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National Health and Medical Research Council

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Australian Recreational Water Quality Guidelines

Public consultation DRAFT | January 2026

NHMRC

Contents

Acknowledgement of Country

The National Health and Medical Research Council (NHMRC) proudly acknowledges the Traditional Custodians of the Country throughout Australia. We pay our respects to Aboriginal and Torres Strait Islander Elders past and present who have preserved and continue to care for the lands and waters on which we live and work, and from which we benefit each day.

We honour the ongoing deep spiritual, cultural and customary connections of Aboriginal and Torres Strait Island peoples to the Australian landscape, including Australia's coastal, estuarine and freshwaters. Water connects Aboriginal and Torres Strait Islander peoples to their ancestors, stories and responsibilities to care for Country. It takes many forms; fresh, salt, muddy, and across many places including rivers, wetlands, billabongs, floodplains, springs and saltwater Country.

Through the Australian Recreational Water Quality Guidelines, we recognise the strengths and knowledge Aboriginal and Torres Strait Islander peoples provide to caring for our water environments and thank them for their ongoing contributions. We emphasise the importance of working with Aboriginal and Torres Strait Islander communities to embed First Nations knowledge and wisdom to ensure the ongoing preservation of spiritual and cultural values of land and waters, care for Country and protection of human health from water quality hazards.

A Note on Terminology

The term *"recreational water"* is retained in these guidelines to maintain consistency with international standards and public health frameworks that focus on managing water quality risks associated with activities such as swimming and other water-based recreation. We acknowledge that this term does not fully reflect the cultural and spiritual relationships that Aboriginal and Torres Strait Islander peoples have with water and Country. Water is not only a place for recreation but a source of life, identity, and spirituality, deeply connected to cultural practices and custodianship responsibilities.

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The Guidelines

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Executive summary and Guideline recommendations

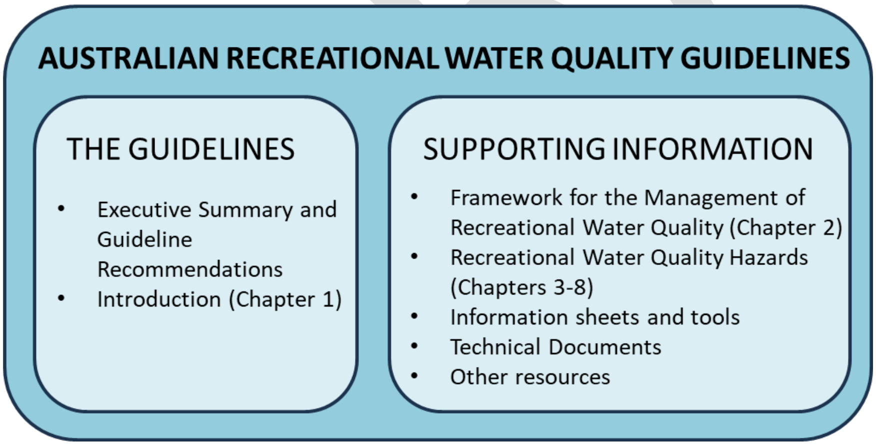
The National Health and Medical Research Council (NHMRC) *Australian recreational water quality guidelines* (the Guidelines) aim to protect human health from water quality hazards in coastal, estuarine and freshwater environments.

Biological, chemical or radiological hazards in water have the potential to cause harm to human health. To prevent adverse health outcomes, the Guidelines provide a best-practice approach aimed to support the responsible management of water quality hazards in coastal, estuarine and freshwaters that are used for recreational or cultural purposes.

The Guidelines consist of several parts (see Figure 1.1), including:

- **The Guidelines** – this includes the *Executive Summary* and *Introduction* (Chapter 1), which outline the key guideline recommendations and the scope of the Guidelines.
- **Supporting information**:
    - Chapters 2-8, which provide guidance on the underpinning preventive risk management approach outlined in the Guidelines and the potential hazards associated with recreational water bodies
    - Information sheets and tools, which provide more detailed technical information to support the guideline recommendations, including derivation of guideline values
    - Technical documents, including the Administrative Report and evidence evaluation reports.

Figure 1.1 - Structure of the Guidelines



Preventive risk management framework

The Guidelines advocate a preventive approach to the management of water quality risks in recreational water to ensure that these water environments are managed as safely as possible. This approach focuses on assessing and managing hazards and hazardous events within a preventive risk management framework (the Framework) (refer to *Chapter 2 - Framework for the Management of Recreational Water Quality*). This includes having a water quality risk management plan in place to help minimise potential public health risks.

The Framework encompasses principles for implementation with an emphasis on consulting and planning, including with First Nations communities, as prerequisite requirements to ensure responsible management of recreational water sites.

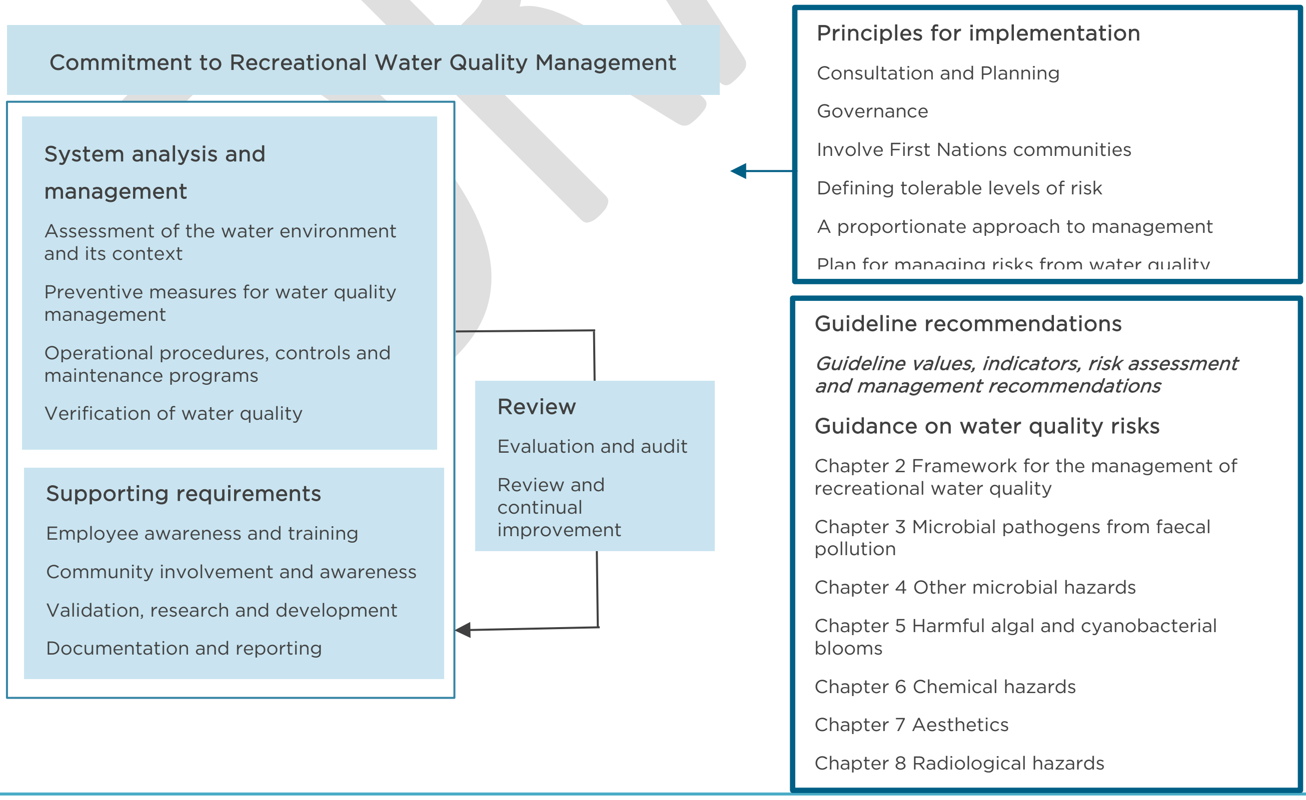
The Guidelines provide recommendations and technical information on the specific water quality hazards:

- microbial pathogens from faecal sources (Chapter 3)
- other microbial hazards (Chapter 4)
- harmful algal and cyanobacterial blooms (Chapter 5)
- chemical hazards (Chapter 6)
- aesthetic aspects (Chapter 7)
- radiological hazards (Chapter 8)

Chapters 3-8 describe the occurrence of these water quality hazards and their relevance to human health and provide guidance on risk assessment and management approaches specific to these hazards. These chapters underpin the implementation of the Framework and development of the Water Quality Risk Management Plan.

Figure 1.2 gives an overview of the application of the Guidelines using a preventive risk management approach and the key elements of the supporting chapters.

Figure 1.2. - Framework for the management of recreational water quality



Several comprehensive evidence reviews were undertaken to help inform the current state of knowledge on water quality hazards in recreational water environments. The reviews covered human health risks from these hazards as well as monitoring and risk management approaches required to ensure protection of public health. The findings of these reports were considered by the Recreational Water Quality Advisory Committee when considering options for risk management recommendations and calculating guideline values through an evidence-to-decision process. Further information on this process is provided in the Administrative Report.

Guideline recommendations

The guideline recommendations below should be read in conjunction with detailed descriptions in Chapters 2-8 and relevant supporting information sheets.

Framework for the management of recreational water quality (Chapter 2)
Manage water quality hazards in accordance with a preventive risk management framework. Apply the principles for implementation as prerequisite requirements to ensure responsible management of recreational water sites.

Microbial hazards from faecal sources (Chapter 3)
The health risks associated with faecal contamination for a recreational water site should be assessed by combining the outcomes of a sanitary inspection with a microbial water quality assessment. Preventive risk management practices should be adopted to ensure that designated recreational water bodies are protected against faecal contamination. Effective management oversight and public communication should be adopted to minimise microbial risks to public health.

Other microbial hazards (Chapter 4)
Recreational water users and responsible entities should be aware that serious infections can result from exposure to microbial hazards that are naturally present in surface waters, especially among immunocompromised individuals. Site specific risks should be assessed as part of a preventive risk management approach. Where the risk assessment of a water site identifies that the local environment supports the presence of microbial hazards, the emphasis should be on managing the risk of exposure and raising public awareness of the risks and opportunities to take personal preventive measures.

Other microbial hazards (Chapter 4)

Where environmental conditions at a water site potentially support *Naegleria fowleri*, health advice should include information to help recreational water users understand the elevated risk associated with activities where water is likely to enter the nasal passage.

Harmful algal and cyanobacterial blooms (Chapter 5)

Effective management oversight and public communication should be adopted to minimise exposure to harmful algal and cyanobacterial blooms in recreational water environments to reduce risks to public health.

Consistent with a preventive risk management approach, a situation assessment and alert level framework should be implemented to facilitate a proactive and staged response to the presence and development of harmful algal and cyanobacterial blooms.

As part of determining appropriate actions using an alert level framework, recreational water bodies should not contain:

- ≥ 20 µg/L of anatoxins
- ≥ 6 µg/L of cylindrospermopsins
- ≥ 8 µg/L of microcystin-LR* or other microcystins and nodularin toxins
- ≥ 30 µg/L of saxitoxins
- biovolume equivalent of ≥ 3 mm^3/L for the combined total of all cyanobacteria
- chlorophyll *a* of ≥ 8 µg/L (with a dominance of cyanobacteria)
- cyanobacterial or algal scum** or visible presence of cyanobacteria or algae with visibility <1 metre
- *Moorea producens* (formerly *Lyngbya majuscula*) and *Microcoleus* (formally *Phormidium*) in high abundance.

*This guideline value represents the sum value of all microcystins and nodularin toxins present. A toxicity equivalence factor of one should be used for all microcystin and nodularin congeners.

**Algal scum: dense accumulation of cyanobacterial or algal cells at or near the surface of the water forming a layer of distinct discolouration (green, blue, brown or red).

Chemical hazards (Chapter 6)
Water contaminated with chemicals at concentrations that may cause harm to humans is unsuitable for recreation. Where default chemical hazard screening values (determined by multiplying the current Australian drinking water guideline value by 20) are exceeded, further risk assessment should be undertaken. Site specific screening values for chemical hazards of concern can be developed in consultation with the relevant health authority or regulator. Recreational water bodies should have pH in the range of 6.5-8.5 (a pH range of 5-9 is acceptable in recreational water bodies with very poor buffering capacity) and a dissolved oxygen content greater than 80%.

Aesthetic aspects of recreational water (Chapter 7)
Recreational water bodies should be aesthetically acceptable to recreational water users. The water should be free from: visible materials that may settle to form objectionable deposits; floating debris, oil, scum and other matters; substances producing objectionable colour, odour, taster or turbidity and; substances and conditions that produce undesirable aquatic life.

Radiological hazards (Chapter 8)
Regular monitoring for radiological hazards is not recommended for all recreational water bodies; however, monitoring for radiological hazards should be considered on a case-by-case basis if a recreational water body may be of concern (i.e. based on legacy or planned exposures, past activities). For protection of people against radiation exposure from recreational and cultural water use, the recommended reference level is 10 millisievert per year (10 mSv/year). Where default radiological screening values are exceeded, further risk assessment should be undertaken.

1. Introduction

1.1. Overview

Water-based recreational activities are popular in Australia and provide a valuable contribution to an active and healthy lifestyle. Coastal beaches, estuaries, freshwater rivers and lakes are being increasingly developed and managed for recreational purposes. Waterways are also culturally significant for Aboriginal and Torres Strait Islander peoples, who have deep cultural and spiritual connections to waters on Country. Recreational water bodies can, however, contain water quality hazards that may lead to adverse health outcomes in recreational water users. Microorganisms, algae, cyanobacteria, chemicals or radiological hazards in water have the potential to cause harm to human health. Water bodies used for recreational or cultural purposes need to be managed to protect human health from these water quality hazards.

1.1.1. Aim of the Guidelines

The aim of this document - the *Australian Recreational Water Quality Guidelines* (the Guidelines) - is to protect human health. The Guidelines provide a best-practice, hands-on, practical approach aimed at helping those managing recreational water quality. The Guidelines 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 gain benefit from recreational and cultural water use.

The Guidelines are not mandatory and 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
- to encourage the adoption of a nationally harmonised approach to managing the quality of water used for recreational and cultural purposes.

The Guidelines are intended to be applied at designated and classified water bodies that have been formally assessed and assigned a specific use category by the relevant regulator. However, this does not mean that water quality can be allowed to deteriorate at unclassified water bodies.

In natural water environments, it is not possible to guarantee the complete absence of risk. Instead, the Guidelines aim to reduce health risks to levels considered acceptable for recreational and cultural use. A concentration or measure of a contaminant in recreational water may be regarded as “safe” if, based on current knowledge, it does not give rise to an appreciable health risk under normal conditions of recreational exposure. However, the inherent variability of natural waters means that some level of risk is always present.

1.1.2. Intended audience

The Guidelines are intended for end users that will implement the Guidelines to manage water sites where humans might be exposed to the water (e.g. government agencies, local councils, private water site managers) (see examples of guideline users in Table 1.1). It is anticipated that there will also be public interest, particularly in topics where there is community concern about local waterways.

Table 1.1 - Examples of guideline users and how they might use the Guidelines

Guideline end user	Notes
Regulators	Development of legislation by adopting/adapting the Guidelines as standards for best practice in their jurisdictions
Private water site managers	Risk management of private water supplies
Event organisers	Risk assessment and management of private water sites used for events
Water utilities	Management of catchments and water sources used for recreational purposes
Communities	Awareness of risks

1.2. Scope of the Guidelines

The Guidelines are intended to provide advice on the management of any natural or artificial water bodies that do not have a chemical residual added specifically for disinfection purposes. These water bodies may be used for recreational and/or cultural activities where human exposure to water occurs. The 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. Examples of types of water bodies and recreational and cultural water uses are listed in Table 1.2 and Table 1.3.

Importantly, the updated Guidelines focus on public health risks associated with the water quality of a recreational water body. This includes biological, chemical and radiological hazards that affect the quality of water that people might be exposed to in and around water bodies. Unlike the previous *Guidelines for Managing Risks in Recreational Water* (2008), the updated Guidelines do not address other risks associated with water use such as physical risks (e.g. drowning, animal attacks). In addition, the Guidelines do not cover details on rescue, resuscitation or treatment associated with risks from water quality. These risks should be considered as part of the risk management planning process for a water site and there are resources available with information on these types of risks (see *Information sheet – Resources on water quality and other hazards*).

Included in the Guidelines:

- Risks to human health resulting from exposure to water in and around natural or artificial water bodies that do not have a chemical disinfection residual (including risks from microbial, algal, cyanobacterial, chemical and radiological hazards). Examples of key definitions of recreational and cultural water use and water sites/environments are provided in Table 1.2 and Table 1.3.

Excluded from the Guidelines:

- Aquatic facilities and other water sites that use chemical disinfection (e.g. swimming pools and spas)
- Risks from sun, heat and cold and other physical hazards that can be associated with water use in and around water bodies (e.g. sunburn, drowning, animal attacks). This includes risks from water temperature (e.g. hypothermia, hyperthermia).
- Risks associated with human exposure to foodstuffs (e.g. fish, shellfish, plants) collected from water environments or their surroundings
- Risks from water quality to stock and domestic animals in and around water bodies
- Risks associated with ancillary facilities that are not part of the water environment other than risks that may affect water quality (e.g. toilet facilities in adjacent areas are not considered unless these need to be managed to minimise contamination of the water body)
- Adverse health effects that are not caused by water quality (e.g. seasickness, the 'bends' from diving)
- Risks from sand/soil around water bodies including airborne events (unless disturbances of sand/soil affect water quality); however, application of a preventive risk management approach (see *Chapter 2 – Framework for the management of recreational water quality*) should include assessment of these risks
- Therapeutic uses of waters (e.g. hydrotherapy pools)
- Protection of aquatic life
- Occupational exposures of people working in recreational water environments
- Guidance on rescue, resuscitation or treatment.

