for each evaluated parameter and the results of visual inspections, along with suggestions for improvements. Such a system gives the public confidence that their concerns are being taken seriously and has encouraged many municipalities to improve the aesthetic aspects of their bathing areas.

To assess loads and volumes of rubbish and pollutants additional monitoring during wet weather events should occur in addition to regular dry weather monitoring. A larger volume of gross pollutants, i.e. bottles, plastics, leaves, are flushed out of gutters and mangroves during rain events.

Methods of conducting marine debris surveys have been discussed elsewhere (Bartram and Rees 2000). The purposes of marine debris monitoring may include one or more of the following:

- to provide information on the types, quantities and distribution of marine debris (Williams and Simmons 1997);
- to provide insight into problems and threats associated with an area (Rees and Pond 1995);
- to assess the effectiveness of legislation and coastal management policies (Earll *et al* 1997);
- to identify sources of marine debris (Earll *et al* 1997);
- to explore public health issues relating to marine debris (Philipp 1993, Philipp *et al* 1997); and
- to increase public awareness of the condition of the coastline (Rees and Pond 1995).

Large-scale monitoring programs for marine debris often rely on volunteers to survey the beaches and collect data (Marine Conservation Society 2002). However, it is not usually possible to verify the findings in a sample of locations before the next high tide. Tide changes can also be accompanied by changes in water currents and wind direction. Nevertheless, reliable data can be collected if comprehensive guidance is given to ensure comparable approaches by different groups of volunteers and if validated questionnaire methods are used consistently and uniformly. Internal cross-checks of such methods have confirmed the consistency of the data collected (Philipp 1993).

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APPENDIX I WATER BODY ASSESSMENT FOR OCCURRENCE OF FRESHWATER CYANOBACTERIA

The water body inspection does not constitute a report. Its purpose is to identify potential water risk factors for freshwater recreational areas.

A1.1 SITE ASSESSMENT

This water body inspection provides a starting point, and identifies the basic process by which an assessment should be carried out and the critical environmental factors that should be investigated.

Start the assessment of the cyanobacterial status of a recreational site with a review of previous history and where applicable an assessment of what triggers cyanobacterial blooms, including when and how the guidelines are exceeded. The cyanobacterial data and the need for any further information, much of which may already be available, should be assessed. Important information may include weather conditions and nutrient levels.

Local authorities will usually have GIS systems or maps to identify important conditions that could cause a problem. The initial emphasis of any assessment should be on existing conditions and any possible changes to the environment and should use resource information, local data and historical information. In addition, *identifying what is not known is important*. Gaps in knowledge about the area can be addressed by inspecting water body and reviewing known existing conditions.

To assess the immediate area an annotated map of the water body and surrounding area is required. The water body inspection can be used to verify that all aspects and areas that should be included on the map have been added. All possible recreational uses of the lake should be identified and included. Possible sources of nutrients that could support the growth of cyanobacteria should also be identified (rivers, streams, stormwater drains, outfalls etc) and included on the map. Where available maps of the surrounding area, indicating land use, topography and infrastructure networks (sewage, wastewater and stormwater sources etc) should be included.

Environmental factors that contribute to cyanobacterial growth are complex. However, some basic conditions can be identified to provide a measure of the likelihood of a cyanobacterial bloom occurring in a water body. These include a history of cyanobacteria, temperature, nutrients and thermal stratification. With these measurements a susceptibility category can be identified using Table A1.1. Note that these values are only a guide and special situations not covered in the table may occur supporting the formation of a bloom.

Table A1.1 Susceptibility category

Organisms	Environmental factor			
	History of cyanobacteria	Water temperature (°C)	Nutrients: total phosphorus (µg/L)	Thermal stratification
Very low (good)	No	< 15	< 10	No
Low	Yes	15–20	< 10	Infrequent
Moderate	Yes	20–25	10–25	Occasional
High	Yes	> 25	25–100	Frequent and persistent
Very high (poor)	Yes	> 25	> 100	Frequent and persistent/strong

A1.2 HISTORY OF CYANOBACTERIA

The presence of cyanobacteria in a water body is a good indicator of possible future problems. Have there been specific incidents, such as animal deaths or human illness, that have been suspected of being associated with exposure to cyanobacteria and toxins? Have there been historical blooms of cyanobacteria?

A1.3 TEMPERATURE

Cyanobacterial and algal growth rate is temperature dependent. Growth can occur at low temperatures, although experience has shown that there is significant potential for growth above about 15°C, and maximum growth rates are attained by most cyanobacteria at temperatures above 25°C.

A1.4 NUTRIENTS

Mass developments of cyanobacteria are associated with high nutrient concentrations. Phosphorus is usually the key nutrient controlling proliferation, although the availability of nitrogen may be an important variable to assess because it can influence whether or not nitrogen-fixing species dominate. However, total phosphorus concentration in the water body can be a simple guide to the influence of nutrients on cyanobacterial growth. In general, a total phosphorus level of 10–25 µg/L presents a moderate risk of the growth of cyanobacteria. The phosphorus concentration reflects the potential for increased algal and cyanobacterial biomass. For levels less than 10 µg/L there is a low risk of cyanobacterial growth; a level greater than 25 µg/L provides good growth potential.

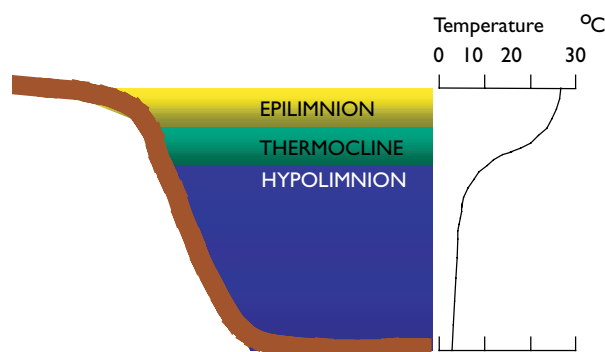
When assessing a water body, any sources or potential sources of nutrients should be identified. These could include:

- sewage outfall;
- on-site or private sewage disposal systems;
- intensive agricultural activities, possibly resulting in run-off of untreated animal effluent;
- rivers and streams;
- slopes affected by erosion; and
- urban stormwater.

A1.5 STRATIFICATION

The thermal stratification of a water body is influenced by its morphology, the latitude, weather conditions and the physical properties of the water. It can be determined by measuring vertical profiles of temperature within the water body. Where thermal stratification occurs, it results in a water body functioning as two separate masses of water (the epilimnion and the hypolimnion) with different physicochemical characteristics and cyanobacterial populations, and with a transitional layer (the thermocline) sandwiched between (Figure A1.1). Cyanobacteria are able to regulate their buoyancy and move between these layers into areas of optimal light conditions which gives them an advantage over other phytoplankton that cannot regulate their buoyancy and migrate in this way.

Figure A1.1 Stratification of a typical freshwater body



Stratification can also result in substantial release of phosphorus from sediments, causing an increase in the internal loading of the water body, which in turn can result in an increase in cyanobacterial biomass. During stratified conditions, iron-bound phosphorus in the sediments can become a major source of phosphorus for cyanobacteria. Under oxygenated conditions (ie in a well-mixed water body) phosphorus-rich sediments are sealed by an oxidised surface layer involving an iron–phosphorus complex. However, under stratified conditions (ie in an unmixed water body) the sediment surface becomes anoxic because of microbial activity in the sediments. Under these conditions the complex breaks down, resulting in phosphorus release from the sediments.

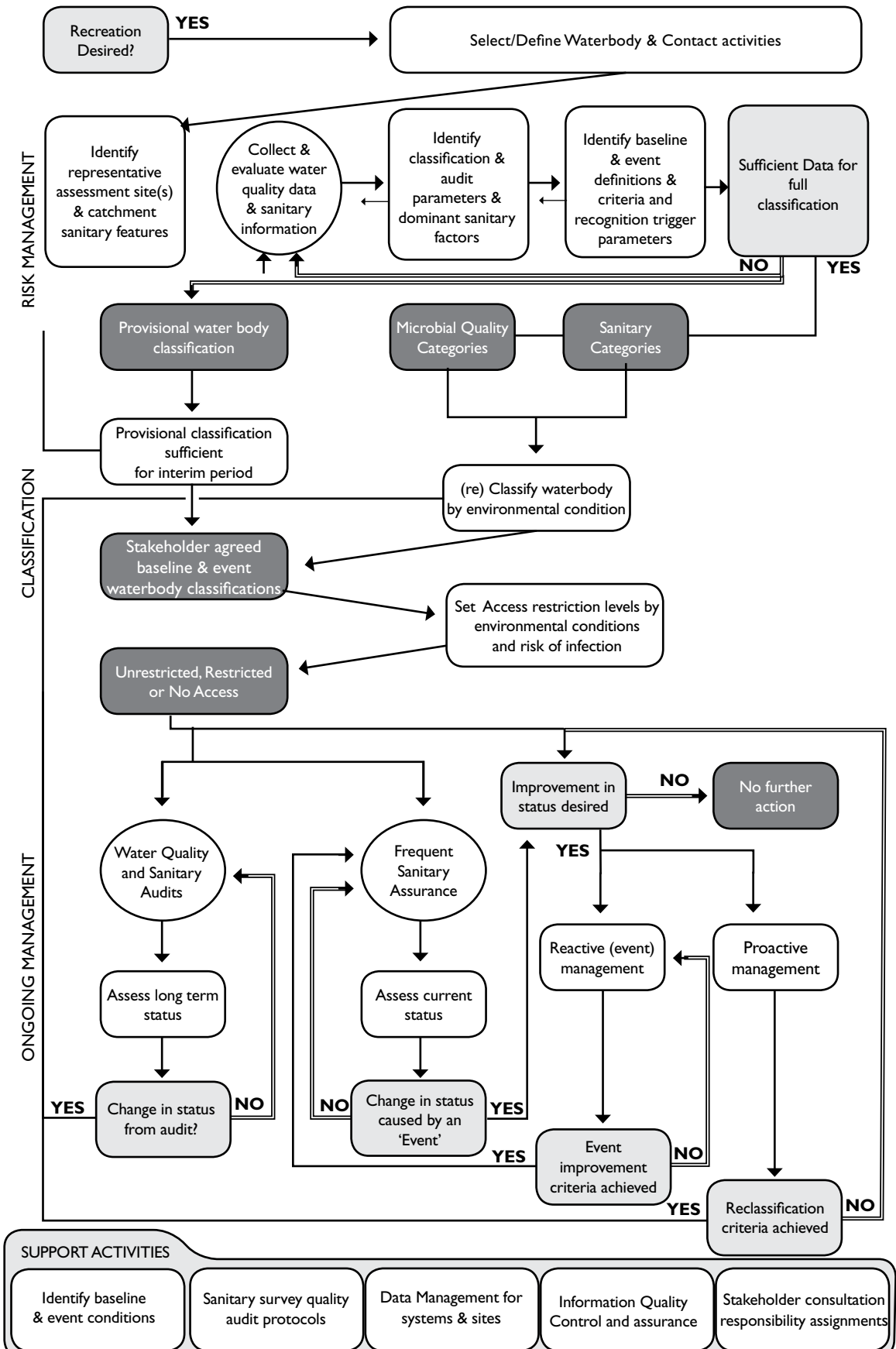
AI.6 BLOOM FORMATION

In contrast to true algae many species of planktonic cyanobacteria possess specialised, intracellular gas vesicles, which enable the cells to regulate their buoyancy and thus to actively seek water depths with optimal growth conditions, as explained above. However, regulation of buoyancy by changing the amount of gas in the vesicles is slow. Species that have adapted to turbulent mixing by enlarging their gas vesicles will take a few days to reduce their buoyancy in order to adapt to quieter conditions. When the weather changes from stormy to fine, changing the water from turbulent to strongly stratified, many excessively buoyant cells or colonies of cells may accumulate at the surface. Light winds drive them to leeward shores and bays where they form scums. In extreme cases, such agglomerations may become very dense and even acquire a gelatinous consistency. More frequently they are seen as blooms, which are streaks or slimy scums that may even look like blue-green paint or jelly. Blooms distributed evenly throughout the upper water layer may be dense enough to cause visible discolouration. Scums, however, have frequently been reported to accumulate cells by a factor of 1000 or more; million-fold accumulations to pea-soup consistency have been observed and scums of species with substantial amounts of mucilage may reach gelatinous consistency. These situations can pose a serious health risk to recreational users of the area.