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.

Recreational water activities can adversely affect the other values of the water environment including biodiversity and cultural values. Additional risks may be involved if recreational water activities impact the quality and security of water resources, particularly those used for drinking water. The Guidelines do not specifically address how to manage recreational activities to prevent adverse impacts. Instead, they emphasise the importance of assessing potential adverse impacts as part of the decision-making and planning process outlined in the *Framework for the management of recreational water quality* (Chapter 2).

1.2.1. Key definitions

The following examples are provided to help risk managers define the water environment and its recreational and cultural water use as part of a risk assessment. The examples provided below are not intended to be exhaustive.

Table 1.2 – Types of water sites and environments

Term	Definition
Water sites and environments	Included: Any natural or artificial water bodies without a chemical disinfectant residual that are intended to be used for recreational and/or cultural activities where human exposure to water occurs. This includes coastal, estuarine and freshwater environments. Includes public, private, commercial and non-commercial water sites. Includes unique natural or constructed unregulated water sites such as wave pools, ocean- or river-fed swimming pools, artificial lagoons and water ski parks. Excluded: Aquatic facilities using chemical disinfection including swimming pools, spas, splash parks. Ornamental water sites. Examples of water sites and environments where human exposure might occur include: artificial lagoons; beaches (marine, freshwater - from the high tide waterline down); coastal waters in close proximity to land (and thus influenced by land-based sources); dams; estuaries, including tidally influenced estuarine beaches; flowing waters (canals, creeks, rivers, streams, waterfalls); billabongs; foreshores; hot springs; lakes; ocean pools; ponds; reservoirs; riverbanks; rockpools; sea baths; shorelines; splash parks; springs; thermal pools; wading pools; waterholes; water parks; water ski parks; wave parks/pools; wetlands.
Water use	*Included*: Any human activity relating to sport, pleasure/relaxation and cultural use that involves whole body contact or incidental exposure (through any exposure route) to water environments (e.g. swimming, diving, boating, fishing). Can be designated or undesignated. *Excluded*: Consuming the catch from fishing or foodstuffs collected from water environments and their surroundings. Therapeutic uses of waters (e.g. hydrotherapy pools). Occupational exposure. Examples of recreational and cultural water use are provided in Table 1.3.

Term	Definition
Water users	*Included:* Individuals and groups that use water environments for recreational and cultural purposes where exposure to water might occur including: • the general public, including people at all relevant life stages, ages and states of health other than persons that are explicitly advised to avoid such activities (e.g. for specific medical conditions) • Aboriginal and Torres Strait Islander communities caring for waterways on Country • tourists • specialist sporting users (e.g. athletes, anglers, kayakers, divers, surfers) • special interest groups that undertake activities in and around water bodies (e.g. scout groups, citizen science groups) • any groups that may have high exposures to water environments. *Excluded*: • occupational exposures of people working in recreational water environments persons that are explicitly advised to avoid exposure to untreated water bodies (e.g. for specific medical conditions).

1.2.2. Designation of recreational water 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 and cultural 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 2021). 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 and cultural activities can be classified by the degree of water contact as follows:

- **Whole-body 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 (e.g. swimming, diving, surfing, waterskiing or whitewater canoeing). Inadvertent immersion, through being swept into the water by a wave or slipping, would also result in whole-body contact (WHO 2021). Sometimes referred to as primary contact (NHMRC 2008).
- **Incidental contact**: activity in which only the limbs are regularly wet and in which greater contact (including swallowing water) is unusual (e.g. boating, fishing, wading) (WHO 2021).

Includes occasional and inadvertent partial immersion through slipping or being swept into the water by a wave. Sometimes referred to as secondary contact (NHMRC 2008).

- **Passive contact**: activity around or near water sites/environments in which water is incidental to the activity or where there is normally no direct contact with water but can result in some exposure to water, such as direct surface contact through splashing or inhalation of sprays/aerosols (e.g. walking along the beach or near waterfalls, rock fishing). Sometimes referred to as no contact or aesthetic uses (NHMRC 2008).

Examples of recreational and cultural activities for each classification are provided in Table 1.3

In whole-body contact activities, the probability that some water will be ingested is high, although data on the quantities swallowed during recreational and cultural water use are difficult to obtain (WHO 2021). 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.

Table 1.3 - Examples of recreational and cultural water activities with different classifications of exposure

Contact	Examples
Whole-body contact	bathing; bodysurfing; bodyboarding; canyoning; diving (e.g. cliff/rock diving and jumping); jet skiing; kiteboarding; kitesurfing, parasailing (from the beach or behind a boat); scuba diving; snorkelling; spearfishing; sporting events involving a water activity (e.g. triathlons, pentathlons); sail boarding; surfing; swimming; wakeboarding; water and splash park/playground activities (e.g. water slides, other water play involving splashing, sprays); water sports (e.g. water polo); waterskiing; wave boarding; white water rafting/canoeing; wind surfing; full emersion baptism; ritual ablution.
Incidental contact	boating; canoeing; fishing/angling from boats, canoes, kayaks; fishing/angling with wading; kayaking; paddling; paddle boarding; rowing; sailing; wading.
Passive contact	cycling; fishing/angling from a shoreline or riverbank; public/private events held near/next to water bodies, e.g. scout camps, festivals, celebrations; running; sunbathing; walking.

1.2.3. Susceptible groups

Certain groups of users may be more exposed to hazards than others and may need special consideration when deciding on risk management and risk communication; for example, children, the elderly and those with disabilities, tourists and people from culturally and linguistically diverse backgrounds.

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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 2021). 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. They might also engage in activities such as jumping from piers or jetties that will push water up their nose.

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). Additionally, there may be language barriers (not being able to translate/interpret warning signage) or have different cultural expectations around where is safe to swim.

1.3. Application of the Guidelines

The Guidelines should be applied within the broader context of protecting public health. As such, they are not intended to be prescriptive given the variety of water environments, settings and climates across Australia.

The inclusion of a preventive risk management framework (the Framework) (see Chapter 2 - Framework for the management of recreational water quality) is intended to allow for structured risk assessment and risk management planning across the wide variety of existing and emerging water environments that Australian risk managers might encounter. This also includes any unique water sites that are currently unregulated and may present risks to public health. It is expected that implementing the Guidelines, particularly for some water managers, will take time and resources. The Guidelines are not a pass/ fail metric, instead they are intended to provide the basis for further investigations and/or to determine the level of risk management required to protect public health. The most important step is getting started, particularly with knowing your catchment.

Application of the Framework and guideline recommendations will vary depending on the arrangements within each jurisdiction. This is likely to affect the manner and degree to which the

Framework is implemented. However, all risk managers responsible for recreational water bodies should still be encouraged to use the Framework as a model for best practice.

Although the Guidelines are recommendations only, some jurisdictions may choose to regulate recreational water quality using the Guidelines in the future. In determining how the Guidelines are translated into standards, regulators should consider costs and benefits of these actions as well as developing an appropriate implementation timetable.

1.3.1. Preventive risk management approach

These Guidelines advocate a preventive approach to the management of water quality risks in recreational water, focusing on assessing and managing hazards and hazardous events within a preventive risk management framework (see Chapter 2 - *Framework for the management of recreational water quality*).

A number of jargon terms that are used extensively in the Guidelines have specific meanings in the context of risk assessment. These are defined in table 1.4.

The distinction between hazard and risk needs to be understood, so that attention and resources in risk management planning can be directed to actions based primarily on the level of risk rather than just the existence of a hazard.

Table 1.4 - Definitions of terms used in the context of risk assessment

Term	Definition
Hazard	A hazard is a potential source of harm that can be biological, chemical, physical or a radionuclide. *Example*: the protozoan parasite *Cryptosporidium hominis* is a hazard to human health.
Exposure	Exposure is the magnitude (either measured or estimated), frequency and duration of human contact with a hazardous agent. Exposure can occur through multiple pathways including: • direct surface contact (e.g. skin, eyes, mucous membrane exposure while swimming in a lake) • inhalation (e.g. breathing in sprays, aerosols during activities such as water-skiing or walking around waterfalls) • ingestion (e.g. children accidentally swallowing water while paddling). The degree of contact with a water body (passive, incidental, whole body) will also determine exposure and the level of risk to a water user.

Term	Definition
Hazardous event	A hazardous event is an incident, event or situation that can lead to the presence of a hazard—what/how it can happen. *Example*: failure at an upstream tertiary wastewater treatment plant leading to infectious *C. hominis* being discharged at elevated levels and reaching a water site where human exposure can occur is a hazardous event.
Risk	Risk is the likelihood of an identified hazard causing harm in exposed populations or receiving environments in a specified timeframe, including the severity of the consequence (risk = likelihood × consequence). *Example*: the likelihood of *C. hominis* being present in source water and passing through the treatment plant in sufficient numbers to cause illness in water users is a risk to health.

The approach outlined in the updated Guidelines is consistent with that developed by the World Health Organization (WHO) in 2021. The WHO approach has formalised the use of risk assessment and management frameworks for all water sources and uses, and started with the development of the 'Annapolis Protocol' for recreational water bodies.[1] 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 period of 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.

This document combines much of the international consensus on healthy recreational water use (such as WHO (2021)) with current understanding of Australian waters, to provide guidance relevant to local conditions.

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 water quality hazards that require management in recreational water bodies, including:

- microbial pathogens from faecal sources

[1] 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.

- other microbial pathogens including free-living microorganisms
- harmful algal and cyanobacterial blooms
- chemical hazards
- radiological hazards.

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.

1.4. Development of the Guidelines

A summary of the methods used to develop the Guidelines is provided below. Further details on the development of the Guidelines are available in the Administrative Report.

1.4.1. Prioritisation of review topics

NHMRC undertook a scoping process with key stakeholders to prioritise areas for review. This process was informed by expert advice from the NHMRC Water Quality Advisory Committee and the Environmental Health Standing Committee (enHealth) and included:

- targeted consultation with key stakeholders to identify sections of greatest importance to stakeholders, highlight information gaps, and capture emerging issues related to recreational water quality.
- comparative review of international, national and jurisdictional recreational water guidelines with the existing Guidelines to provide further evidence supporting the need for review in specific areas.

Based on this scoping activity NHMRC identified the critical areas for review which are outlined in the Administrative Report.

1.4.2. Evidence reviews

For each topic, a comprehensive and systematic narrative review was undertaken following a pre-specified research protocol by independent expert reviewers. The reviews covered human health risks from these hazards as well as monitoring and risk management approaches required to ensure protection of public health.

The following reviews were undertaken:

- Chemical hazards in recreational water (Ecos Environmental Consulting)

- Microbial quality of recreational water (Ecos Environmental Consulting)
- Cyanobacteria and algae in recreational water (Australis Water Consulting)
- Free-living organisms in recreational water (Commonwealth Scientific and Industrial Research Organisation (CSIRO))
- Radiological water quality (Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) in collaboration with NHMRC).

For each review an evidence evaluation report and technical report has been produced summarising the state of the evidence for each research question. This includes the process used to search and critically appraise the evidence used to answer the research questions.

The findings of these reports were considered by the Recreational Water Quality Advisory Committee when considering options for risk management recommendations and calculating guideline values through an evidence-to-decision process. Further information is provided in the Administrative Report.

1.4.3. Guideline assumptions and default parameters

The guideline recommendations are informed by epidemiological studies, human case reports or toxicological data from experiments on laboratory animals.

Where guideline values or screening values have been recommended, water ingestion is assumed to be the primary route of exposure. Children are likely to spend more time in direct contact with water and ingest more water than adults. Consistent with WHO (2021), the default bodyweight of a young child and the volume of water unintentionally swallowed are 15 kilograms and 250 millilitres per event.

Where chronic exposure is relevant to assessing the health outcomes for a specific water quality hazard, a default event frequency of 150 days per year is adopted based on the *Australian Exposure Factor Guide* (enHealth 2012). This frequency is an upper estimate, so is likely to be protective in most scenarios.

For more information about the basis of guideline assumptions and default parameters see *Information sheet – Exposure assumptions* and the relevant guideline chapters.

1.4.4. About the Guideline recommendations

For the purposes of these Guidelines, a guideline recommendation can be any of the following:

- a level of management
- a concentration of a constituent (e.g. chemical or pathogen) that does not represent a significant risk to the health of individual members of significant user groups
- a condition under which hazardous concentrations are unlikely to occur
- a combination of the above.

A guideline value does not imply that environmental quality should be allowed to degrade to this level. 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
- 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 and cultural water use may occur over very short periods (e.g. 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 water users are not at risk during periods of actual or potential use. In practice this may be difficult to achieve; in which case, appropriate warnings should be issued.

1.5. References

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WHO (World Health Organization) (1999). Health-based monitoring of recreational water: the feasibility of a new approach (the "Annapolis Protocol"). Geneva: WHO.

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2. Framework for the management of recreational water quality

2.1. Overview

This chapter introduces the *Framework for the management of recreational water quality* (the Framework) and describes its purpose, benefits and structure. It also describes principles for implementation including the importance of consultation and planning as prerequisite requirements to ensure responsible management of recreational water sites.

2.1.1. A preventive approach for managing recreational water sites

Recreational and cultural activities in and around natural water bodies have recognised public health benefits; however, among the variety of risks associated with these activities are health risks from water quality hazards. The greatest potential risk is from microorganisms like bacteria, viruses, parasites, harmful algal and cyanobacterial blooms. Most water bodies contain these microorganisms, but their numbers vary with flow rates and contaminant concentrations. Microbial contamination can lead to outbreaks and illnesses. The most common illness from poor water quality is gastroenteritis. Respiratory, skin, ear and eye infections are less common. Agricultural and urban run off can introduce chemicals, stormwater, litter, sewage and animal waste to the water. Heavy rain can produce more run-off and lower water quality. There have been instances where health risks have been underestimated or not identified at water sites, resulting in harms to health. Globally, recreational water bodies have been associated with waterborne outbreaks of gastrointestinal disease, and in some cases severe infections and death (O'Connor 2021; Puzon et al. 2024; Burch 2021; WHO 2021; Graciaa et al. 2018).

A preventive approach to managing water quality risks involves proactively assessing and managing hazards and hazardous events within a risk management framework. A preventive risk management framework can facilitate effective management of complex and variable water quality risks. The approach applied in this type of framework is used to help assess, prevent and manage hazards by focusing on hazard prevention rather than a sole reliance on taking corrective approaches in response to hazard detection (Tsoukalas and Tsitsifli 2018). In this sense, preventive risk management frameworks facilitate proactive—rather than reactive—risk management.

As mentioned in *Chapter 1 - Introduction*, recreational water activities can adversely affect the other values of the water environment. For example, additional risks may be involved if recreational water activities impact the quality and security of drinking water resources. The Guidelines do not specifically address how to manage recreational activities to prevent these adverse impacts, but rather emphasise the importance of assessing potential adverse impacts and safeguarding catchments as part of the decision-making and planning process outlined in the Framework.

The *Guidelines for Managing Risks in Recreational Water* (NHMRC 2008) advocated a preventive approach to the management of recreational water. These updated Guidelines build upon the preventive approach by applying 12 elements of a preventive risk management framework (the

Framework) to support a systematic approach to developing and implementing a Water Quality Risk Management Plan.

The Framework is about both preventing contamination arising in the first place and preventing exposure to contamination if it should arise. It enables transparency and accountability in how risks are assessed and managed.

An underestimation of potential health risks can lead to unacceptable harms to human health. Conversely, an overestimation of risks can result in the unnecessary closure of recreational water sites. This may have flow on implications, such as impacts on public health if access to water-related activities that promote community health and wellbeing are restricted. Water site closures may also have impacts on local economies that might depend on access to water.

Key benefits of the Framework include:

- the systematic assessment of hazards and exposure scenarios, taking into account the unique characteristics of the water site. This means that management oversight and the development of a Water Quality Risk Management Plan will be purposefully targeted to protecting water users against hazards.
- Site specific assessment of risks with targeted strategies to proactively mitigate or minimise risks. This reduces the sole reliance on water quality parameters that cannot be measured in-situ in a timely manner to protect public health.
- An adaptive approach for managing risk through ongoing oversight and continuous review. This process acknowledges that risks to water quality fluctuate and that the risk profile is subject to change with climate change impacts and environmental degradation.

Preventive risk management frameworks are already adopted in the *Australian Drinking Water Guidelines* and *Australian Guidelines for Water Recycling*. Applying a 12 element risk management framework in the recreational water context has both similarities and differences when compared to these other guidelines. A key difference is that, unlike drinking water and recycled water, recreational water bodies are not treated. Critical control points are applied to control a water quality hazard to ensure drinking water safety. However, in the case of recreational water bodies, controls to prevent or minimise risks to public health are predominately pollution mitigation within the catchment, modelling and monitoring, and public communications.

2.1.2. The structure of the Framework

The World Health Organization (WHO) has applied a recreational water safety framework into the revised *Guidelines for Recreational Water Quality* (WHO 2021). The WHO approach has been largely adapted to the Australian context in the Framework.

The Framework (Figure 2.1) underpins the planning and management of risks associated with water quality at public or commercial untreated water sites that are currently used or proposed for recreational or cultural purposes (see *Chapter 1 - Introduction*). The Framework includes 12 elements considered good practice for system management of recreational water quality (Table 2.2).

The Framework can also be applied to managing water quality risks at private recreational water sites; however, in these instances professional advice and/or consultation with relevant health authorities is strongly recommended.

While physical risks, such as drowning, and threats from larger organisms and wildlife are out of scope of these Guidelines, these risks should be assessed and managed. Information on how to plan for and manage these risks is provided by other agencies. More information including useful resources is available in *Information sheet – Resources on water quality and other hazards*.

This guidance includes instructions on how to apply the Framework. Information on the purpose of each framework element and the actions needed to effectively respond to each element are also provided. The *Water quality risk management planning checklist* summarises the elements and associated actions.

Figure 2.1 - Framework for the management of recreational water quality

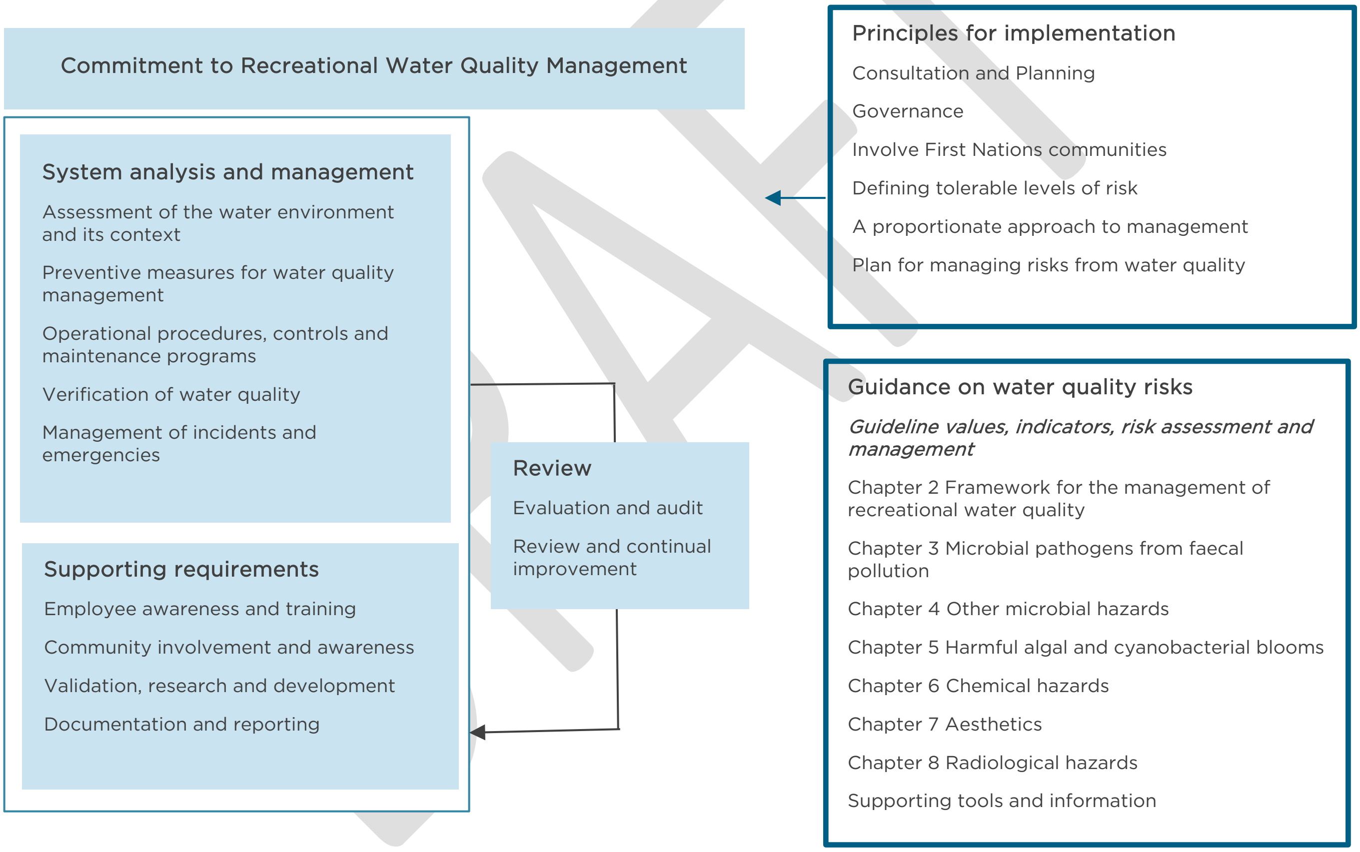


Table 2.2 - Framework for the management of recreational water quality

COMMITMENT TO RECREATIONAL WATER QUALITY MANAGEMENT
Element 1 Commitment to recreational water quality management
Identify responsible authorities
Regulatory and formal requirements
Engage stakeholders
Recreational water quality policy
Ensure capability
SYSTEM ANALYSIS AND MANAGEMENT
Element 2 Risk assessment
Consider the water environment and its context
Collect relevant data
Assess hazards, hazardous events and risks
Element 3 Risk Management
Determine preventive measures and performance targets
Element 4 Implement operational procedures and maintenance programs
Element 5 Set up processes to monitor and verify water quality
Element 6 Planning for incidents and emergencies
SUPPORTING REQUIREMENTS
Element 7 Communications and training
Communications planning
Training
Element 8 Community involvement and awareness
Element 9 Validation, research and development
Element 10 Documentation and reporting
REVIEW
Element 11 Evaluate and audit
Element 12 Review and improve

2.1.3. Principles of implementation

2.1.3.1. Consultation and planning

Consultation and planning should be undertaken prior to establishing sites for recreational water activities or in reviewing the suitability of existing water sites. This will ensure effective management oversight and no unintended consequences. Consultation and planning are important to understanding key issues around governance and accountability that should be addressed early in the planning process. This includes identifying who will be impacted by any decisions about risk management of water bodies on Country.

In some cases, recreational activities themselves may be the source of harmful microorganisms and chemicals, adversely impacting on other values of the water body (e.g. sunscreen from swimmers impacting coral reefs or pristine waters in national parks).

While consultation is always necessary for effective water quality management, in the recreational water context consultation must lead the entire process. This is essential to:

- understanding custodianship or ownership of the land and water body, governance and complexity of site management
- establishing clear lines of responsibility for managing and safety of the water site
- understanding how people use or want to use the water site so that exposure routes and scenarios are appropriately characterised in the risk assessment process; or conversely early management of expectations, that is, 'a reality check'
- facilitating early identification of water quality risks and complexity of management
- identifying values of the water site that must be protected
- ensuring the water site is authorised for recreational use and permission is sought where required
- identifying site management plans currently in place (e.g. water safety plans to address other hazards associated with the water site such as drowning; industry, cultural and heritage protection plans; asset management plans; emergency response plans).

Questions that should be asked during the planning and consultation phase include:

- Who owns and/or manages this water site/s?
- Who are the First Nations communities and Traditional Owners of the water on this Country?
- Who is responsible and accountable for the safety of the water site/s?
- Who has the authority to make decisions?
- What expertise do we need?
- What are the regulatory requirements?
- Is there a risk management plan in place?

2.1.3.2. Governance

The governance and accountability, including the hierarchy of authority and responsibility for water sites used by the public, needs to be clearly identified and understood. This is not always obvious and it is important to define the roles, responsibilities and duties of any people or organisations who might be involved in any decision-making or held to account for the water site. This involves individuals or agencies/organisations who own, develop, manage or maintain water sites and the environments around it, or are responsible for public health and safety for that context or environment, such as:

- state/territory/local agencies who are responsible for public health and safety
- state/territory/local agencies who are responsible for the water site
- Traditional Owners
- site owners or landlords
- site designers, installers
- site operators, maintainers
- site managers
- local communities and individual water users who care for the water site.

Importantly, the responsible entity that is ultimately accountable for managing water quality risks and protecting the public needs to be clearly defined. Key roles in the governance of water sites for recreational or cultural use are provided in Table 2.3.

It may be that governance arrangements do not currently exist or are inadequate for implementation of the Framework. In such instances, those governance arrangements may need to adapt and that may take time. Experience with implementing preventive risk management framework approaches within Australia and globally has provided valuable insights. In the broader water and sanitation sector, these approaches have been applied with varying success. Evidence shows it may take years until such frameworks can be fully established. Therefore, a phased transition should be considered acceptable and realistic for stakeholders. In some cases, this may require new agreements or memoranda of understanding to be developed. Funding commitments may need to be long term and ongoing to cover operational activities indefinitely.

Table 2.3 - Key roles in the governance of water sites for recreational or cultural use

Role	Example entities	Example responsibilities and tasks
Leaders (responsible entity)	Relevant government agencies Local or regional government bodies	National, state/territory and/or local leadership and responsibility for the water site and/or water quality. Accountable for managing water quality risks and protecting the public. Ensure that water quality management is undertaken according to relevant standards and legislation as required. Responsible for ensuring organisation capability to manage risk.

Role	Example entities	Example responsibilities and tasks
Coordinators	Regional government bodies Local government on public land Facility management arms of state or territory government agencies in parks Site managers on private land Water utilities responsible for water and sanitation infrastructure	State/territory, regional and/or local level of responsibility for coordinating the management of the water site and water quality. Broader management of water quality and engagement with diverse stakeholders. Develop, implement, oversee and maintain a Water Quality Risk Management Plan.
Site managers	Local councils Water utilities Site operators	On ground operational responsibility for the water site. This may be formalised at a legislative level under a relevant act or regulation that may specify a water quality manager and/or site manager. Develop and implement a **site management plan** (for individual water sites or groups of similar local water sites) to guide and coordinate operations. Manage site access in the context of water quality. Monitor and manage some aspects of water quality. Communicate with water users and the general public where required.
Champions	Elders Community leaders Local community and advocacy groups Sporting associations	Assist in risk communication with local communities and water users [see Sections 2.27 and 2.28].

2.1.3.3. Engagement with First Nations communities and Traditional Owners

Water holds deep cultural and spiritual significance to Aboriginal and Torres Strait Islander peoples. For thousands of years, First Nations peoples have cared for and understood waterways through cultural knowledge, observation and the continuation of sustainable management practices on their countries.

Engaging meaningfully in partnership with First Nations communities is essential for effective, culturally appropriate risk management in recreational water quality. Such engagement ensures that Aboriginal and Torres Strait Islander peoples' knowledge, values, and perspectives are recognised and incorporated into all levels of decision-making. This section sets out the key principles that underpins effective engagement and provides practical steps to consultation and partnership throughout all stages of recreational water quality risk management.

Key principles

Key principles of engagement with First Nations communities include (Collings 2012; Jackson 2012):

- **Respect and recognition**: value the unique cultural, spiritual, and historical connections of First Nations peoples to land and water and acknowledge the diversity of communities.
- **Early and ongoing engagement**: commit to consulting and planning with First Nations stakeholders early and maintain meaningful partnerships.
- **Cultural protocols and knowledge protection**: adhere to local cultural protocols and community preferences, seeking guidance from appropriate representatives or peak bodies.
- **Transparency**: be open about the purpose, process, and influence of engagement, ensuring that input from First Nations stakeholders genuinely shapes decision.
- **Tailored communication**: Ensure communication is responsive to local context, cultural protocols and needs.
- **Participation and capacity building and participation**: encourage and empower First Nations participation, leadership, and capacity building in water quality management.
- **Continuous improvement**: Provide feedback on how input has been considered and evaluate engagement processes for ongoing improvement.

Table 2.4 outlines practical steps to help put these principles into action, ensuring that engagement with First Nations stakeholders is both respectful, culturally safe, respectful, and meaningful. The practices are recommended based on existing guidance (Collings 2012; Jackson 2012; Australian Government Department of Agriculture and Water Resources & New Zealand Ministry for the Environment 2018) and stakeholder feedback (see Administrative Report).

Table 2.4 - Steps for engagement with First Nations communities/stakeholders

Steps	Key Actions
Preparation	• Seek guidance from Aboriginal and Torres Strait Islander peak bodies and land councils. • Identify the relevant Traditional Owners, Elders, and community organisations, and engage with the appropriate representatives. • Understand the local history, cultural significance, and established protocols of each community.

Steps	Key Actions
Consultation	• Acknowledge the diversity of First Nations communities and tailor engagement to local context. • Begin consultation early and maintain meaningful partnership throughout all phases. • Prioritise face-to-face engagement where possible and select communication channels based on local preferences and accessibility • Document all approaches in the risk communication plan (see Information sheet – Preparing a risk communication plan and Risk communication planning checklist)
Collaboration	• Involve First Nations stakeholders in risk identification and management planning. • Co-design communication plans with community representatives. Adopt clear inclusive communication approaches considering language, accessibility, culture and infrastructure when planning communication (e.g. provide updates on water testing results and health advisories in preferred formats and language). • Respect the value of traditional ways of knowing, being and doing as essential insight and understanding into water management and risk assessment (e.g. observations of water colour, smell, and taste). • Adapt methods to local capacity, using trusted intermediaries or community hubs, when resources are limited. If remote methods are necessary, ensure cultural appropriateness and follow up. • Ensure data sovereignty principles are followed allowing for transparency and accessibility of information (e.g. sharing water testing results and risk assessments in formats and languages that are meaningful to the community).
Documentation and feedback	• Document and reflect on consultation outcomes, including how feedback has been incorporated. • Ensure that all data use respects cultural authority, community ownership and intellectual rights.

Incorporating cultural and spiritual values into water quality planning

Assessing and integrating First Nations cultural and spiritual values within water quality management is a vital part of determining and evaluating community values and supports consultation in line with First Nations engagement protocols. The Australia and New Zealand Guidelines for Fresh and Marine Water Quality (2018) present a proposed pathway for incorporating these values into water quality planning (available at https://www.waterquality.gov.au/anz-guidelines/guideline-values/derive/cultural-values).

2.1.3.4. Defining tolerable levels of risk

Natural and untreated water bodies contain many unseen and unpredictable hazards that cannot be removed or controlled. Water quality is variable and as a result the risk profile of a recreational water body can be dynamic and unpredictable. Recreational activities in themselves can be responsible for causing waterborne disease outbreaks, predominately through bather shedding. Because of inherent characteristics, the public should be made aware that there is always an inherent risk associated with activities on or around water bodies.

Risk assessment and determination of a tolerable level of risk for recreational water use must be conducted pragmatically. The outcomes of a risk assessment help to identify when risk mitigation is required. They also highlight opportunities to communicate risks effectively to water users. In some cases, water users can be enabled to make informed decisions on risk taking. However, for those that are most vulnerable, notably children, this is not the case. In such cases a precautionary approach is needed to manage risk, especially at water sites that are readily accessible or promoted for use by young children.

In these Guidelines, guideline values such as screening values, reference values and indicators provide quantifiable metrics for defining what is a tolerable health outcome. For example, the health outcomes for microbial hazards (see *Chapter 3 – Microbial pathogens from faecal sources*) are expressed in terms of the risk of gastrointestinal (GI) illness and acute febrile respiratory illness (AFRI).

2.1.3.5. A proportionate approach to water quality risk management oversight

One size does not 'fit all' when applying the Framework. The character and magnitude of risks vary among different water sites and for different water-based activities around Australia. The management of water quality risks should be commensurate with the risk to public health.

The risk to public health is dependent on:

- the degree and nature of personal exposure to the water while undertaking recreational or cultural activities.
- the real and anticipated hazards that may be present, informed by a risk assessment.
- whether there are any possible ways to prevent or minimise the risks.

A proportionate approach to water quality risk management oversight is illustrated in Figure 2.4. It allows responsible entities to determine the appropriate level of management oversight to minimise public health risks. This includes applying the 12 elements of the Framework in a purposeful manner. This ensures that controls are fit-for-purpose and resources are allocated effectively.

The proportionate approach distinguishes between:

- **water sites that require minimal intervention to manage risks and recreational activities that will not compromise other values of the water body.** This may include:
    - water bodies with low susceptibility to hazards, used for recreational or cultural activities involving full or limited contact with water, where recreational activities do not compromise other values of the water body (e.g. remote coastal beaches); or
    - water bodies with high susceptibility to hazards, where recreational and cultural activities do not involve contact with water (e.g. passive recreation along urban creek with permanent warning signs and restrictions, and periodic inspections).

  For such settings management oversight required to minimise public health risk is minimal, and therefore a basic Water Quality Risk Management Plan or site management plan would be suitable.

- **Water sites whereby universal controls apply to manage risk.** This may include water bodies, used for recreational or cultural activities involving full or limited contact with water, that are potentially susceptible to hazards in extreme events or known discrete seasonal events (e.g. popular bay beach with periodic sanitary inspections and faecal indicator monitoring such as Beachwatch program and warnings/restrictions during elevated periods of risk).

  For such settings, management oversight is defined by known discrete periods of elevated risk and universal controls apply, and therefore a generic Water Quality Risk Management Plan would be suitable.

- **Water sites that have unique and/or dynamic risks that warrant closer and more continuous attention to manage.** This may include:
    - water body that is susceptible to hazards, that is actively promoted or purposed for recreational or cultural activities involving full or limited contact with water (e.g. club/sport events, watercraft, waterskiing, swimming/bathing, fun parks/events, hot springs); or
    - recreational activities that have the potential to compromise other values of the water body.

  For such settings, intensive management oversight and formal targeted controls are required to minimise public health risk, and therefore a customised Water Quality Risk Management Plan is needed.

To establish the appropriate level of oversight an initial risk assessment for a given water body is essential. This should consider both the water quality and the known or likely nature of activities undertaken at the water site. However, risk is not static, and the risk profile of a water body may change due to climatic conditions, pollution sources not previously identified or emerging contaminants. The degree of management oversight required to manage public health risks should be continually reviewed and adapted based on the changing risk profile to water quality or exposure scenarios.