While accumulations of cyanobacteria are usually caused by planktonic species in eutrophic waters, benthic mats in oligotrophic waters can occasionally cause problems. These surface-covering mats can grow only in clear water, in which sunlight penetrates to the bottom. During sunny days their photosynthesis may lead to high rates of oxygen production, causing bubbles, which loosen parts of the mats and drive them to the surface. Again, these situations can pose a serious health risk.

APPENDIX 2 MICROBIAL WATER QUALITY ASSESSMENT AND MANAGEMENT FLOW CHART

Risk based Recreational Water Quality Management



APPENDIX 3 CALCULATION OF THE 95TH PERCENTILE

Individual regulatory authorities should decide on the most appropriate method for calculation of percentiles based on data availability, statistical considerations and local resources. Two main approaches can be used — parametric and nonparametric.

Parametric approach

The parametric approach is based on the samples having been drawn from a particular statistical distribution — typically the lognormal distribution for microbial data. The 95th percentile of that distribution is used, calculated from the estimated population parameters, which are derived from the mean and standard deviation of the logarithms of the data. A variation of the parametric approach, using Shapiro–Wilk coefficients, may be suitable in some circumstances. The nonparametric approach (see below) uses data ranking and does not assume any particular distribution.

The standard parametric approach for lognormal distributions is outlined in Bartram and Rees (2000). This approach requires sufficient data to define the mean and standard deviation of the $\log_{10}$ faecal indicator counts. Where the data fit a lognormal distribution, this method gives a robust estimate of the 95th percentile, with less variance than any other method. Ideally, there should be complete enumeration by the microbiology laboratory to avoid producing censored data items (reported, for example, as < 10 per 100 mL). Also, there should be no zero counts.

Adjustments are sometimes used when these conditions are not fulfilled, although they are not consistent with a lognormal distribution and they exaggerate the mean and reduce the standard deviation. Possible adjustments include:

- avoiding zero counts by increasing every reading by one and reducing the resultant geometric mean by one (Bartram and Rees 2000);
- using half the detection limit as a substitute value when levels below the limit of detection are reported; and
- doubling the maximum detection limit when detections are reported as too numerous to count.

Mostly, these adjustments will produce 95th percentile estimates that are too low.

Instead of making such adjustments, a better approach where the conditions for the standard parametric assessment are not fulfilled would be to make use of the Shapiro–Wilk coefficients of the ranked, $\log_{10}$ transformed enumerations. By this means the normality of the dataset may be tested (Royston 1995), a best linear unbiased estimate of the standard deviation made, the mean estimated and a 95th percentile calculation carried out. Censorship of up to 80% of the results may be accommodated provided the sample size is sufficient (Royston 1993).

For datasets with sufficient entries and complete enumeration the 95th percentile point of the lognormal probability density function is defined as:

$$\text{Log}_{10} 95\text{ile} = \text{Arithmetic mean log}_{10} \text{ bacterial concentration} + (1.6449 \text{ standard deviation of log}_{10} \text{ bacterial concentration}).$$

In calculating this statistic for a column of bacterial data acquired from one water body all enumerations should be converted to $\log_{10}$ values and the mean and standard deviation should be calculated on the $\log_{10}$ transformed data.

Nonparametric approach

Sample percentiles can also be calculated by a two-step nonparametric procedure. First, the data are ranked in ascending order and the value of the required percentile is calculated using an appropriate formula — each formula giving a different result. The calculated result is seldom an integer, so in the second step an interpolation is required between adjacent data. The interpolation is commonly carried out on the raw data but as Hunter (2002) has pointed out, the relevant $\log_{10}$ transformed data should be used, on the default assumption that the bacteria will be lognormally distributed. On this basis the appropriate formula is:

$$\log_{10} X_{0.95} = (1 - r_{\text{frac}}) \log_{10} X_r + r_{\text{frac}} \log_{10} X(r + 1)$$

Where:

- $X_{0.95}$ is the required 95th percentile
- $X_1, X_2, \dots, X_n$ are the n data arranged in ascending order
- X_r is the r_{intth} ordered datum
- r is the ranking formula being used for the 95th percentile (see below)
- r_{frac} is the fractional part of r .

Where a water body is well managed to ensure that recreational activities are not undertaken during periods when the water body quality is influenced by rainfall, samples taken during such periods should not be used in the overall assessment of the ranking.

Formulae

Various formulae have been used in the water industry (Ellis 1989) but only two offer a close approximation to the lognormal distribution: the Hazen, which yields 95th percentile estimates that are slightly low and the Blom, which yields estimates that are slightly high. For the most part, the average of these two yield estimates is more accurate than either on its own. For the 95th percentile their formulae are:

$$r_{\text{Hazen}} = \frac{1}{2} + 0.95n$$

$$r_{\text{Blom}} = 0.375 + 0.95(n + 0.25)$$

$$r_{\text{Average}} = 0.4375 + 0.95(n + 0.125)$$

For $n = 13$ or 32 , the Blom formula is more accurate; for $n = 17$ – 26 , the Hazen formula is more accurate.

The Blom formula needs at least 13 samples to calculate the 95th percentile, whereas the Hazen formula will yield a result with only 10 samples (the highest reading is the 95th percentile estimate in this case). Note that the ExcelTM spreadsheet percentile formula gives estimates that are too low to be satisfactory. Bayesian approaches to estimate percentile compliance are described by McBride and Ellis (2001).

The exact value of the best point estimate, or expectation, of $X_{0.95}$ (for a normal distribution) may be ascertained from tables of normal order statistics¹⁰, deriving r_{frac} by interpolation between the standardised normal scores of the relevant ranks. Although any of the above formulae will provide a reasonable approximation to the lognormal 95th percentile, their confidence intervals are wider than the standard parametric or Shapiro–Wilk approaches described above (R Lugg, Leederville, Western Australia, pers comm). Also, the absence of any quantitative measure of the dispersion of the data make interpretation problematic.