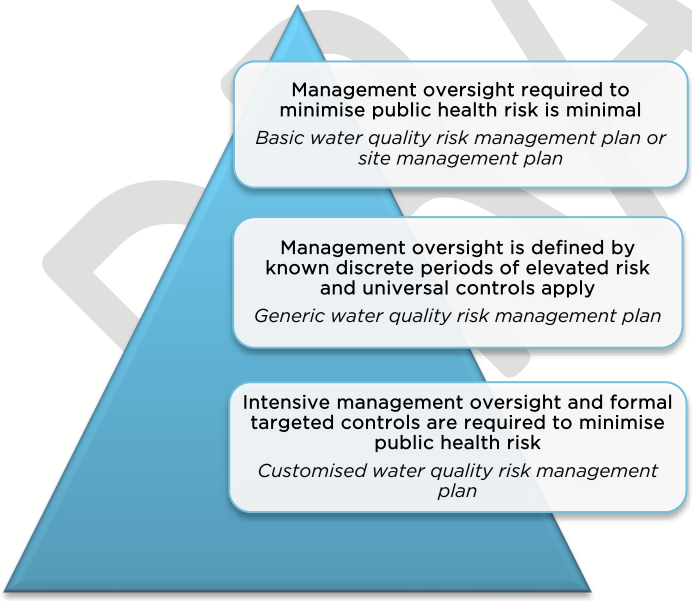
Key steps to determining the appropriate level of water quality risk management oversight that applies to a specific water body include:

- consultation and planning, especially with the relevant regulator/authority.
- undertaking a risk assessment (e.g. sanitary inspection) to identify potential pollution sources. This can be used to determine whether there are any microbial, chemical or radiological hazards that might present a risk to public health.
- determining the level of risk management oversight required to minimise public health risk. This can be based on the exposure/activity planned or authorised at the water site, and/or susceptibility to water quality hazards.

Additional advice on how to apply the Framework to a specific water site can be sought from the relevant authority or regulator.

The implementation of the Framework in Australia may be a change in practice for some site managers, operators and local councils. It will take time, investment and possible changes in legislation to establish regulations and lines of accountability if they do not already exist. Additional resources may need to be committed to provide the financial, organisational and technical capacity to implement the Framework at some water sites.

Figure 2.4 - Proportionate approach to water quality risk management oversight



2.1.3.6. Plan for managing risks from water quality

For many water environments used for recreational or cultural purposes, the 'water site' in practice may be much broader than a clearly defined point (e.g. billabong or beach); it may include whole stretches of coastline or river reaches.

A Water Quality Risk Management Plan is the product of the Framework. When developing a Water Quality Risk Management Plan, it is important to understand how it will be embedded into existing organisational processes and other relevant site management plans. This includes the local water safety plan for addressing risks of drowning and serious injury (Royal Life Saving Australia 2021).

Water Quality Risk Management Plan

A Water Quality Risk Management Plan describes how responsible entities will protect public health by managing water quality risks. The detail and complexity of a Water Quality Risk Management Plan will vary depending on the inherent water quality risks and level of management oversight needed to protect public health:

- a basic Water Quality Risk Management Plan (or none if controls can be sufficiently documented in a site management plan, e.g. sign maintenance, periodic inspections) is appropriate where public health risk is assessed to be minimal
- a generic Water Quality Risk Management Plan is appropriate for water sites where universal approaches and controls are sufficient to manage risk to public health
- a customised Water Quality Risk Management Plan is appropriate for water sites where intensive oversight and targeted controls are needed to manage risk.

A Water Quality Risk Management Plan needs to be tailored to the region, area and specific water sites and associated recreational and cultural activities under consideration. Given the locality- and catchment-specific nature of these actions, this work should be undertaken by a risk assessment team including individuals, group and agencies who operate in the area (see sections 2.2.1.1 and 2.2.2.1).

A best practice Water Quality Risk Management Plan will include details on how to achieve the 12 elements outlined in this Framework (see section 2.2). To assist responsible entities in developing their Water Quality Risk Management Plan, the following resources have been developed:

- *Water quality risk management planning checklist*
- *Water Quality Risk Management Plan template.*

2.2. Framework for management of recreational water quality: the 12 elements

2.2.1. Commitment to recreational water quality management (element 1)

The effective management of recreational water quality requires a long term commitment from the responsible entity. Senior executives of the responsible entity should be committed to:

- understanding their responsibilities and the importance of recreational water quality management and how decisions affect the protection of public health
- leading muti agency involvement and stakeholder engagement
- the development of an organisational philosophy that fosters commitment to continual improvement and cultivates employee responsibility and motivation
- actively maintaining and reinforcing the importance of recreational water quality management to all employees as well as those outside the organisation
- ensuring that its actions and policies support the effective management of recreational water quality (e.g. appropriate staffing, training of employees, provision of adequate financial resources, active participation and reporting to the board or chief executive).

2.2.1.1. Identify responsible authorities

Key actions
☐ Identify the leadership entities that will lead and manage water quality and public health
☐ Identify a coordinating entity to lead and oversee risk management actions
☐ Nominate a site manager for the water site/s.

Whatever the scale of the water environment, the responsibilities and accountabilities for all relevant entities need to be understood, documented and communicated.

The leadership/coordination roles could be single or multiple organisations, committees or groups and include key environmental health officers from local government and water utilities. Local councils, alliances of agencies, or environment agencies can all fulfil these types of roles, depending on the context. In addition, the coordination and site management roles might be held by the same entity.

In practice, the governance arrangements would be less complex for water sites that involved fewer stakeholders and required minimal oversight to manage risks. It is expected that for water sites associated with several values that need to be protected, and where multiple stakeholders would need to be involved to manage risk, coordination is necessary to ensure clear lines of accountability and responsibilities.

2.2.1.2. Regulatory and formal requirements

Key actions
☐ Identify and document all relevant regulatory and formal requirements
☐ Establish a plan to regularly update the list of relevant regulatory and formal requirements
☐ Relevant obligations should be communicated to the appropriate stakeholders.

All water sites used for recreational or cultural purposes will fall under a number of legislated responsibilities and formal requirements. These should be identified and documented to help site managers and operators meet these obligations.

These regulatory and formal requirements may relate to:

- protecting the values associated with the water site such as legislation pertaining to environmental and biodiversity protection, cultural and heritage protection, public health and safety, water resource management and flood protection.
- protecting water users from potential harms associated with recreational water activities including illness and physical safety.

It is also important to identify any existing site-related operating licences and agreements including any policies relating to First Nations cultural practices and traditions.

Regulatory requirements and relevant obligations should be listed in a site management plan. In addition, the Water Quality Risk Management Plan should provide details explaining the relevance of all identified requirements and how they help to protect water quality and public health.

Relevant obligations should be communicated to the appropriate stakeholders to ensure that they are understood and can be implemented. The coordinating entity should regularly update the list of requirements to reflect any changes. These changes should be communicated to relevant stakeholders when they occur.

2.2.1.3. Engage stakeholders

Key actions
☐ Identify and document key stakeholders
☐ Involve stakeholders with responsibilities and expertise in public health in relation to water environments
☐ Engage stakeholder groups to obtain early feedback such as public values and preferences, any local factors that will impact risk management
☐ Consult and plan with First Nations communities and Traditional Owners regarding water sites on Country
☐ Engage water users on forms of recreational and cultural activities, responsibilities and strategies for risk communication.

The roles and contact details of all key stakeholders and their responsibilities for water resources that support water environments that are used for recreational or cultural purposes should be documented in a Water Quality Risk Management Plan. The list should cover all stakeholders (including the public) affecting, or affected by, decisions or activities related to the use of the water site/s.

At recreational water sites where water contact activities are restricted, routine engagement with stakeholders is likely to not be necessary. In such cases, the responsibility for maintaining controls may reside with a single entity. These roles and responsibilities should be documented in a site management plan. For complex water sites, the coordinating entity should organise the actions and activities of stakeholders via formal or informal committee and stakeholder engagement processes.

The coordinating entity should periodically review the list of relevant agencies and associated details to ensure the list remains current.

The coordinating entity should develop appropriate mechanisms and documentation for stakeholder commitment and involvement. Partnerships should be established with agencies or organisations as necessary. This should occur under the oversight of the coordinating entity. These partnerships can support the effective management of water environments used for recreational or cultural purposes. Multiple stakeholders may need to perform key active roles in the care or management of the water site and the surrounding environment.

Engaging with water users is essential to ensure all relevant exposure pathways are considered in the risk assessment. This includes understanding type of recreational activities, exposure pathways, exposure volumes, duration and frequency. Understanding the profile of water users will help inform communication strategies that are culturally appropriate and meaningful.

Table 2.4 provides an overview of additional or indirect stakeholders with a potential role or interest in the management of water quality at public water sites. Stakeholders with direct governance or operational roles (e.g. government agencies, local councils, water utilities, site managers, Aboriginal land councils) are listed in Table 2.3.

Table 2.4 - Stakeholders with a potential role or interest in the management of water quality at water sites

Stakeholder Group	Potential stakeholders	Role/Interest
Landowners and custodians	• Traditional Owners • private ownership • trusts • knowledge holders	Responsible for land and water stewardship; may hold legal or cultural rights.
Water users	• members of the public • tourists • recreational clubs, schools	Direct users of water sites for recreation, education or cultural purposes.

Stakeholder Group	Potential stakeholders	Role/Interest
Community groups	• environment and conservation community groups and associations • sporting associations	Represent community interests, promote awareness, and advocate for water quality.
Industry and Commercial Operators	• tourism industry • agriculture • extractive industries including mining and forestry • primary industries • industrial and commercial sectors (including chemical manufacturing and processing plants, legacy sites, waste management facilities) • local council for stormwater management	Conduct activities that may impact water quality and have responsibility for managing possible point sources of pollution.
Scientific and technical community	• universities and research institutions conducting water quality monitoring and research to improve water quality • laboratories	Provide research, monitoring, technical advice and innovation.
Stock and domestic users	• rural land holders • domestic water users	Use water for stock watering or household purposes.

2.2.1.4. Recreational water quality policy

Key actions
☐ Develop a water safety policy for the recreational or cultural use of water sites, endorsed senior managers ☐ Establish partnerships with agencies or organisations ☐ Regularly update the list of relevant agencies and their details.

The first and overarching element of the Framework is the explicit commitment to recreational water quality management by the responsible entity. A recreational water quality policy (developed, understood and endorsed by senior management and the board) will provide guard rails and appropriate allocation of resources for effective implementation of the entire Framework.

The policy should provide a basis for developing more detailed guiding principles and implementation strategies. The policy should be endorsed by senior managers, to be implemented within the organisation and with support from participating agencies. The policy should be clearly visible and communicated, understood and implemented by employees and contractors. As such, it should be clear and succinct and should address broader issues and requirements, such as:

- commitment to the responsible management of water environments
- the application of a risk management approach
- recognition and compliance with relevant regulations and other requirements
- communication and partnership arrangements with agencies with relevant expertise, and with water users
- communication and engagement with employees, contractors, stakeholders, the public and water users
- intention to adopt best-practice management and a multiple barrier approach
- continuous improvement in managing water quality.

Joint agreements and statements of commitment, such as memoranda of understanding or inter-agency management agreements, are a useful tool to clarify and formalise roles and engagement of all stakeholders. Such documents should be signed off at a high organisational level and provide ongoing commitment to the long term management of the identified water site/s and environments. The documents should explicitly identify the responsibilities and accountabilities for governance of the water environments.

Each entity should ensure that responsibilities are understood and communicated to all parties, including employees, contractors and water users. In particular, at the site scale, it is important to engage water users and ensure that their responsibilities are identified and understood.

2.2.1.5. Ensure capability

Key actions
☐ Identify and document the expertise required ☐ Ensure that work is undertaken by agencies and operators with appropriate expertise.

The responsible entity should ensure organisational capability to manage water quality risks in recreational water. The selection, development, management and regulation of water bodies used for recreational or cultural purposes should be undertaken by agencies and operators with the appropriate expertise and training (see Table 2.5). Some technical roles will require certified expertise in that field.

A Water Quality Risk Management Plan should outline the expertise required to understand aspects of water quality relating to water sites used for recreational and cultural purposes. Details on how the required expertise is/will be provided should also be documented.

NHMRC

Table 2.5 - Potential capabilities required

Level/context	Example expertise required
Site level **(local water environment management)**	• site operations and management • public communication and advice • risk assessment • risk and quality management systems • auditing.
Catchment level **(broader water catchment management)**	• catchment and land management • planning and development control • hydrology and hydrogeology • stormwater, plumbing, sewerage and wastewater management • agricultural pollution control • on and in water processes (such as boat sullage, fuel spills, wave/wake boarding, erosion and bather shedding) • pollutant fate and transport on land and in water.
Technical expertise **(supporting local/regional water management)**	• water quality monitoring • water quality management • microbiology • toxicology (chemical risk assessment) • public health.

2.2.2. Risk assessment (element 2)

Effective risk management requires identification of all potential hazards, their sources and hazardous events, and an assessment of the level of risk presented by each. A risk assessment of the water environment that is used or proposed for recreational or cultural purposes is required. A structured approach is important to ensure that significant issues are not overlooked and that areas of greatest risk are identified.

In this context:

- A **hazard** is a biological, chemical, physical or radiological agent that has the potential to cause harm.
- A **hazardous event** is an incident or situation that can lead to the presence of a hazard (what can happen and how).
- **Risk** is the likelihood of identified hazards causing harm in exposed populations in a specified timeframe, including the severity of the consequences.

The aim of the risk assessment is to provide a detailed understanding of:

- the entirety of each water site and its surrounding environment, including its broader context from upstream and downstream (e.g. due to tidal surge) that may influence water and pollution sources through to a specific water site.
- the hazards, sources and events (e.g. weather events, bushfires) that can compromise water quality.
- the level of risk associated with each hazard or hazardous event so that priorities for risk management can be established and documented.
- the preventive measures needed to effectively control the identified hazards and protect public health.

The outcomes of this risk assessment underpin the management strategies including preventive measures needed to protect public health and the level of management oversight required.

Questions that should be asked at this stage include:

- what and where are the possible sources of pollution (including from current and historical activities) at the water site and in the surrounding catchment? How may these change over time?
- what activities and types of exposures will take place at the water site?
- who will use the water site, how often and when?
- what data is available to assess the risks?
- what are the hazards and/or events that might present a risk to human health (including from pollution sources or naturally occurring sources)?
- what are the risk drivers for this water site?
- are there any protective measures in place and are they working?
- what is the risk of these hazards/events happening?

2.2.2.1. Consider the water environment and its context

Key actions
☐ Assemble a risk assessment team with appropriate knowledge and expertise
☐ Identify and document key characteristics of the water environment and its context (e.g. sanitary inspection)
☐ Identify intended and other potential uses of water environments
☐ Identify and consider use of the water site by vulnerable or sensitive populations.

Assemble a risk assessment team

Assessment of the viability and potential risks of water environments used for recreational or cultural uses is important. This process should involve people with expertise in water quality, public health and community attitudes and behaviour. This usually means involving agencies with responsibilities in these areas. This might include groups or clubs that use water sites, or agencies with health protection roles (such as environmental health officers and similar professionals).

The tasks involved in this part of the risk management planning process include a risk assessment of the water site/s and the development of a Water Quality Risk Management Plan.

For complex water sites and events, a risk assessment team with the appropriate knowledge and expertise should be assembled. This team can describe and assess the system and the associated water quality risks and to design and implement controls.

The risk assessment team might consist of representatives of the key stakeholder groups (Table 2.4), experts and support personnel for organising and documenting. The tasks to be completed by the risk assessment team for a system that has yet to develop a Water Quality Risk Management Plan are quite extensive, especially for the first time. On some occasions most of the information is readily available. In these instances, the work will entail assembling and synthesising that information into the Water Quality Risk Management Plan. At worst, there might be major data and information gaps resulting in significant amounts of work to source the relevant information.

In subsequent years, the tasks to be completed by the risk assessment team to update the Water Quality Risk Management Plan are typically much less extensive and primarily involve review and update tasks.

The role of the risk assessment team may vary. In some cases, it may become a standing committee with an ongoing role. In others, it may only be assembled at intervals to review and update the Water Quality Risk Management Plan. This decision will depend on a range of factors. Most notably, this will include the makeup of the team. This includes whether team members have ongoing roles in water management or are only involved during the initial or periodic review of the management plan.

Identify and document key characteristics of the water environment and its context

Effective assessment and management of risk requires an understanding of the water environment and its context. This will encompass the source of water and potential pollutants, through to the specific water sites that will be used for recreational or cultural activities. Each part of the catchment and environment surrounding the water site should be characterised with respect to water quality. This includes understanding the typical levels of microbial, chemical and physical attributes that reflect the quality of the water. It also includes understanding the factors that affect it, and the state of the system and any barriers or process controls. The amount of work and level of detail required to complete this task will depend on the complexity of the system and situation. Information required to be assembled typically includes:

- maps and geographic information system plots showing catchments, rivers, land uses, pollution sources and water sites used for recreational or cultural purposes to help display, catalogue and interpret data
- summaries and descriptions of how water flows, naturally or via pumped systems or transfers, and reaches the water environments
- explicit and reliable identification of all sources of water feeding to, and finishing at, the water environments, including point source discharges that may reach the water site/s
- water quality information relating to hazardous substances present in those source waters and the potential sources of those substances, including the quality of water charging the water site
- summary of the typical characteristics of the water site and surrounding environment
- any intended or potential uses and resulting human exposures to the water site and surrounding environment.

It is important to consider both routine, baseline conditions as well as potential/seasonal events and triggers of change. These events include droughts, floods, pollution spills and other major drivers of change. The necessary information may be available in existing documentation from previous studies or from external agencies.

Useful sources of information for system assessment include:

- resource maps and reports from natural resource management agencies (e.g. for soils, vegetation, geology, groundwater)
- maps of sewerage and stormwater systems
- evidence of vessel movements and vessel sanitary and chemical disposal mechanisms
- land use surveys and catchment maps showing urban areas, unsewered areas, pollution sources and stormwater systems
- existing approvals or licences recording wastewater and recycled water compliance data and recorded discharges of wastewater and recycled water
- records from local authorities (e.g. locations of onsite systems, animal feedlots, sewage treatment plants, historical land use, contaminated sites)
- records from sanitary inspections of catchments see Information sheet – Sanitary inspections
- hydrological records and stormwater flows
- employee knowledge
- experts in specific fields
- inspections and field audits
- research and investigative monitoring results.

For large systems, for practical purposes, there is a need to limit the assessment and focus on components that could reasonably be expected to impact the specific water site.

To help share and communicate the details of the water environment and its context, a conceptual flow diagram, or similar, should be developed to illustrate the context from the catchment and source water through to the points of water user exposure.

The characteristics to be included in flow diagrams will be specific for each system, such as:

- outline of all major catchments and water transfer pathways that can feed the water environments where recreational or cultural activities take place
- indicate any significant pollution sources (including land uses that represent diffuse pollution sources and significant point sources)
- show important steps and processes, such as major pollution sources and pollution control infrastructure or systems
- indicate critical control points and other high priority preventive measures, once identified (see section 2.2.3.1)
- indicate water quality verification monitoring and sampling points (see section 2.2.5)
- show alternative water flow pathways including intermittent inputs (e.g. sewer access points known to surcharge only in very heavy rain)
- show all specific water sites used for recreational or cultural purposes
- highlight any unique or important characteristics/features that need to be considered when assessing the risks.

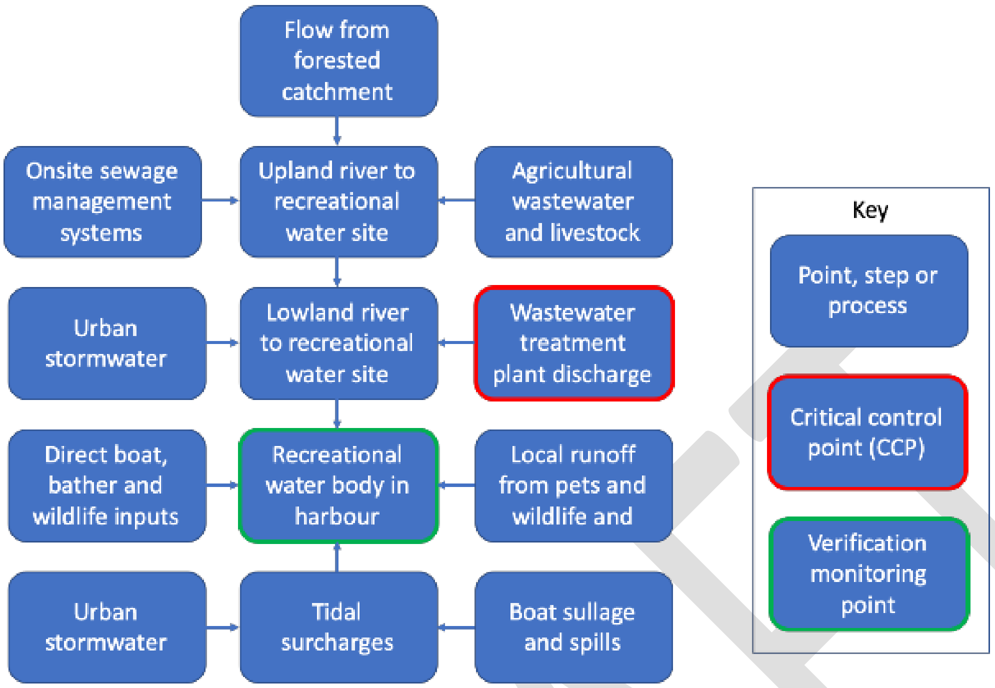
The flow diagram needs to be verified by field audits and checked by those with specific knowledge of the system for its veracity. Ideally the flow diagram should be signed off to attest to its veracity using a suitably informed party.

The flow diagram should be included in the Water Quality Risk Management Plan.

The information assembled to describe the water environment and its context, including maps, descriptions and diagrams, should be subjected to periodical review and update at intervals of typically several years or in response to significant changes.

In practice more than one process flow diagram may be required to illustrate all of the required information. An example is illustrated in Figure 2.5.

Figure 2.5 - Example of a process flow diagram



Identify intended and other potential uses of water site/s

An assessment of risk is built around understanding the activities and exposures to water that may occur at a water site. A prerequisite to assessing risk, defining risk mitigation measures and water quality targets is a clear understanding of the intended water uses, activities and routes of exposure affecting water users, such as:

- what activities might be conducted
- what exposures might arise during those activities (e.g. ingestion, inhalation, skin contact)
- the nature of persons that may become exposed (e.g. life stage and immunological status)
- the extent to which exposures are voluntary and informed allowing those exposed to make informed decisions on accepting risk vs. involuntary and potentially uninformed leading to unintended exposure to risks. Not all recreational users (especially children) are able to make informed decisions, therefore in the case of water sites popular with children, a precautionary approach is required.

While there are different pathways to potential exposures, from a practical perspective most activities can be grouped into one of three categories based on their having similar exposures (see *Chapter 1 - Introduction* for definitions):

- Whole body contact (primary contact)
- Incidental contact (secondary contact)
- No contact (aesthetic uses)

Guideline values, default screening values or management controls specified in these Guidelines relate to activities that result in incidental ingestion of water as the primary route of exposure.

A specific risk assessment is necessary in the following contexts:

- cultural practices or activities that may involve spraying of water that may cause water to be forced into orifices under pressure and may present risks distinct from those in most static water environments; or may generate aerosols due to mists and sprays that may present potential inhalation risks.
- environments may have particularly cold or warm water that may present specific water quality risks that are greater than at ambient temperatures.

Once a water site is open to public access and provides facilities such as car parking, transport links, access tracks and other facilities, it is essential to consider activities that may occur at that water site and not just the nominated activities for which the water site is intended. For instance, while some water sites may be considered safe only for incidental contact with water during recreational or cultural use, there is still a chance that whole body contact could occur. This possibility should be assessed and considered in the evaluation of exposure and risk. Similarly, while access only to defined areas of water or access times might be permitted, the likelihood that persons will move to other locations, or be present at other times, should be assessed and considered in the risk assessment.

In practice it is often the unintended activities and exposures that will determine the level of risk and risk management rather than the intended activities and exposures. Therefore, their consideration should not be an afterthought but may in fact be a core consideration.

A definition of acceptable (accepted or tolerable) risk should recognise that exposure to natural water bodies always carries some risk. It should also consider that people may voluntarily accept certain risks. This informed acceptance of risk can potentially permit a range of risk targets to be accepted for specific populations.

The summary of intended and other potential uses of the water site/s should be collated and explained in the Water Quality Risk Management Plan.

Identify and consider vulnerable or sensitive populations

There may need to be consideration given for persons in vulnerable life stages: the young; the elderly; pregnant persons; and persons with altered immunological status (such as with allergies, immunosuppressed or immunocompromised persons).

Any assessment of risk to the general population needs to consider all stages of a normal life regardless. However, in some circumstances, exposures may be limited to groups that are at significantly higher, or lower, risk due to the exclusion or planned inclusion of at risk groups.

2.2.2.2. Collect relevant data

Key actions
- Assemble relevant data to assess the risks for water environments used for recreational or cultural activities - Collate and present information for use in the subsequent risk assessment - Start the process of filling important data gaps for future assessments.

Historical data should be assembled to help provide an objective evidence base to inform the risk assessment of water sites used for recreational or cultural purposes. Data should be collated both for the specific water sites themselves, as well as for surrounding catchments and waters flowing towards and influencing those environments. Given water quality risk is not static, data requirements to maintain a current state of knowledge should be identified.

For water sites where restrictions apply to prevent water contact, effort in collecting data and filling data gaps is not necessarily needed.

The respective chapters for each water quality hazard provides information on useful data sets that should be collected including specific hazards, indicators and relevant antecedent conditions (e.g. rainfall, flowrates/dilution, water body depth, stratification). Data on water use should include risk profiles of water uses (e.g. population groups with underlying health conditions or life stages), visitation rates, activities occurring and their location and timing and behaviours relating to exposure.

The quality and reliability of data should be carefully assessed, and data screened and prioritised based on its quality. For instance, data using outdated analytical methods, or non-accredited laboratories, may be of less value than more recent or accredited data.

Once assembled, data should be assessed through a systematic analysis and prepared for presentation and summary to stakeholders. Tools, such as control charts and trends analysis, can be used to identify trends and potential problems. Statistical techniques can be used to extract information on compliance and other useful summaries. Presentation techniques can be prepared to help illustrate and communicate concepts, such as comparing water quality data to variables that may correlate with, or even drive, water quality, such as flow and levels of recreational or cultural water activities.

Particular attention should be paid to specific events, such as heavy rainfall, which can lead to poor water quality in receiving environments, and periods of heavy water site usage or harmful algal and cyanobacterial blooms.

The water quality data should be collated and presented in a format that is easy to use and follow in the subsequent risk assessment and reporting process.

Upon collating and analysing the data, it is likely there will be some gaps between the desired and available data. It is important to identify gaps in data early and, to the extent achievable, start the process of filling those gaps. Some data gaps may take a long time to fill, particularly those awaiting seasonal or event related occurrences. In particular, if there is no, or limited data on water quality indicators (e.g. faecal indicator organisms), or data relating to activities occurring at specific water sites, there will be significant challenges in completing the risk assessment.

Publishing and sharing data collected for local risk assessments is encouraged. This data may be useful or relevant to other water bodies and assist communities with fewer resources. In can also support business cases for improving catchment management protections or contribute to the evidence base for future guideline reviews.

2.2.2.3. Assess hazards, hazardous events and risks

Key actions
☐ Plan and undertake a risk assessment of the water site using suitable methods and approaches (e.g. sanitary inspection)
☐ Identify relevant hazards and hazardous events
☐ Identify and assess relevant human exposure pathways and events against each relevant hazard
☐ Estimate the level of risk to water users
☐ Prioritise the most significant risks requiring risk management.

Plan and undertake a risk assessment of the water site using suitable methods and approaches

There are multiple tools and guidelines that can used for risk assessment and many organisations have their own tailored approaches. It is important to use a suitable and fit for purpose approach to risk assessment for the context in which the assessment is taking place. These Guidelines provide just one possible example of a simple approach that is commonly used to qualitatively assess risks based on AS/NZS 4360:2004 (risk management) (see the Water Quality Risk Management Plan template). IEC 31010:2019 *risk management – risk assessment techniques* can be used to provide broader guidance on risk assessment techniques (IEC 2019).

The following should be clearly documented, particularly in a formal Water Quality Risk Management Plan, with reasoning provided for any decisions made:

- the approach/methods used for the risk assessment
- the findings and data collected at each step of the risk assessment
- the estimates of risk, with details on identified hazards and hazardous events
- decisions that prioritise risks requiring management.

At intervals, and in response to relevant changes such as in the surrounding environment, infrastructure or use of the water site, the risk assessment team should review and update the risk assessment to make sure it is accurate and up to date.

There are various levels of risk assessment. In most circumstances, an initial screening risk assessment drawing upon site assessments through a sanitary inspection and desktop review of available information. First Nations' knowledge and sensory observations, informed by long standing relationships with Country, can provide valuable complementary insights and should be considered when assessing risks to water quality. The initial screening risk assessment is typically undertaken to identify priority risks that require further characterisation or quantification through additional site investigations and water quality monitoring. The risk assessment approaches should be appropriate for the hazards being investigated. Table 2.6 summarises risk assessment approaches used for specific hazards.

Table 2.6 - Risk assessment approaches according to specific hazards

Hazard	Risk assessment approaches
Enteric pathogens *Chapter 3 - Microbial pathogens from faecal pollution*	Sanitary inspection Microbial water quality monitoring using faecal indicator organisms or other markers of faecal pollution Quantitative microbial risk assessments
Other microbial hazards including free-living organisms *Chapter 4 - Other microbial risks*	Sanitary inspections Water quality monitoring for potential indicators or pathogens
Harmful algal and cyanobacterial blooms *Chapter 5 - Harmful algal and cyanobacterial bloom risks*	Sanitary inspection Water quality monitoring including: – physiochemical indicators such as temperature, nutrients, pH – cyanobacterial biomass indicators such chlorophyll *a*, biovolume, cell count – analytical methods for presence of cyanotoxins
Chemicals *Chapter 6 - Chemical hazards*	Sanitary inspection Monitoring of physicochemical indicators such as pH, alkalinity, dissolved oxygen, colour, turbidity, temperature Qualitative risk assessment based on sanitary inspection, monitoring of environmental indicators and chemical screening analysis Quantitative risk assessment for specific hazards identified from qualitative risk assessment
Aesthetics *Chapter 7 – Aesthetic hazards*	Sanitary inspection

Hazard	Risk assessment approaches
Radiological *Chapter 8 - Radiological hazards*	Sanitary inspection Geological survey information Monitoring of natural background levels.

Identify relevant hazards and hazardous events

The risk assessment team should identify hazards and their associated hazardous events for all components of the water environment where recreational or cultural use of the water will occur. Some of the hazards and associated hazardous events most commonly identified in water quality risk assessments for water environments are noted in Table 2.7 and detailed in the relevant sections of the Guidelines.

Hazards include microbial, chemical, physical and radiological agents. All potential hazards, sources and events that can lead to the presence of these hazards (what can happen and how) should be identified. This includes point sources of pollution (e.g. human and industrial waste discharges) as well as diffuse sources (e.g. those arising from agricultural and animal husbandry activities). Continuous, intermittent or seasonal pollution patterns should also be considered, as well as extreme and infrequent events such as droughts or floods. The hazard identification and risk assessment should be reviewed and updated periodically because changing conditions may introduce important new hazards or modify risks associated with identified hazards.

Table 2.7 - Examples of commonplace hazards and associated hazardous events

Common hazards	Associated hazardous events and pollution sources	Links
Enteric pathogens	Sewage leaks and overflow, flooding events Agricultural run off, animal presence (e.g. bird nesting) Rain events Recreational users	*Chapter 3 - Microbial pathogens from faecal pollution* *Information sheet - Sanitary inspections*
Free living organisms	Increased water temperatures (e.g. warm water discharges from thermal power stations and other anthropogenic sources)	*Chapter 4 - Other microbial hazards*
Harmful algal and cyanobacterial blooms	Rain events Increased water temperatures Eutrophication Blackwater events	*Chapter 5 - Harmful algal and cyanobacterial blooms*

Common hazards	Associated hazardous events and pollution sources	Links
Chemical contamination	Spills Rain and flooding events Agricultural run-off, spray drift Wastewater discharges	*Chapter 6 - Chemical hazards* *Information sheet - Sanitary inspections*
Radiological hazards	Natural background levels Release of mining waste	*Chapter 8 - Radiological hazards*

Identify and assess relevant human exposure pathways and events against relevant hazards

The potential pathways of exposure to these hazards include ingestion, dermal and inhalation. The relevant pathways for each hazard are discussed in their respective chapters and in the *Information sheet – Exposure assumptions*. Whilst ingestion is considered the primary route of exposure for most hazards; there are exceptions. Therefore, the exposure pathways relevant for each hazard should be considered in the risk assessment. Examples include chemicals with properties conducive to skin permeability; or microbial hazards (e.g. *Naegleria fowleri*) where the nasal pathway is most relevant.

Estimate the level of risk to water users

Once potential hazards and their sources have been identified, the level of risk associated with each hazard or hazardous event should be estimated so that priorities for risk management can be established and documented.

In general terms, the level of risk is higher for activities that involve immersion such as swimming or surfing relative to no or limited water contact activities. Most water bodies are likely to contain microbiological hazards from faecal pollution sources and poses the greatest risk to water users. It is expected that in most cases the risk of exposure to chemical and radiological hazards is low. The potential risks associated with exposure to harmful algal and cyanobacterial blooms is likely to be confined to seasonal patterns when environmental conditions are conducive to their proliferation.

The level of risk for each hazard or hazardous event can be estimated by identifying the **likelihood** of occurrence and evaluating the severity of **consequences** if the hazard were to occur. The aim should be to distinguish between very high and low risks. AS/NZS 4360:2004 (risk management) describes qualitative measures for likelihood and consequence in risk assessment. It also outlines the process for developing a risk matrix, combining the outcomes of the likelihood of the event occurring and consequence if the event did occur. Each hazard hazardous event combination is assigned a qualitative risk estimation (i.e. a risk level or risk rating of low, medium, high or very high). An example of a qualitative approach to estimating the level of risk, adapted from AS/NZS 4360:2004 (risk management) is provided in the *Water Quality Risk Management Plan template* and can be modified to meet the needs of an organisation. The risk should be considered for the full range of conditions that may exacerbate the risk, including worst case scenarios and foreseeable risks.

It is good practice to assess the level of confidence or uncertainty, and evaluate the major sources of uncertainty, associated with each risk estimate and consider actions to reduce uncertainty to help drive continuous improvement (see section 2.2.11.2).