An example of a calculation of a 95th percentile is shown in Box A3.1

Box A3.1 Example calculation of 95th percentile

Assume that we have 100 data, of which the six highest ($X_{95} - X_{100}$) are 200, 320, 357, 389, 410 and 440 (Bartram and Rees 2000, Table 8.3). For $n = 100$ we have $r_{\text{Hazen}} = 95.5$, $r_{\text{Blom}} = 95.6125$ and $r_{\text{Average}} = 95.55625$. Then r_{int} is 95 in all cases, and r_{frac} is 0.5, 0.6125 and 0.55625 respectively. Using the $\log_{10}$ transformed data, the 95th percentile as estimated by the Hazen formula is:

$$X_{0.95} = \text{Antilog}_{10} [(0.5 \times \log_{10} 200) + (0.5 \times \log_{10} 320)] = 253$$

Similarly, the 95th percentile estimated by the Blom formula is:

$$X_{0.95} = \text{Antilog}_{10} [(0.3875 \times \log_{10} 200) + (0.6125 \times \log_{10} 320)] = 267$$

By averaging, we have:

$$X_{0.95} = \text{Antilog}_{10} [(0.44375 \times \log_{10} 200) + (0.55625 \times \log_{10} 320)] = 260$$

The exact value, by interpolation between the standardised normal scores for X_{95} and X_{96} , is 260 ($r_{\text{frac}} = 0.55887$).

¹⁰ see, for example, the Biometrika Tables for Statisticians, Vol II (1976), Table 9

APPENDIX 4 EXAMPLE OF SANITARY INSPECTIONS OF RECREATIONAL WATER QUALITY

PLANNING FOR A SANITARY INSPECTION

Introduction

The purpose of the sanitary inspection is to provide an ‘assessment of the area’s susceptibility of influence from human versus bird and other animal faecal contamination’ (WHO 1999).

The primary source of pathogens is human faecal contamination (WHO 2001). In most cases the most important risk will arise from microbial contamination. It is possible that risks associated with toxic algae may arise in some inland waters and may well be associated with the discharges that would give rise to microbial contamination (ie from the associated nutrients). This part of the guidelines addresses microbial contamination only but the approach can be extended to other risks.

The results of the sanitary inspection will be combined with the microbial (enterococci) indicator measure of faecal contamination to provide a primary classification of the water body. This is discussed in later sections.

The success of a sanitary inspection relies heavily on preparation and planning. It is important that as much accurate, relevant information as possible (including past monitoring results for faecal enterococci, where available) be collected before the survey. This enables important issues to be identified for further investigation, improves quantification of each risk and minimises the need for repeat interviews and visits.

In most cases, the sanitary inspection of the catchment should be undertaken during both dry and wet weather and a beach classification determined for each circumstance. The rationale for this is that under certain conditions (eg during rainfall and for up to three days after heavy rainfall) bathing water quality may deteriorate and a beach classification may be ‘good’ under dry conditions but ‘poor’ during rainfall-driven events. In wet event conditions the sanitary inspection would show additional sources of pollution (eg sewage overflows into stormwater) and this would be expected to be supported by increases in microbial monitoring results.

Define the recreational area

It is important to define the recreational water body of interest in order to focus data collection. For example, is it only the official swimming zone between the flags, is it the entire beach or does it include areas that are officially excluded from access but where people swim anyway?

Information relevant to the assessment includes:

- a map that shows the depth of water and currents;
- the quality of the waters of interest and the time and immediate history relevant to the measurements (particularly before and after rain);
- usage, particularly number of bathers (including proportion of vulnerable people, such as children, the elderly, people with weakened immune systems and international and other tourists where relevant) and existence of toilet facilities;

- information pertinent to the dilution, dispersion and attenuation of discharges in the waters of interest, including information on currents and stratification, temperature, light intensity;
- previous events relating to the water body that led to closure or illness (eg occurrence of microorganisms or other factors such as algal blooms); and
- the significance of the recreational water body, its importance to the community, and community reaction to the water being unsuitable for recreational use.

Identify contaminant sources and assemble relevant information

The quality of information about the unique features of each catchment and each discharge largely determines the accuracy and usefulness of the sanitary inspection.

Information should be gathered as early as possible in the process. Contact with multiple stakeholders is likely to be necessary (eg state natural resources agencies, environmental regulators, catchment management authorities and other water and land management agencies).

As first steps in the information gathering it will be important to:

- Determine, in the relevant catchment
 - where pollution discharges may arise from
 - the contaminants that may travel to the water body
 (The catchment will extend downstream unless there is potential for back flow).
- Identify all possible sources of potentially significant contamination so that information gathering can focus on these sources. The following is a checklist of possibilities.

Likely to be most significant

- bathers;
- wastewater discharges, major centres;
- local sewage discharges (eg toilet facilities, campers, fishermen, boats, septic tanks);
- urban development, stormwater run-off;
- farming, grazing, intensive animal husbandry (especially where animals have direct access to the water body);
- storm events causing high pollutant load;
- native animals near waterways; and
- algal blooms (including nutrients).

Likely to be less significant

- sediments (may store indicators and, to a lesser extent, infective viruses);
- birds (although they contribute high numbers of faecal indicators);
- vegetation (rotting, mobilisation);
- agricultural chemicals;

- forestry;
- transport and roads (eg run-off, erosion);
- landfills;
- spills of hazardous materials (eg fuel, fertilisers, septage);
- industrial (wastes, aerial deposition);
- mining; and
- contaminated groundwater sources.

The following information should be obtained to enable the assessment of sources of contamination. Reasonable effort should be made to gain this information but the list is neither exclusive nor mandatory: other information sources can be used as appropriate.

Maps

- A map of the catchment on which to identify potential contamination sources.

Discharge of stormwater

- **The location of urban areas and their main stormwater drainage systems that lead to the recreational water body, including stormwater retention basins and their storm capacity.**

- The location and type of stormwater treatment, where relevant.
- The frequency and duration of storm events and the flow rate and quality that results, including any information on the first flush.

Discharges of municipal wastewater

- Information on the sewerage system, particularly where common effluent drainage systems may exist, and information on the frequency and location of overflows from the sewerage system and failure of pumping systems (both under storm conditions and through system failure), or significant septic tank systems (and the potential for run-off from these).
- The location of dry weather discharges which have a significant potential for contamination, such as discharges from wastewater treatment plants and from broken pipes, and the level of treatment before discharge.
- Other wet weather and dry weather discharges to streams or drainage systems that can affect the water body.
- Areas where reuse of wastewater occurs and situations in which run-off from these areas may occur.
- The presence and location of any illegal connections from sewerage to stormwater systems.