Determine the most significant risks and document priorities for risk management

Based on the assessment of risks, priorities for risk management and application of preventive measures can be established. Risk should be assessed at 2 levels:

- maximum risk in the absence of preventive measures
- residual risk after consideration of existing preventive measures (see section 2.2.3.1).

Assessing maximum risk is useful for identifying high priority risks, determining where attention should be focused and preparing for emergencies. Residual risk provides an indication of the need for additional preventive measures. The risk assessment should entail consideration of reliability of preventive measures and resilience to future hazardous events or emerging threats.

The Water Quality Risk Management Plan should highlight and present the most significant risks. These significant risks should be summarised and reviewed by senior persons from the coordinating entity and site manager, and potentially other stakeholders, to ensure their understanding of these risks.

Typically for water environments used for recreational or cultural purposes, microbial hazards present the greatest risk, particularly those related to enteric illness. Pathogenic microorganisms from wildlife are found even in the most pristine of natural surface waters that contain bacterial pathogens from wildlife. In addition, water users themselves are a potent source of pathogens including bacteria as well as viruses and pathogenic protozoa. More developed water catchments with more urbanised or intensive agricultural development typically present higher levels of risk.

2.2.3. Risk management (element 3)

Prevention is an essential feature of effective management of water quality risks. Water quality hazards may occur or be introduced within the catchment upstream of the water site, or at the water site including from recreational activities. Preventive measures are those actions, activities and processes used to prevent these hazards from occurring or reduce them to acceptable levels.

While the risk management measures that are possible will depend on the water site/exposure scenario and available resources, the safest approach is to make sure there are measures in place that can help:

- *manage the known* (e.g. prevent or reduce risks from identified sources of pollution such as wastewater treatment plants)

- *manage the unknown* (e.g. preparing responses/actions to minimise risks from events that cannot be controlled (e.g. spills, environmental drivers such as rain/flood events).

Questions that should be asked at this stage include:

- how can we tell if the water is not appropriate for use?
- what are the best measures we can put in place to prevent/manage the risks identified in the risk assessment?
- what can we monitor to make sure our measures are working properly?
- is there a response plan in the event of an emergency or exceedance?

In order to responsibly manage risks, a concerted effort is needed to ensure all elements of the preventive measures are applied. For complex water sites, it is likely that the preventive measures will be bespoke to that specific water site. For most water sites, it would be expected that preventive measures already universally practised are implemented. For water sites that are considered low risk due to no water contact the focus would be on ensuring controls to restrict water contact are effective. For water sites with inherently low risks to water quality, periodic catchment and site inspections to ensure the risk assessment remains valid would be appropriate.

2.2.3.1 Determine preventive measures and performance targets

Key actions
☐ Identify and assess existing and additional preventive measures for each significant hazard or hazardous event and estimate residual risk
☐ Document the preventive measures and strategies into a plan addressing each significant risk
☐ Prioritise preventive measures and identify any critical control points
☐ Establish appropriate performance targets
☐ Identify appropriate response actions and corrective actions.

Identify and assess preventive measures for each significant hazard or hazardous event and estimate residual risk

The risk assessment team should identify and consider any relevant preventive measures when estimating the level of risk to water users. Preventive measures should be formally identified system wide for each significant hazard and hazardous event combination. Some of these are preventive measures that are relevant at the catchment scale and others at the water site scale. Table 2.8 provides examples of preventive measures.

Assessment of preventive measures involves:

- identifying existing preventive measures from catchment to water user for each significant hazard and hazardous event combination

- evaluating whether the preventive measures, when considered together, are effective in reducing risk to acceptable levels (i.e. residual risk)
- if improvement is required, evaluating alternative and additional preventive measures that could be applied.

The level of protection to control a hazard should be proportional to the associated risk. In the protection of public health, multiple barriers are strongly recommended. Reliance should not be placed on a single preventive measure as a barrier to protect public health. Rather, multiple preventive measures should be in place to proactively protect public health through multiple barriers. This longstanding risk management principle is important to avoid reliance on limited barriers that could fail and leave water users exposed.

Many preventive measures may control more than one hazard, while, as prescribed by the multiple barrier approach, effective control of some hazards may require more than one preventive measure. Preventive measures should be applied as close to the source as possible. The focus should be on prevention in catchments, such as eliminating the pollution source. This is more effective than relying solely on downstream controls such as water quality monitoring or alert systems.

If additional measures are required, factors such as level of risk, benefits, effectiveness, cost, community expectations and willingness to pay should be considered. Preventive measures often require considerable expenditure. Decisions about water quality improvements cannot be made in isolation. They need to consider other aspects of water supply that also compete for limited financial resources. Priorities will need to be established, and many improvements may need to be phased in over time.

Table 2.8 - Examples of preventive measures

Preventive measures	Examples
Improved planning and regulation of water environments used for recreational or cultural use	- planning and environmental overlays - buffer zones from water body shorelines - regulate pollution sources and apply the waste hierarchy (e.g. avoid or minimise discharges, trade waste controls, formal consideration of recreational or cultural use of nearby water sites in impact assessments and issuing licenses for environmental discharge) - clear lines of authority and governance - prohibitions and controls on chemical use within the catchment - remediate contaminated sites.

Preventive measures	Examples
Broader catchment management programs	- catchment management authorities and groups overseeing and implementing water quality protection and improvement interventions - good land management practices that reduce the discharge of faecal matter from livestock to waterways (e.g. fencing and riparian zones) - catchment, farm and landscape management planning programs to minimise run-off from agricultural land, reduce soil erosion.
Ongoing wastewater and sewer management programs	• sewer relining and rehabilitation • remedying stormwater connections to sewer, and wastewater connections to stormwater • advanced treatment of sewer discharges • onsite sewage management system monitoring and management programs • sewer backlog programs • upgrading hydraulic capacity of sewerage systems and pump stations.
Water sensitive urban design measures	• stormwater treatment and mitigation processes that help to control discharge quality • water-sensitive urban design features including wetlands and retarding basins that can help trap and reduce concentrations of common pollutants.
On site risk management	- requirements for sanitation systems for watercraft including houseboats or other on water activities - managing the density of water users at a water site applying limits on visitor numbers to reduce risk of person-to-person transmission and pathogen inputs due to shedding from users - proactive management of water site access to warn or discourage activity during periods of elevated risk - sufficient sanitation infrastructure to support use of water site (e.g. toilets, bins) - signs and fencing.
Public risk awareness and education/involvement	- public education and awareness campaigns aimed at reducing pollution of catchments (e.g. community river committees; citizen science programs for water quality monitoring).

Controls that do not necessary prevent hazard events, but rather may reduce exposure of the public to hazards include:

- preemptive risk management based on satellite imagery or predictive modelling using surrogates or indicators and other data to trigger action and public advisories
- incident and emergency procedures to trigger action and public advisories (e.g. supervisory control and data acquisition (SCADA) systems to remotely monitor and control sewer pump stations)
- operational procedures and working practices for limiting who can be present at a water site, how many people, what they can do and how they should behave to limit pollution and/or exposure.

Document the preventive measures and strategies into a Water Quality Risk Management Plan addressing each significant risk

For each significant risk, the corresponding preventive measures and strategies should be documented in the Water Quality Risk Management Plan. A risk register (see Table 2.9) provides a systematic means of documenting for each hazardous event. It includes the corresponding risk rating (the product of consequence and likelihood of occurrence) and current controls in place to manage the risk. This includes how the risk is monitored and what additional measures are needed to reduce the risk.

Table 2.9 - Examples risk register

Hazardous event	Risk rating (potential consequence and likelihood of occurrence)	Is the hazard controlled?	If yes what is the control?	How is this control monitored?	What additional measures will reduce the risk?	Timeframe for action
Access by farm animals (microbial hazards)	High	No	Not applicable	Not applicable	Fencing to restrict stock access Restore riparian buffer	12 months 2 years
Sewer pump station water overflow (microbial hazards)	Very high	Yes	Pump station alarmed in the event of a fault or spill.	Water utility SCADA system and asset management system	Upgrade pump station capacity to reduce frequency Develop, test, implement incident notification and response protocols.	5 years 6 months

Prioritise preventive measures and identify any critical control points

Many different risks and possible preventive measures may be identified during the risk assessment process. One of the benefits to ranking and prioritising risks during a risk assessment is that it can help to rank and prioritise preventive measures. This will allow responsible authorities to focus their resources on preventive measures that make the most significant contributions to reducing risk and are the most practical to implement.

All preventive measures are important and should be given ongoing attention. However, some can significantly prevent or reduce hazards and are amenable to greater operational control and monitoring than others. These measures could be considered as critical control points. In practice there might not be many opportunities to control sources of pollution around water sites used for recreational or cultural purposes. However, if identified they can play an important role in predicting and assuring water quality. This is particularly important in scenarios where major point discharges can present serious health risks to water users.

A good example of a critical control point is a wastewater treatment plant that discharges into a river. In this case, the responsibility for implementing and maintaining critical control points lies with the water corporation operating the plant. The treatment plant will have formal operational systems in place to ensure that wastewater discharge meets regulatory requirements. Failure in the operating system to sufficiently treat or monitor discharges could provide early warning of potential risks at water sites downstream. Effective risk management would be highly dependent on factors such as establishing reliable lines of communication between plant operators and responsible authorities (e.g. site managers). Site managers could then undertake pre-emptive actions to monitor or manage the potential risks to water users.

Where opportunities do exist to apply critical control points, these should be clearly defined and integrated into the Water Quality Risk Management Plan.

Establish appropriate performance targets

Site managers and other responsible authorities who manage and monitor water quality risks need a way to determine whether the chosen preventive measures are working or not. Performance of preventive measures can be assessed by applying:

- target criteria
- alert limits
- critical limits (for critical control points).

Identification of performance targets for individual systems will depend on the outcomes of the risk assessment. They should also take into consideration the objectives associated with the activities occurring at the water site based on the highest exposure activity permitted. Community values and preferences about use of the water site should also be considered when determining targets.

Descriptions and examples are provided in Table 2.10.

Table 2.10 - Examples of performance targets for preventive measures

Preventive measure	Description	Examples	Example response actions
Target criteria	Performance goals that set out the objectives for a preventive measure	Targets might be set on: • performance of an upstream wastewater disinfection system • the number of water users permitted at a water site, particularly during peak periods (e.g. long weekends, public holidays during summer).	Deviation from established targets should be regarded as a trend towards loss of control of the process and should result in appropriate actions being taken, e.g.: • immediate investigation into cause of deviation • actions (corrections or improvements) made to remove/stop cause of deviation (e.g. removing excess sedimentation in basins to increase detention times) If cause of deviation cannot be stopped/removed: • improve/increase performance of additional barriers • tighten restrictions on activities at water site.
Alert limits	Provide an early warning that a process is not in control or is trending out of control. More stringent than critical limits (where applicable) to permit a corrective action to be instituted before an unacceptable health risk arises	For example, remediation capacity exceedances for a pond retention system might set alert limits on: • turbidity leaving that structure • flow rate as a surrogate for residence time.	See above.

Preventive measure	Description	Examples	Example response actions
Critical limits	For critical control points only. Prescribed tolerance levels that distinguish between acceptable and unacceptable performance. Can be quantitative or qualitative.	UV dose for a UV disinfection system Level alarms on a sewer pump station.	Deviation outside critical limits represents loss of control of a process and indicates that there may be an unacceptable health risk. Immediate corrective actions implemented (see above for examples) to resume control. Notification of health regulator and other responsible authorities.

Any performance targets should be based on objective evidence as determined by the assessment team. In addition, they should ideally be formally validated and documented in a Water Quality Risk Management Plan. If suitable evidence is unavailable, efforts should be made to undertake research or investigations to better understand and support any performance targets (see section 2.2.9).

Determine response actions and corrective actions

When operational monitoring indicates the preventive measure is not functioning effectively, a response action is required to immediately address the problem (see Table 2.10) and corrective action is required to prevent its recurrence.

The underlying cause of the problem that triggered the response, should be determined and corrective actions implemented to address the root cause of the problem to prevent its recurrence. Analysis of the causes may identify possible solutions, such as modifying an operating procedure or improving training.

Details of all incidents should be recorded and reported. While advance planning is important, it will not always be possible to anticipate every type of event. Rapid communication systems should be established to deal with these events.

Response actions and corrective actions should be documented in the RQWRMP, verified and periodically tested.

2.2.4. Implement operational procedures and maintenance programs (element 4)

Key actions
- Establish operational procedures for monitoring the performance of preventive measures - Formalise operational procedures and maintenance programs.

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Establish operational procedures for monitoring the performance of preventive measures

Having identified the most important preventive measures, reliable mechanisms for evaluating the performance of these measures should be established. This includes planning for:

- operational monitoring
- actions that should be undertaken when there are deviations from performance targets.

Where opportunities for critical control points exist, these mechanisms are likely to include formalised operational procedures and process controls that will ensure reliable performance of the preventive measures identified (see Table 2.11).

The Water Quality Risk Management Plan should explicitly include or refer to operational procedures for the identified preventive measures. The operational procedures should set out the routine operation of those preventive measures to provide clarity around their operation.

Some preventive management approaches involve modelling informed by historical monitoring. These approaches often include prediction and frequent testing to detect contamination before hazardous contaminant levels are realised or persist for extensive periods. If those approaches are sufficiently predictive, they can be considered preventive measures. Some approaches rely on contamination being detected after exposures occur. If action is only taken at this point, then in practice these methods are more akin to the verification monitoring and corrective response protocols. As described in section 2.2.5, they are not strictly considered preventive measures. Such management regimes should be captured as part of verification monitoring within the Water Quality Risk Management Plan, and not as preventive measures.

Table 2.11 - Mechanisms for evaluating and managing performance of preventive measures

Operational process	Description
Operational monitoring	• used to confirm that preventive measures are functioning properly and effectively • data can be used as triggers for: - immediate response/corrective actions to protect water quality - early action to protect water users from poor water quality • requires the selection of operational parameters (including surrogates) against which to assess performance • procedures should provide detailed instructions on requirements and methods for operational monitoring. See *Information sheet - Monitoring programs* for more information.

Operational process	Description
Operational corrections	• used to undertake corrective action where operational parameters are not met • aim to re-establish control in a timely fashion before risks to water users occur but take potential exposure into consideration • protocols should include detailed instructions on actions and requirements such as: - required adjustments and process control changes - monitoring to check corrections are effective and not causing secondary impacts to system - investigation of underlying cause to prevent further occurrences and improve operations (e.g. changes to procedures, training) - roles and responsibilities of specified personnel - documentation and reporting requirements - communication/notification requirements and processes (e.g. reporting of exceedances) including for unexpected events • total failure of operational control may trigger emergency/incident responses (see below).

Operational process	Description
Maintenance programs	• relates to capability and maintenance of equipment that will be used in operational programs • equipment, infrastructure and processes need to be: - adequately designed and of sufficient capacity to achieve their intended objectives - validated through appropriate research and development (see section 2.2.9) • equipment for operational monitoring: - needs to be sufficiently accurate and sensitive to perform at the levels required - should allow for online and continuous monitoring of critical control points (such as disinfection) with alarm systems to indicate when operational target criteria have not been met - should not compromise the system when monitoring failures occur, with spare parts, units and backup equipment readily available and installed where appropriate - should be well understood by operators so that malfunctions and spurious results can be recognised and rectified • the coordinating entity and site manager should establish a program for regular inspection and maintenance of all equipment and infrastructure, detailing: - operational procedures and records for the maintenance of equipment, including the calibration of monitoring equipment - schedules and timelines - responsibilities - resource requirements.

Formalise operational procedures and maintenance programs

Depending on the regulatory requirements of a particular water site, detailed formalised procedures may be required for the operation of preventive measures and related activities (both ongoing and periodic). Formal processes may also be required to guide responses to adverse monitoring results and observations. The procedures should form part of formal operational management systems.

The coordinating entity and site manager should identify procedures required for all processes and activities applied within the whole water system (water source to point of exposure) such as those listed above. Procedures are most effective when the persons that will implement them on a daily basis are involved in their development, documentation and verification. Participation helps to ensure that all relevant activities are included, improves operator and water user training and awareness and fosters commitment to operational and process control.

Process control programs should be documented in operations manuals or other similar guidance documents. Controlled copies should be readily accessible to all appropriate personnel. Summaries and extracts can be created to help with communication for routine operation and use.

2.2.5. Set up processes to monitor and verify water quality (element 5)

Key actions
☐ Determine the characteristics to be monitored and design an appropriate sampling program ☐ Implement systems to assess and respond to feedback from water users ☐ Establish mechanisms to report on performance and respond to exceedances.

This section discusses monitoring and verification of water quality. Verification of water quality assesses the overall performance of the system. It determines the ultimate quality of the water being experienced during recreational or cultural activities. It provides:

- confidence for all stakeholders, including water users and regulators, in the quality of the water to which persons are exposed and the functionality of the system as a whole
- an indication of problems and a trigger for any immediate short term corrective actions, or incident and emergency responses.

Verification monitoring is often conducted more frequently during the first months or years of managing a water environment. This helps demonstrate that water quality targets are being achieved and builds confidence that the target criteria for water quality will be reliably achieved in the future. For many water environment target criteria, the ultimate verification of a sustainable system may require years of monitoring.

Verification should be regarded as the final overall check that preventive measures are working effectively and that the target criteria or critical limits set for those preventive measures are appropriate. As such, the purpose of verification is different from that of the initial validation stage (section 2.2.9) or operational monitoring (section 2.2.4). The types of monitoring also differ in what, where and how often water quality characteristics are measured.

Determine the characteristics to be monitored and design an appropriate sampling program

Key components of a monitoring program include selection of parameters, program design, and ensuring quality and reliable results.