Other potentially significant discharges

- Other sources of potentially significant microbial contamination such as feedlots, abattoirs, farms with cattle/sheep/pigs/horses/chickens, refuse depots/dumps.
- Sources of potentially significant contamination from industrial manufacturing operations.
- Other sources that are generally less likely to give rise to significant contamination including leakage from fuel depots, pesticides (eg herbicides, chemical spray drift, intensive horticulture, forestry) or spills such as may occur from traffic accidents (if there is limited dilution and incidents are likely).
- The presence of large populations of birds (eg waterfowl, etc) which contribute mainly faecal indicators, although seagulls may also transport bacterial and other pathogens if the birds feed on nearby sewage ponds.

Assemble information and review

The assembled information should be thoroughly reviewed before the field inspection to maximise the effectiveness and efficiency of the field work and interviews. Summary tables and diagrams are particularly useful for ensuring that the system and the issues are well understood before the next stage.

CARRY OUT FIELD INSPECTION, INTERVIEWS AND WORKSHOP

Field inspection

In undertaking the sanitary field inspection it is important to be systematic so that issues are not overlooked. It is recommended that a checklist of issues that need to be considered be developed at the outset.

Only personnel who are familiar with the catchment and with good operational knowledge of water, wastewater and stormwater systems should undertake the sanitary inspection.

The inspection involves visits to locations identified in the data review stage as potential sources of faecal contamination.

Interviews

People with knowledge of the catchment and water body should be interviewed to identify things that could pose a risk for the quality of received water. For example, those to be interviewed should include staff from authorities responsible for:

- the recreational water body;
- river discharges to the water body;
- urban drainage and other discharges, such as septic tanks;
- discharges from the sewerage system; and
- environmental regulation (such as the state or territory environment protection agency).

Workshop

A workshop with stakeholders may be held to identify and assess the risks arising from the hazards identified during the initial data review, site visit and interviews.

A workshop is particularly useful if there are several areas and catchments to be assessed and if there are other authorities with relevant responsibilities (such as the environment protection agency or catchment management board) who need to understand the issues and their management responsibilities. If there is only one recreational area and catchment to be assessed a workshop may not be needed.

The workshop should be facilitated by a person with significant experience in HACCP and risk assessment to keep the responses focused within the framework. The workshop might need to consider large amounts of information, with significant consequences, so the approach needs to be focused to make best use of the knowledge and ideas generated.

Source: Adapted from WSAA (2003)

APPENDIX 5 PROCESS REPORT

In 2001, the National Health and Medical Research Council (NHMRC) established the Working Group on Healthy Recreational Water Use (Working Group) to oversee the development of guidelines on the use of recreational water.

The guidelines would address natural fresh, estuarine and marine recreational water bodies but specifically exclude swimming pools, spas and hydrotherapy pools. The guidelines would replace the 1990 NHMRC *Australian Guidelines for Recreational Water Use*.

New Australian guidelines were required to address recent developments in risk assessment approaches to the management of microbiological water quality and provide guidance on cyanotoxins and other physical and chemical hazards. This analysis was undertaken after a request for tender to undertake a literature review. Flinders University (microbial aspects), the Australian Water Quality Centre (cyanobacterial aspects) and Murdoch University (physical, chemical and aesthetic aspects) undertook the literature review on behalf of the NHMRC.

Public consultation on the draft document was undertaken during June and July 2004, with the draft guidelines advertised in the *Government Notices Gazette* and *The Weekend Australian*, and invitations forwarded to key stakeholders and those with a known interest in recreational water quality. The Working Group met on 30–31 August 2004 to consider the submissions. All submissions received during the consultation were taken into consideration. The draft guidelines underwent an independent review against the NHMRC key criteria for assessing public health guidelines. The guidelines were then considered by the Health Advisory Committee before being endorsed by the NHMRC in July 2005.

Submissions were received from the following individuals and organisations:

Dr Glen Shaw	National Research Centre for Environmental Toxicology
Dr David Sheeham	SGC Environmental Services
Mr Greg Vickery	Australian Red Cross
Dr Peter Hobson	Australian Water Quality Centre
Dr Andrew Negri	Australian Institute of Marine Sciences
Mr John Toohey	Clarence City Council
Dr David Cunliffe	SA Department of Health
Mr Peter Boettcher	Sun Water
Mr Peter Agnew	Surf Life Saving Australia
Dr Piet Filet	Brisbane City Council
Dr Anne Graesser	Goulburn–Murray Water
Mr Peter Scott	Melbourne Water
Ms Fiona Campbell	NSW Department of Infrastructure, Planning and Natural Resources
Dr Paul Byleveld	NSW Department of Health
Dr Mark Feldwick	WA Department of Health
A/Prof Ron Neller	University of the Sunshine Coast
Mr Michael Jackson	enHealth Council
Ms Christine Coughanowr	Tasmanian Department of Primary Industries, Water and Environment

Working party membership

Chair

Professor Nicholas Ashbolt University of New South Wales

Members

Dr Richard Lugg	Health Department of Western Australia
Ms Clare Bailey	Qld Department of Local Government, Planning, Sport and Recreation
Dr Mike Burch	Australian Water Quality Centre
Mr Alec Percival	Consumers' Health Forum of Australia Inc
Dr Paul Byleveld	NSW Department of Health
Mr Andrew Stevens	QLD Environment Protection Agency Secretariat
Mr Phil Callan	National Health and Medical Research Council
Ms Simone Patton	National Health and Medical Research Council

Terms of reference

The terms of reference of the NHMRC Working Group on Healthy Recreational Water Use are to:

1. Undertake redrafting of the NHMRC *Australian Guidelines for Recreational Use of Water* (1990), ensuring that;
 - the revised guidelines have broad acceptance as an authoritative guide for the protection of public health
 - appropriate international guidelines have been taken into consideration
 - the NHMRC guidelines are evidence based (taking into consideration epidemiological evidence and risk assessment)
 - the NHMRC guidelines are sufficiently explained and understandable for relevant authorities to readily apply
 - the NHMRC guidelines are subject to public consultation in accordance with NHMRC requirements;
2. Develop recreational water guidelines for fresh, estuarine and marine waters and specifically not treated recreational water facilities to be published as a standalone publication and also incorporated into the ANZECC *Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ 2000);
3. Develop a strategy for implementation and dissemination of the final NHMRC guidelines;
4. Routinely report to NHMRC and NRMCC; and
5. The revised guidelines are to be endorsed by NHMRC and NRMCC.