A considered approach is required to designing a monitoring program to monitor and verify water quality. It is neither physically nor economically feasible to test for all water quality parameters equally. Therefore, monitoring efforts and resources should be directed at significant or 'key' parameters. These are the parameters identified in the risk assessment process as likely to be present based on local conditions.

Further information on monitoring is provided in *Information sheet – Monitoring programs*.

Implement systems to assess and respond to feedback from water users

Comments and complaints from water users can provide valuable information on problems that may not have been identified by operational or other forms of verification monitoring. Complaints are more likely to be received from environments involving whole body contact with water. Water user perceptions of water environments may relate to water quality and aesthetic issues, rather than evidence of noncompliance with guideline values. It may also provide an additional warning system of adverse health impacts at water sites (see section 2.2.6).

The site manager should establish an inquiry and response program for water users, including appropriate training of people responsible for the program. The program should seek to provide a forum to gather and respond to feedback from water users about their perceptions of water quality.

A complaint and response program should be established, operated by appropriately trained personnel. Dissatisfaction with water sites and surrounding environments, if not dealt with appropriately, may lead to negative perceptions that have a potential to escalate. Water user satisfaction is a major component of the success of water sites used for recreational or cultural purposes. In the long term, complaints and responses should be evaluated according to type, pattern and change in the number of complaints received.

Establish mechanisms to report on performance and respond to exceedances

Protocols should be established for the review of monitoring data and feedback from water users. The site manager should set up reporting mechanisms internally and externally, where required. The mechanisms should include established and documented procedures for corrective responses to exceedances of trigger values from monitoring or adverse feedback from water users. Rapid communication systems should be established to deal with unexpected events which may include triggering an incident response (section 2.2.6).

The classification of water environments is described in the relevant chapters focused on specific hazards (e.g. faecal indictor organisms, cyanotoxins, phytoplankton, opportunistic pathogens and chemicals) which identify the water quality that is compatible with specified recreational or cultural water activities. The responsible site manager should assess and report results against those classes and take action in response to exceedance of defined triggers.

Setting the specific objectives, such as health based targets, guideline values or trigger values, for the specific parameters that are tested, should be informed by the relevant chapters within these Guidelines. Triggers for action and reporting are often based on a combination of both annual measures of central tendency or reporting statistics (e.g. arithmetic or geometric means, medians or 95th percentiles) as well as rapid warnings and responses to short term exceedances of upper bound values (e.g. maxima or 95th percentiles). Therefore, there are typically 2 timeframes against which reporting should occur:

- Longer term monitoring and reporting have the objective of classifying water sites based on long term water quality performance. Classifications include whether sites are suitable for whole body or incidental contact water activities, in the former case, whether the sites are from low ('very good') to high ('very poor') risk (see Chapter 3 - Microbial pathogens from faecal sources).

- Shorter term monitoring and reporting have the objective of informing routine operations of water environments to help make decisions on whether to open or close water sites or restrict activities at those water sites. For instance, a water site may be opened conditionally provided it is regularly tested for *Naegleria fowleri* and cyanobacterial toxins but shuts down access to the water site if exceedances of trigger levels are reported until multiple follow up results are within those trigger levels.

2.2.6. Planning for incidents and emergencies (element 6)

Key actions
Establish protocols to assess and respond to incidents and emergencies
Establish mechanisms to investigate and report on incidents and emergencies.

Considered and controlled responses to incidents or emergencies that can compromise water quality are essential. Such responses protect public health - they also help to maintain water user confidence in water quality and the site manager's reputation.

Some events cannot be anticipated or controlled or are so unlikely to occur that providing preventive measures would be too costly. For such incidents, there should be an adaptive capability to respond constructively and efficiently to protect public health.

Examples of potential incident and emergency situations include:

- risks are not being reliably controlled (demonstrated by nonconformance with set alert/critical limits, trigger levels, guideline values or other requirements)
- events/accidents that increase levels of contaminants (e.g. spills in catchments, illegal discharges into collection systems and blooms of toxigenic cyanobacteria)
- equipment breakdown and mechanical failure
- evidence of inappropriate use or behaviour at water sites
- extreme weather events (such as flash flooding or cyclones)
- natural disasters (such as fire, earthquakes or lightning)
- human actions (such as serious error, sabotage, strikes)
- outbreaks of illness leading to increased pathogen risks at water sites (e.g. bather shedding)
- noticeable changes in aesthetic conditions (e.g. odours, appearance)
- kills of fish or other aquatic life
- evidence of adverse symptoms being experienced by water users.

Incident and emergency response protocols

The site manager and/or coordinating entity should define potential incidents and emergencies and document procedures and response plans. Plans and procedures should be developed in consultation with relevant regulatory authorities and other key agencies and should be consistent with existing government emergency response arrangements. In an emergency, there will not be time to establish confidence and goodwill. To be effective, plans and procedures should be established during normal operation with parties who will be partners in responding to an emergency.

Key areas to be addressed in incident and emergency response plans include clearly specified:

- response actions, including increased monitoring
- responsibilities and authorities internal and external to the organisation
- predetermined agreements on lead agencies for decisions on health impacts
- plans for alternative water site/s
- communication protocols and strategies, including notification procedures (internal, regulatory body, media and public)
- mechanisms for increased health or environmental surveillance.

Employees should be trained in emergency response and incident protocols. Emergency response plans should be regularly reviewed and practiced. Such activities improve preparedness and provide opportunities to improve the effectiveness of plans before an emergency occurs.

Investigation and reporting of incidents and emergencies

Following any incident or emergency, an investigation should be undertaken, and all involved staff should be debriefed to discuss performance and address any issues or concerns. The investigation should consider factors such as:

- What was the initiating cause of the problem?
- How was the problem first identified or recognised?
- What were the most critical actions required?
- What communication problems arose and how were they addressed?
- What were the immediate and longer-term consequences?
- How well did the response protocol function?
- What can be learnt from any incidents and emergencies about the preventive actions to assess and improve their effectiveness?

Appropriate documentation and reporting of the incident or emergency should also be established. The responsible authorities should learn as much as possible from the incident to improve preparedness and planning for future incidents. Review of the incident may show how existing protocols need to be modified and be used to update or modify the Water Quality Risk Management Plan.

2.2.7. Communication and training (element 7)

Planning for communication and capacity building is required to responsibly manage and communicate the risks associated with water environments used for recreational or cultural purposes. This needs to be tailored to water sites to ensure it is fit for purpose. For complex water sites where risk fluctuates or is not considered low, communication requirements require dedicated resourcing.

This includes planning for ways to improve risk awareness and education/training for the public and personnel such as operators, contractors and other water users. This is important, because the knowledge, skills, motivation and commitment of operators, contractors and water users ultimately determine whether:

- a responsibility authority has the ability to successfully manage and operate a water site, including maintaining any preventive measures
- risk management measures such as access/activity restrictions placed on water users will work effectively, particularly where those preventive measures are relied upon to protect public health and depend upon the ability of water users to make safe decisions based on their risk awareness and available information.

Consultation with water users, stakeholders and the general community is an essential component for successful implementation of a Water Quality Risk Management Plan.

Questions that should be asked at this stage include:

- what training is required for the different roles involved in managing the water?
- who do we need to communicate with and when?
- do we have communication plans and protocols in place, particularly in the event of an emergency?
- how can we raise public awareness of the risks at the water site?
- how much information do we need to provide to enable informed consent?

2.2.7.1. Communications planning

Key actions
☐ Develop a communications plan that supports the responsible management of water sites, including incident and emergency response ☐ Communicate the risks in terms and ways that the community can understand and access.

Communications planning

Effective communication is vital in managing operations at water sites, including responses to incidents and emergencies. Clearly defined protocols for both internal and external communications should be established in an overarching communications plan for a water site or a region. The site manager and/or coordinating entity should define communication protocols with the involvement of relevant agencies and prepare a contact list of key people, agencies and stakeholders.

Communication strategies or protocols should be developed for activities such as:

- internal communications including notification and reporting processes for normal operations as well as incidents and emergencies
- external communications including media strategies and public messaging for normal operations as well as incidents and emergencies
- any planned consultation activities or risk awareness/risk communication campaigns with stakeholder groups including the public
- managing mis- or disinformation campaigns
- any feedback/evaluation processes.

Communication protocols for incidents and emergencies should include:

- a contact list of key people, agencies and businesses that is current
- detailed notification forms
- procedures for internal and external notification
- definitions of responsibilities and authorities.

The site manager and/or coordinating entity should develop a public and media communications strategy. Water user confidence and trust during and after an incident or emergency are essential and are largely affected by how incidents and emergencies are handled. Personnel involved in responding to incidents and emergencies and communicating with the public are appropriately trained.

Water users should be told when an incident has ended and should be provided with information on the cause and actions taken to minimise future occurrences. This type of communication maintains trust in authorities. Post incident surveys of the community are valuable to establish the perceptions of water users to events and how they were managed.

Ensure clear, appropriate, accessible and fit for purpose communication

Any communications that are intended to convey information such as processes, protocols and public health messaging should be clear, appropriate and understandable to the people who will need to use it, whether it is for internal or external purposes. For example, information signs for educational or awareness purposes should avoid using warning asphetics (e.g. no danger icons, avoid the colour red). These should be reserved for 'warning signs' to avoid message desensitisation.

Consultation with the intended audience can help determine their needs and preferences.

2.2.7.2. Training

Key actions
Increase awareness and participation of personnel including water users Ensure personnel with important roles are appropriately skilled and trained.

Operator, contractor and water user awareness and involvement

The coordinating entity and site manager should develop mechanisms and procedures to increase awareness and participation of personnel, including operators, contractors and water users, to ensure that they are aware of the potential consequences of system failure, and of how decisions can affect public health.

Personnel relied upon to manage preventive measures and participate in operational monitoring should all be aware of:

- the organisation's water quality policy
- the principles of risk management
- characteristics of the water environment and preventive measures
- regulatory and legislative requirements
- roles and responsibilities of employees and departments
- how their actions can affect water quality and public health.

Methods to increase personnel awareness can include employee education and induction programs, newsletters, guidelines, manuals, notice boards, seminars, briefings and meetings.

Participation and involvement in decision making is an important part of establishing the commitment needed to continually improve water quality management. Personnel should be encouraged to participate in decisions that affect their areas of responsibility. This provides a sense of ownership for decisions and their implications. Open and positive communication is a foundation for a participatory culture, and personnel should be encouraged to discuss issues and actions with management.

Water users should be made aware of the importance of activity restrictions. As a minimum, all water users should be aware of:

- restrictions on recreational or cultural activities
- management requirements that are essential to minimising risks to human health and other values of the water site

- preventive measures that they must take to minimise risks to their own health
- any activity, including behaviours of water users, that will threaten human health.

Operator, contractor and water user training

All personnel involved in the management and operation of water environments need to have the appropriate skills and training to undertake their responsibilities. Personnel relied upon to manage preventive measures and participate in operational monitoring should be appropriately skilled and trained. This is because their actions can have a major impact on water quality and public health. This situation also applies to many water users where activity restrictions apply and are relied upon to protect public health. Such personnel should have a sound knowledge base from which to make effective decisions. This requires training in the methods and skills required to perform their tasks efficiently and competently. It also required knowledge and understanding of the impact their activities can have on water quality and public health.

For example, to avoid pollution reaching water sites, upstream wastewater treatment plant operators should understand water treatment concepts. They should be able to apply these concepts and adjust processes appropriately to respond to variations in water quality. Similarly, farmers should understand how to prevent stock access to waterways and why it is important for public health.

For water users and site managers, the training should be appropriate to ensure compliance with activity restrictions. It is important to ensure that water users understand why restrictions and management requirements are necessary, particularly the implications to human health if not complying with them.

Training needs should be identified and adequate resources made available to support appropriate programs. Examples of relevant areas to address are:

- water quality management
- water microbiology and water chemistry
- catchment management and pollution control
- conducting sanitary inspections
- sampling, monitoring and analysis of water quality
- interpretation and recording of results
- communicating with water users.

Personnel should also be trained in other aspects of water quality management, including incident and emergency response, documentation, record keeping and reporting.

Commonly used training techniques and methods include formal training courses accredited by a national training body, in house training, on the job experience, mentor programs, workshops, demonstrations, seminars, courses and conferences.

Training programs should encourage personnel to communicate and think critically about the operational aspects of their work.

Methods to achieve awareness and understanding among water users include brochures, meetings, manuals, newsletters, induction programs, practical training sessions and demonstrations.

Training should be documented in the Water Quality Risk Management Plan, or in referenced documentation, and records of all personnel who have participated in training should be maintained. Mechanisms for evaluating the effectiveness of training should also be established and documented. Training is an ongoing process, and requirements should be reviewed regularly to ensure that personnel maintain appropriate experience and qualifications. Where activities have a significant impact on water quality, periodic verification of the capability and understanding of personnel responsible for managing those risks is necessary, which may possibly include water users.

Where possible, accredited training programs and certification of personnel should be used.

2.2.8. Community involvement and risk awareness (element 8)

Key actions
☐ Develop an active two-way communication program to promote community involvement and risk awareness in water quality protection and risk minimisation

Community awareness and knowledge of water quality issues can help ensure water environments are responsibly managed and used. The coordinating entity should assess requirements for effective involvement of water users and the community and develop a comprehensive strategy for such consultation and communication focussing on:

- promoting awareness of water quality issues including the risks and impacts associated with unauthorised activities
- education about the harms recreational users may cause to the values of water sites and water quality, their responsibilities in minimising these harms and
- education about protecting the catchment from inappropriate discharges and pollution source
- mobilising community involvement in strategies and campaigns to improve water quality such as citizen science programs, litter surveys and clean-up programs.

Importantly, the management of water quality hazards in most circumstances relies on water users to take action to protect themselves and make informed decisions. Therefore, effective communication and transparency is critical to protecting the public. The methods and techniques deployed to promote community risk awareness should monitored and evaluated to verify their effectiveness.

In some settings a tailored, fit for purpose set of guidance documents will need to be prepared for members of the community. For example, site specific guidance could be developed to assist community and volunteer groups and local government environmental health officers in understanding their roles in the management of water quality or a water site. This might be particularly true in remote and rural areas with minimal resources where there are no locally based formal responsible parties or site managers.

Such guidance could be prepared at a national, state/territory, regional or local level to fit its purpose and to comply with any legal responsibilities unless otherwise agreed to by the appropriate regulator.

Site specific guidance will need to be reviewed regularly by responsible authorities to make sure it is up to date. Relevant stakeholders, such as the intended audience, need to be aware the guidance is available and where to find the most recent versions. Involving the intended audience in the development of the guidance will ensure that it is clear, useful and appropriate.

2.2.9. Validation, research and development (element 9)

Key actions
- Confirm that preventive measures and response actions mitigate risks effectively - Conduct research to validate new processes and procedures - Collaborate to increase understanding of water environments.

Validation, research and development is applicable to most water sites, especially to confirm strategies and controls that are in place to mitigate or minimise risk are effective, and to assess the impact of changes in catchment characteristics, climate change or a potential emerging hazard of concern (i.e. cyanotoxins, other microbial hazards).

Validation of processes and procedures

The aim of validation is to confirm that the processes and procedures that underpin the preventive measures can actually control hazards and mitigate risks effectively.

Validation is achieved by obtaining evidence that demonstrates that processes are performing effectively in a manner that can be operationally monitored. Validation involves evaluating available scientific and technical information (including historical data and operational experience). It also involves undertaking investigations to validate system-specific operational procedures, target criteria and alert and critical limits where necessary. This can include data collected through validation monitoring activities (see *Information sheet – Monitoring programs*), laboratory based testing, pilot trials and pre-commissioned testing. It can also include an assessment of published reliable evidence from comparable water sites and situations if site specific data is not available.

Validation is particularly important for innovative preventive measures and for water sites involving relatively high exposures (such as regular whole body contact water activities). In some cases, validation may include evaluation of specific activity restrictions for human health protection. Seasonal variations should be considered in designing validation programs.

Processes and procedures should be revalidated when variations occur that may affect performance or when the context sits outside the boundary conditions described as part of the original validation. Any new processes or procedures should be evaluated using bench top, pilot-scale or full scale experimental studies to confirm that the required results are produced under conditions specific to the context.

Conduct research to validate new processes and procedures

It is important that coordinating entities, site managers, regulators and resource managers are committed to research and development activities on water quality issues, including investigation of innovative processes and solutions and validation of outcomes.

Research and development should be undertaken when designing new processes and procedures underpinning preventive measures or when implementing design changes. New processes and procedures may require pilot-scale research and evaluation before full scale implementation. Design specifications should be established to ensure that new processes and procedures are able to meet the intended requirements and provide necessary process flexibility and controllability.

Other considerations for ensuring the reliability of processes and procedures related to preventive measures include designing equipment and facilities to withstand natural disasters (such as earthquakes and flooding) and providing backup systems for emergency use (such as alternative power generation). Appropriate consideration of these factors during the design phase will reduce the risk that failure will cause major disruptions or pose risks to health.

Collaborate to undertake investigative studies and research monitoring

Investigative studies and research monitoring include strategic programs designed to increase understanding of the water environment in its broader context, to identify and characterise potential hazards and to fill gaps in knowledge.

Further information on monitoring is provided in *Information sheet – Monitoring programs*. Hazard specific knowledge and development needs are outlined in the respective chapters.

2.2.10. Documentation and reporting (element 10)

Key actions
- Develop a document-control and record-keeping system for managing and updating relevant information - Establish processes for conducting internal and external reporting.

Establish processes for documentation and record keeping

This section is about best practice documentation and record keeping processes that promote transparency and accountability. Appropriate documentation provides a foundation for establishing and maintaining effective water quality management systems.