Second stage public consultation

Subsequent to the publication of the guidelines a number of inconsistencies were identified in the document. The document was withdrawn from the NHMRC website while the inconsistencies were checked and a hold was placed on the dissemination of hard copies through NHMRC's external distribution channels. In November and December 2006 the guidelines were released for a second round of public consultation.

The NHMRC Guidelines for Managing Risks in Recreational Water Working Committee (Working Committee) was established in February 2007 to consider changes recommended as a result of the public consultation and to recommend inclusion in the guidelines as appropriate. The Working Committee met in April 2007.

Submissions were received from the following individuals and organisations:

Ms Helen Ptolemy	NSW Department of Health
Mr Glenn McGregor	QLD Dept of Natural Resources and Water
Mr Mark Akester	Clean Ocean Foundation
Dr Philip Orr	SEQWater
Mr Peter Scott	Melbourne Water Corporation
Ms Bree Abbott	Environmental Health Directorate, WA Department of Health
Ms Jan Bowman	VIC Department of Human Services
Mr John Woollard	Health Protection Service, ACT Health
Dr Richard Lugg	Environmental Health Consultant, WA Department of Health
Mr W Stanton	Valentine Area Progress Association
Mr George Lasek	ACT National Capital Authority

The Working Committee recommended that a peer review be undertaken to ensure the revised guidelines reflected the latest evidence available. The peer review was undertaken in June 2007 by Professor Don Bursill, Chair of the NHMRC Water Quality Advisory Committee.

Working party membership

Chair

Dr Mike Burch	Australian Water Quality Centre
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Members

Professor Howard Fallowfield	Flinders University
A/Professor Heather Chapmen	CRC Water Quality and Treatment
Dr Martha Sinclair	Cooperative Research Centre for Water Quality and Treatment
Dr Glen Shaw	Griffith University

Terms of reference

The NHMRC Guidelines for Managing Risks in Recreational Water Working Committee will advise the CEO of NHMRC on:

1. Proposed changes to the Draft Guidelines for Managing Risks in Recreational Water (the Guidelines) arising from the public consultation held in November and December 2006; and
2. A revised guideline incorporating recommended amendments, ensuring that:
 - recommendations are based on current scientific evidence;
 - recommendations are in line with appropriate international guidelines; and
 - justification is provided for all amendments.

Consultants

During the development of the guidelines contributions were incorporated from a range of experts including:

A/Professor Nancy Cromar	Flinders University
Dr Peter Hobson	Australian Water Quality Centre
Dr Duncan Craig	Flinders University
Dr Muriel Lepesteur-Thompson	Murdoch University

The guidelines were considered by the Water Quality Advisory Committee prior to being submitted to the NHMRC Council for endorsement and recommendation to the NHMRC CEO for approval.

The NHMRC has established a vast network of stakeholders including health, environment, resource management and water agencies, government and non-government agencies and companies. The NHMRC will ensure that the guidelines are widely disseminated through well-established channels to ensure that all relevant agencies are advised of the release of the guidelines and to encourage adoption by state and territory governments.

APPENDIX 6 GLOSSARY

Algae

A large group of diverse unicellular and multicellular aquatic plants that occur in both fresh water and seawater.

Algal bloom

A sudden increase in the number of algae in a water body to levels that cause visible discolouration of the water.

Alkaloids

A class of over 3,000 nitrogen-containing chemicals that are produced by plants and have effects in humans and animals.

Allergic/Allergy

A reaction to a foreign substance by the immune system (the body's system of defense against foreign organisms) resulting in conditions such as hay fever, asthma, eczema and in severe cases anaphylaxis.

Anabaena

A free floating filamentous cyanobacteria that can be solitary or form into a gelatinous mass with some species producing cyanotoxins.

Anabaena circinalis

A species of *Anabaena* that produces neurotoxins, anatoxin-a and paralytic shellfish poisons.

Anthropogenic

Derived from human activity.

Atopic

A tendency to suffer from a group of conditions including eczema, asthma and hayfever.

Autotrophs

Organisms that are able to make their own food (in the form of sugars) by using the energy of the sun.

Bioaccumulation

Accumulation of a substance in a living organism as a result of its intake both in its food and also from the environment.

Biovolume

A measure of the volume of space occupied by a biological individual or group of individuals. Biovolume is used as quantitative measure of the volume of cell material of algae or cyanobacteria in an environmental sample.

Brevetoxins

Lipophilic 10- and 11-ring polyether chemicals which can cause Neurotoxic Shellfish Poisoning.

Campylobacter

A group of bacteria that is a major cause of diarrhoeal illness.

Carcinogenic

Any substance or agent that causes cancer.

Catchment

Area of land that collects rainfall and contributes to a recreational water body (streams, rivers, beaches).

Ciguatoxins

Large, heat stable, polyethers produced by certain strains of *Gambierdiscus* found in tropical and subtropical waters around the world and are responsible for the poisoning syndrome known as ciguatera.

Codex Alimentarius

A food quality and safety code developed by the Codex Alimentarius Commission of the Food and Agriculture Organization of the United Nations and the World Health Organization.

Cohort study

An observational study in which a defined group of people (the cohort) is followed over time and outcomes are compared in subsets of the cohort who were exposed or not exposed, or exposed at different levels, to an intervention or other factor of interest.

Coliform bacteria

Group of bacteria whose presence in drinking water can be used as an indicator for operational monitoring. The monitoring of thermotolerant (faecal) coliforms has now been replaced by direct enumeration of the major type, *Escherichia coli*, and for recreational waters generally by the alternative faecal indicator group, intestinal enterococci.

Composite

Aggregate of more than one sampling effort. A composite sample is collected by mixing together (ie integrating) a number of separate samples collected separately over time or over space.

Conjunctiva

A thin clear moist membrane that coats the inner surfaces of the eyelids and the outer surface of the eye.

Critical limit

A prescribed tolerance that must be met to ensure that a critical control point effectively controls a potential health hazard; a criterion that separates acceptability from unacceptability (adapted from Codex Alimentarius).

Cryptosporidium

A parasitic protozoan, the oocysts stage of which is commonly found in lakes and rivers and is highly resistant to disinfection. *Cryptosporidium* has caused several large outbreaks of gastrointestinal illness, with symptoms that include diarrhoea, nausea and stomach cramps. People with severely weakened immune systems (ie severely immunocompromised people) are likely to have more severe and more persistent symptoms than healthy individuals.

Cyanobacteria

Bacteria containing chlorophyll and phycobilins, commonly known as 'blue-green algae'.

Cyanotoxins

A general term for the range of toxins produced by cyanobacteria.

Cylindrospermopsin

A cyclic alkaloid produced by cyanobacteria that can be very toxic for plants and animals including humans.

Debromoaplysiatoxin

Alkaloid toxin produced by *Lyngbya majuscula*.

Dermatological

Involving the condition of the skin.

Destratification

Agitation of water body to break up and mix otherwise stable layers of water.

Diarrhoeic shellfish poisoning

A shellfish associated illness caused by dinoflagellates of the genus *Dinophysis*.

Dinoflagellate

Single-celled, aquatic organism bearing two dissimilar flagella and having characteristics of both plants and animals.

Dinoflagellates

Unicellular aquatic organisms, motile and heterotrophic, parasitic, and/or photosynthetic.

Dinophysistoxins

Heat-stable polyether and lipophilic toxic compounds isolated from dinoflagellates.

Domoic acid

A water soluble toxic amino-acid mimic produced by the marine diatoms *Pseudo-nitzschia* responsible for Amnesic Shellfish Poisoning.

Dose-response

The quantitative relationship between the dose of an agent and an effect caused by the agent.

Enteric pathogen

Pathogen found in the gut.

Enterococci

Group of faecal bacteria common to the faecal matter of warm-blooded animals, including humans; a subset of the faecal streptococci, but generally the vast majority; now referred to in Europe as the intestinal enterococci.

Epidemiology

The study of the distribution and determinants of health/disease states in human populations.

Erythema

Redness or inflammation of the skin or mucous membranes.

***Escherichia coli* (*E. coli*)**

Bacterium found in the gut, used as an indicator of faecal contamination of water (from warm-blooded animals and humans).

Eucaryote

An organism with a defined nucleus (animals, plants and fungi, but not bacteria or cyanobacteria).

Eutrophication

Degradation of water quality due to enrichment by nutrients such as nitrogen and phosphorus, resulting in excessive algal growth and decay and often with low dissolved oxygen in the water.

Eutrophic/Eutrophication

Used to describe the process whereby a water body becomes enriched over time by high levels of plants nutrients, particularly phosphorus and nitrogen. This can occur naturally as a gradual process but can be accelerated by human activity.

Exposure

Contact of a chemical, physical or biological agent with the outer boundary of an organism (eg through inhalation, ingestion or dermal contact).

Exposure assessment

The estimation (qualitative or quantitative) of the magnitude, frequency, duration, route and extent of exposure to one or more contaminated media.

Faecal indicators

see Indicator organisms.

Filamentous

Growth form of many algae and cyanobacteria where they form of long rods, filaments or strands many times longer than wide.

Gastrointestinal

Large, muscular tube that extends from the mouth to the anus, where the movement of muscles and release of hormones and enzymes digest food.

Giardia lamblia

A protozoan frequently found in rivers and lakes. If water containing infectious cysts of *Giardia* is ingested, the protozoan can cause a severe gastrointestinal disease called giardiasis.

Guideline value

The concentration or measure of a water quality characteristic that, based on present knowledge, either does not result in any significant risk to the health of the consumer (health-related guideline value), or is associated with good quality water (aesthetic guideline value).

Hazard

A biological, chemical, physical or radiological agent that has the potential to cause harm.

Hazard analysis critical control point (HACCP) system

A systematic methodology to control safety hazards in a process by applying a two-part technique: first, an analysis that identifies hazards and their severity and likelihood of occurrence; and second, identification of critical control points and their monitoring criteria to establish controls that will reduce, prevent or eliminate the identified hazards.

Hazard control

The application or implementation of preventive measures that can be used to control identified hazards.

Hazard identification

The process of recognising that a hazard exists and defining its characteristics (AS/NZS 3931:1998).

Hazardous event

An incident or situation that can lead to the presence of a hazard (what can happen and how).

Helminth

A worm-like invertebrate of the order Helminthes.

Hepatotoxic

Toxic to the liver.

Heterotrophic bacteria

Bacteria that use organic matter synthesised by other organisms for energy and growth.

Indicator

A specific contaminant, group of contaminants or constituent that signals the presence of something else (eg *E. coli* indicate the possible presence of pathogenic bacteria).

Indicator organisms

Microorganisms whose presence is indicative of pollution or of more harmful microorganisms.

Idiosyncratic

Abnormal susceptibility to a stimulus or substance peculiar to the individual.

Ingestion

Taking into the body by mouth.

Integrated catchment management

The coordinated planning, use and management of water, land, vegetation and other natural resources in a recreational water body catchment, based on cooperation between community groups and government agencies to consider all aspects of catchment management.

Intranasal

Entering the body through the nose.

Intraperitoneal

Into the gut or peritoneum, common method for injecting drugs into the extracellular fluid for gradual absorption into the bloodstream.

Irritation

An observable physiological reaction by the body (ie. skin, eyes, nose and throat) to a stimulus or substance.

Karenia brevis

A single-celled, motile photosynthetic organism that is planktonic and belongs to the group called dinoflagellates. It is a marine species that forms 'red-tide' blooms in oceanic, coastal and estuarine locations in warm-temperate to subtropical waters. It was formerly called *Ptychodiscus brevis* and *Gymnodinium breve* and is known to produce brevetoxins and derivatives.

Leptospirosis

A disease caused by bacteria of the genus *Leptospira* in water contaminated with animal urine, particularly that of rodents. Symptoms include high fever, severe headache, chills, muscle aches and vomiting, and may include jaundice, red eyes, abdominal pain, diarrhoea or a rash. If not treated, the patient could develop kidney damage, meningitis, liver failure and respiratory distress. In rare cases death occurs.

Lipopolysaccharide

Is a large molecule that contains both a lipid and a carbohydrate which makes up the major suprastructure of a gram-negative bacteria and contributes to the structural integrity of the bacteria.

LPS

See lipopolysaccharide.

Lyngbyatoxin

An indole alkaloid toxin produced by *Lyngbya majuscula*.

Lyngbya majuscula

Lyngbya majuscula (Lyngbya) is a naturally occurring, filamentous, bluegreen algae that has occurred in bloom proportions, particularly in sub-tropical coastal waters. It is one of the causes of the human skin irritation 'seaweed dermatitis'. It is also known as 'Fireweed'. Lyngbya produces the alkaloid toxin Lyngbyatoxin.

Maximum risk

Risk in the absence of preventive measures.

Microcystins

Cyclic non-ribosomal peptides produced by cyanobacteria that can be very toxic for plants and animals including humans.

Microcystis

A free floating single cell cyanobacterium that can form large dense colonies with some species producing the toxin microcystin.

Microcystis aeruginosa

A species of *Microcystis* which was historically the first to be identified as producing microcystin.

Microorganism

Organism too small to be visible to the naked eye. Bacteria, viruses, protozoa and some fungi and algae are microorganisms.

Naegleria fowleri

A free-living amoeba that causes primary amoebic meningoencephalitis, an almost invariably fatal condition.

Nematocysts

Individual cells used to inject toxins for defence or capture of prey.

Nodularins

Cyclic nonribosomal peptides produced by cyanobacteria that can be very toxic for plants and animals including humans.

Neurotoxins

A toxin that acts specifically on nerve cells or neurons, usually by interacting with membrane proteins and ion channels and can cause paralysis.

NOAEL

An exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control.

Non-atopic

A tendency not to be atopic.

Particle count

The results of a microscopic examination of treated water with a 'particle counter' — an instrument that classifies suspended particles by number and size.

Pathogen

A disease-causing organism (eg bacteria, viruses, protozoa and helminths).

Peptides

Molecules that hydrolyze into amino acids and form the basic building blocks of proteins.

Pfiesteria piscicida

A microscopic, free-swimming, single-celled organism belonging to the dinoflagellates. *Pfiesteria* has been known to cause fish kills and lesions in fish in coastal waters. Water or water vapor containing this microbe can also produce skin irritation and lesions, gastrointestinal problems, short-term memory loss and other cognitive impairments in humans.

pH

An expression of the intensity of the basic or acid condition of a liquid. Natural waters usually have a pH between 6.5 and 8.5.

Phytoplankton

Microscopic plants that live in the ocean and are the foundation of the marine food chain.

Preventive measure

Any planned action, activity or process that is used to prevent hazards from occurring or reduce them to acceptable levels.

Prokaryote

An organism whose nucleus is not clearly defined (bacteria and cyanobacteria but not animals, plants or fungi).

Protein Phosphatase

Protein phosphatases are enzymes that remove phosphate groups that have been attached to amino acid residues of proteins by protein kinases.

Protozoa

A phylum of single-celled animals.

Quality

The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs; the term 'quality' should not be used to express a degree of excellence (AS/NZS ISO 8402:1994).

Quality assurance

All the planned and systematic activities implemented within the quality system and demonstrated as needed to provide adequate confidence that an entity will fulfil requirements for quality (AS/NZS ISO 8402:1994).

Quality control

Operational techniques and activities that are used to fulfil requirements for quality (AS/NZS ISO 8402:1994).

Quality management

Includes both quality control and quality assurance, as well as additional concepts of quality policy, quality planning and quality improvement. Quality management operates throughout the quality system (AS/NZS ISO 8402:1994).

Quality system

Organisational structure, procedures, processes and resources needed to implement quality management (AS/NZS ISO 8402:1994).

Residual risk

The risk remaining after consideration of existing preventive measures.

Risk

The likelihood of a hazard causing harm in exposed populations in a specified timeframe, including the magnitude of that harm.

Risk assessment

The overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences (adapted from AS/NZS 4360:1999).

Risk management

The systematic evaluation of a system, the identification of hazards and hazardous events, the assessment of risks and the development and implementation of preventive strategies to manage the risks.

Safety Factor

Reductive factor by which an observed or estimated no observed adverse effect level (NOAEL) concentration or dose is divided to arrive at a criterion or standard that is considered safe or without appreciable risk.

Saxitoxins

An alkaloid neurotoxin originally isolated from shellfish where they are concentrated from marine dinoflagellates. Also commonly known as Paralytic Shellfish Poisons (PSPs)

Self-limiting

Limited by its own peculiarities and not by outside influence.

Sensitisation

Sensitisation is the process that causes the body to become highly sensitive to a particular substance. It often involves repeated exposure to that substance.

Stratification

The formation of separate layers (of temperature, plant or animal life) in a water body. Each layer has similar characteristics (eg all water in the layer has the same temperature).

Subacute

Adverse effects occurring as a result of repeated daily dosing of a chemical or exposure to the chemical for part of an organism's lifespan (usually not exceeding 10%). With experimental animals the period of exposure may range from a few days to 6 months.

Surrogate

See Indicator.

Target criteria

Quantitative or qualitative parameters established for preventive measures to indicate performance; performance goals.

Thermotolerant coliforms

See Coliform bacteria.

Total coliforms

See Coliform bacteria.

Toxicology

The study of poisons, their effects, antidotes and detection.

Trichodesmium

A filamentous marine cyanobacterium which sometimes forms large blooms. The blooms are sometimes called 'sea sawdust'.

Tumour-promoting

A non-carcinogenic substance that enhances tumor production in a tissue previously exposed to sub-carcinogenic doses of a carcinogen.

Turbidity

The cloudiness of water caused by the presence of fine suspended matter.

Unicellular

Describes an organism that has only one cell.

Viruses

Molecules of nucleic acid (RNA or DNA) that can enter cells and replicate in them.

APPENDIX 7 ACRONYMS

AFRI	acute febrile respiratory infection
ANZECC	Australia and New Zealand Environment and Conservation Council
CFU	colony forming unit
GI	gastrointestinal infection
GIS	geographical information system
HACCP	hazard analysis critical control points
LOAEL	lowest observed adverse effect level
NHMRC	National Health and Medical Research Council
NOAEL	no observed adverse effect level
NRMCC	Natural Resource Management Ministerial Council
PFU	plaque forming unit
QMRA	quantitative microbial risk assessment
SLRA	screening-level risk assessment
SOPs	standard operating procedures
SPF	sun protection factor
UPF	ultraviolet protection factor
UVR	ultraviolet radiation
WHO	World Health Organization
WSAA	Water Services Association of Australia



WARNING
HEALTH HAZARD

NO SWIMMING