Documentation should:

- demonstrate that a systematic approach is established and is implemented effectively

- develop and protect the organisation's knowledge base
- provide an accountability mechanism and tool
- satisfy regulatory requirements
- facilitate reviews and audits by providing written evidence of the system
- establish due diligence and credibility.

Documentation provides a basis for effective communication within the organisation, as well as with the community and various stakeholders. A system of regular reporting, both internal and external, is important for ensuring that the relevant people receive the information needed to make informed decisions about the management or regulation of water quality and the system (from catchment to water site and water user).

Documentation pertinent to all aspects of managing water quality at water sites used by the public should describe activities and explain procedures, including detailed information on:

- roles and responsibilities
- preventive measures including critical control points and associated target criteria, alert and critical limits
- operational procedures, monitoring protocols and corrective actions
- maintenance procedures
- incident and emergency response plans
- training programs
- procedures for evaluating results and reporting
- communication protocols and internal and external reporting requirements
- data and records management requirements.

A **document control system** should be developed to ensure that only the most recent version of an appropriately approved document is in use.

Documentation should be visible and readily available to those that need it, when and where required. Mechanisms should be established to ensure that personnel read, understand and adhere to the appropriate documents.

Record keeping needs to be formalised since operation of systems and processes generates large amounts of data that need to be recorded. Efficient record keeping can indicate and forewarn of potential problems and provide evidence that the system is operating effectively. Activities that generate records include:

- assessment of the water environment (flow diagrams, potential hazards, etc.)
- operational and verification monitoring of water quality and water user activity
- corrective actions
- incident and emergency responses

- training of personnel
- research and development, validation and verification
- community consultation
- performance evaluations, audits and reviews.

Documentation and records systems should be kept as simple and focused as possible. There should be sufficient detail to provide assurance of operational control when coupled with a suitably qualified and competent operator or site manager. Retention of corporate memory should also be considered in documentation of procedures.

Documents should be periodically reviewed and revised to reflect changing circumstances. They should be assembled in a manner that will enable any necessary modifications to be made easily.

Records of all activities should be easily accessible but should be stored in a way that protects them against damage, deterioration or loss. A system should be in place to ensure that operators and site managers (where required) are properly trained to fill out records, and that records are regularly reviewed by the appropriate authority, signed and dated.

Documents and records can be stored as written documents, electronic files and databases, video and audiotapes and visual specifications (flow charts, posters, etc). Computer based documentation is preferable, as it provides faster and easier access, distribution and updating. Electronic documentation should be backed up regularly.

Establish processes for internal and external reporting

Reporting includes the internal and external reporting of activities relating to water quality management at water sites where there is recreational or cultural use of water.

Internal reporting supports effective decision making at the various levels of the organisation, including operations staff and management, senior executive and boards of directors. It also provides a way to communicate decisions to employees throughout the organisation and to site managers and water users.

Internal reporting requirements should be defined and a system developed for communication between the various levels of the organisation. Documented procedures (including definition of responsibilities and authorities) should be established for regular reporting (daily, weekly, monthly, etc). These reports should include summaries of monitoring data, performance evaluation and significant operational problems that occurred during the reporting period. Results from audit and management reviews should also be communicated to those within the organisation responsible for performance.

External reporting ensures that water quality management is open and transparent. It includes reporting to regulatory bodies, water users and other stakeholders in accordance with requirements. External reporting requirements should be established in consultation with water users and the relevant regulatory authorities; procedures for information dissemination should also be developed.

Details should be sought from health and other relevant regulators on requirements for:

- regular reports summarising performance and monitoring data
- event reports on significant system failures that may pose a public health or adversely affect water quality for an extended period.

Reports should be provided to regulatory authorities on incidents defined in agreed incident and emergency response protocols. If necessary, the health authority can then ensure that public health concerns are reported to the community.

An **annual report** should be produced and made available to water users, regulatory authorities and stakeholders. The annual report should:

- summarise water quality performance over the preceding year against numerical guideline values, regulatory requirements or agreed levels of service and identify water quality trends and problems
- summarise any system failures and the action taken to resolve them
- specify to whom the site manager is accountable along with their statutory or legislative requirements and minimum reporting requirements
- indicate whether monitoring was conducted in accordance with the principles of risk management set out in these Guidelines, requirements set by regulators and any requirements contained in agreed levels of service.

Annual reports should contain sufficient information to enable individuals or groups to make informed judgments about the water quality of a water site used for recreational or cultural purposes. They should also provide a basis for discussions about the priorities that will be given to improving water quality. The annual report represents an opportunity to canvass feedback, and it should therefore encourage water users and stakeholders to provide comment.

2.2.11. Review

This section addresses the need to evaluate and review the risk management process to check how it is performing and how it can be improved.

Questions that should be asked at this stage include:

- Have the preventive measures been effective and efficient in controlling hazards and reducing risk, in both design and operation?
- Have any gaps been identified in the risk assessment process? Is further information required to improve the risk assessment?
- What are the lessons learnt from risk events? Have there been near-misses, changes, trends, successes and failures?
- Have there been changes in the risk context, which may require revision of risk management process and priorities?
- Have any emerging risks been identified that may require changes to the risk management plan?

2.2.11.1. Evaluate and audit (element 11)

Key actions
Collect and evaluate long-term data to assess performance and identify problems
Establish processes and requirements for internal and external audits.

Long term collection and evaluation of results

Long term evaluation of water quality results and audit of water quality management at water sites used for recreational or cultural purposes are required to determine whether preventive strategies are effective and whether they are being implemented appropriately. This long term evaluation allows performance to be measured against objectives and helps to identify opportunities for improvement.

A review of all relevant historical monitoring results over an extended period (typically the preceding 12 months or longer for low risk water sites) is required to:

- assess overall performance against numerical guideline values, regulatory requirements or agreed levels of service
- identify emerging problems and trends
- assist in determining priorities for improving water quality management.

There will inevitably be instances when the system does not comply with operational criteria or numerical guideline values. Each event will need to be assessed, and appropriate responses determined. This should include understanding the root causes that led to the event, implementing corrective actions to address the root causes including potential any required improvements to systems, processes and procedures, and follow-up training of staff.

An active reporting system should be in place to cultivate a culture of learning and capture potential near misses in real time so that corrective actions can be undertaken in a timely manner.

Mechanisms for evaluation of results should be documented with responsibilities, accountabilities and reporting requirements defined. Useful tools to interpret datasets include statistical evaluation of results and graphs or trend charts.

Evaluation should be reported internally to senior managers and externally to water users, stakeholders and regulatory authorities in accordance with established requirements. Water user confidence in water environments will be improved if they are given assurance that data are reviewed regularly and that improvements are made in response to identified problems.

Audit of the Water Quality Risk Management Plan

The responsible entity should be committed to establishing processes and requirements for internal and external audits in accordance with relevant standards. ISO 19011:2019 provides guidelines for auditing management systems.

Auditing is the systematic evaluation of activities and processes to confirm that objectives are being met, including assessment of the implementation and capability of management systems. It provides valuable information on those aspects of the system that are effective and identifies opportunities for improving poor operational practices. Periodic auditing of all aspects of water quality management is needed to confirm that activities are being conducted according to defined requirements and are producing the required outcomes. This should include auditing of the actions of all stakeholders including operators, managers, site managers and water users, including the implementation and adherence to onsite activity restrictions.

The frequency and schedule of audits, as well as the responsibilities, requirements, procedures and reporting mechanisms, should be defined. The extent of auditing will generally be proportional to the potential for health impacts, taking into account the extent and types of uses and the risks applicable to the water environment under consideration. Auditing requirements will be greater for larger water sites where there is frequent whole body contact water use under the influence of polluted catchments. In contrast, remote water sites supporting water activities where there is incidental water contact in otherwise pristine contexts will have lower auditing requirements. The audit process can take place over several weeks and should be comprehensive.

Internal audits will involve trained staff and should include review of the management system and associated operational procedures and monitoring programs. Audits should also cover the records generated to ensure that the system is being implemented correctly and is effective.

Auditing could involve active participation by site managers and water users, particularly in relation to the application of preventive measures occurring onsite, such as activity restrictions, and in assessment of onsite impacts to the water environment.

The responsible entity should consider external auditing, which can be useful in establishing credibility and maintaining confidence among water users. External auditing could be achieved by peer review or undertaken by an independent third party. Affiliation and qualifications of external auditors should be recorded. External audits should focus on confirming implementation and results of internal audits.

External audits could be conducted on:

- the management system
- operational activities
- water quality performance
- application of water user onsite controls and adherence to activity restrictions
- the effectiveness of incident and emergency response or other specific aspects of water quality management
- water quality indicators and performance.

Audit results should be appropriately documented and communicated to management and personnel responsible. Results of audits should also be considered as part of the review by senior executive.

2.2.11.2. Review and improve (element 12)

Key actions
Review risk assessment and risk management system and evaluate the need for change Develop and implement a water quality improvement plan.

Review system and evaluate the need for change

The responsible entity should have a process in place to review the risk assessment and efficacy of preventive measures to manage risk. Risk is not static and the critical assumptions underpinning the risk assessment may change. For example, there may be changes in the planning scheme that introduce a new threat to water quality, ageing stormwater or wastewater infrastructure resulting in reduced efficacy of upstream controls or changes in the landscape due to extreme events. Additionally, evaluating trends overtime may indicate that site controls are no longer fit for purpose.

The responsible entity should have an action plan and commit resources to continuously review the effectiveness of its approach to water quality management and evaluate the need for change, by:

- reviewing reports from audits, water quality performance and previous management reviews
- considering concerns of water users, regulators and other stakeholders
- evaluating the suitability of any water quality policies, objectives and preventive strategies in relation to changing internal and external conditions such as
    - changes to legislation, expectations and requirements
    - changes in the activities of the organisation
    - advances in science and technology
    - outcomes of water quality incidents and emergencies
- periodically reviewing the sanitary inspection
- reporting and communication.

The review by senior managers should be documented.

Develop a water quality improvement plan

An improvement plan should be developed to address identified needs and be endorsed by senior executive. Improvement plans may encompass:

- capital works
- training of personnel
- enhanced operational procedures
- consultation programs
- research and development
- incident protocols
- communication and reporting.

Improvement plans can be short term (e.g. one year) or long term. Short term improvements might include actions such as improving onsite audit programs, increasing staffing and developing community awareness programs. Long term capital works projects could include increasing storage capacity, extending distribution systems, or improving coagulation and filtration processes.

Improvement plans should include objectives, actions to be taken, accountability, timelines and reporting. They should be communicated throughout the organisation and to the community, regulators and other agencies.

Making improvements will often have significant budgetary implications and therefore may require detailed cost benefit analysis and careful prioritisation with reference to the outcomes of risk assessment. Implementation of plans should be monitored to confirm that improvements have been made and are effective.

2.3 Supporting tools and information

Information sheet - Exposure assumptions

Information sheet - Sanitary inspections

Information sheet – Monitoring programs

Information sheet – Preparing a risk communication plan

Water quality risk management planning checklist

Risk communication planning checklist

Water Quality Risk Management Plan template

2.4 References

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BUILDING
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Supporting information

NHMRC

3. Microbial pathogens from faecal sources

Guideline recommendation

The health risks associated with faecal contamination for a recreational water site should be assessed by combining the outcomes of a sanitary inspection with a microbial water quality assessment.

Preventive risk management practices should be adopted to ensure that designated recreational water bodies are protected against faecal contamination. Effective management oversight and public communication should be adopted to minimise microbial risks to public health.

3.1. Overview

Recreational water bodies are susceptible to faecal contamination. Contamination with faecal matter from humans and animals can lead to health problems because of the presence of disease-causing microorganisms (i.e. pathogens such as viruses, bacteria, protozoan parasites and helminths).

The microbial quality of recreational water is influenced by land uses and human activities within a catchment, and factors such as rainfall which can lead to short periods of elevated faecal contamination. The extent of contamination depends upon the characteristics of the faecal sources, the landscape and the level of protection for the recreational water body. Recreational water users themselves can also be a source of faecal contamination in recreational water bodies through bather shedding in water and open defecation near water bodies.

This chapter addresses:

- health risks associated with microbial pathogens in recreational water (section 3.2)
- development of recreational water quality criteria from epidemiological studies (section 3.3)
- sources of faecal contamination and occurrence of microbial pathogens in recreational water (section 3.4)
- risk characterisation based on a microbial classification which combines the outcomes from a sanitary inspection and microbial water quality assessment (section 3.5)
- management of risks (section 3.6)
- research and development (section 3.7).

The approach to assessing the health risks from microbial pathogens in recreational water is initially based on a microbial classification, combining the outcomes of the sanitary inspection (sanitary inspection category) and microbial water quality assessment (microbial assessment category). The emphasis is on characterising potential faecal sources and collecting numerical data to assess the risk to public health.

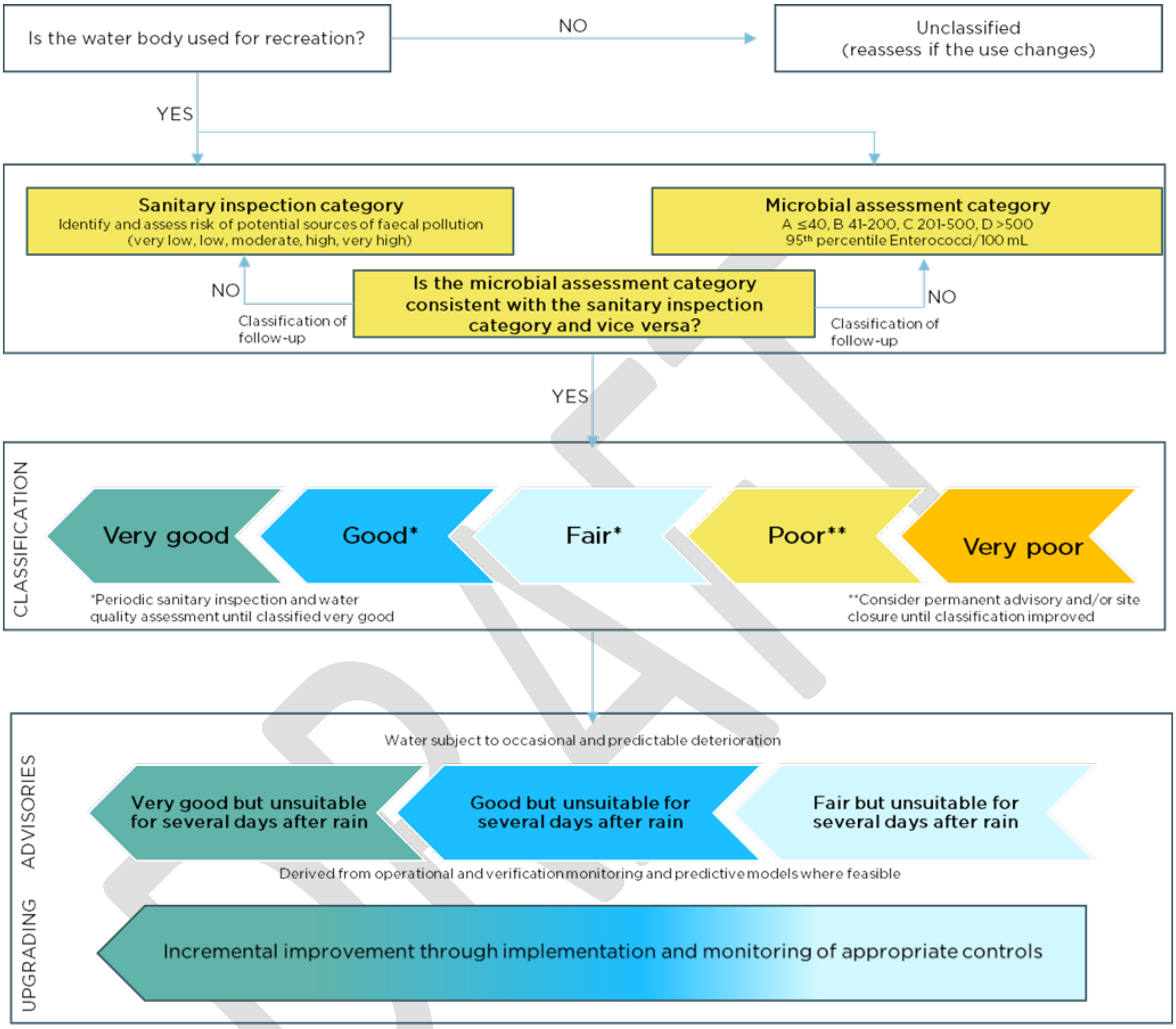
This approach can be used to:

- communicate the level of risk associated with a particular water site to the public
- assist in identification and promotion of effective management interventions
- provide a basis for regulatory requirements and assessment of compliance.

A flowchart summarising the process for assessing risks associated with microbial pathogens from faecal sources in recreational water bodies is provided in Figure 3.1. The assessment and management of microbial pathogens should be embedded within the Water Quality Risk Management Plan or site management plan (see *Chapter 2 - Framework for the management of recreational water quality*).

The content of this chapter has been adapted to the Australian context from the World Health Organization's (WHO) *Guidelines on recreational water quality. Volume 1: coastal and fresh waters* (WHO 2021) and the "Annapolis Protocol" (WHO 1999). This chapter has also been informed by a review of the evidence base, including any relevant Australian studies (O'Connor 2022).

Figure 3.1 - Flowchart for assessing risks associated with microbial pathogens in recreational water



Source: adapted from WHO (2021).

3.2. Health risks associated with microbial pathogens in recreational water

Disease outbreaks associated with recreational water exposure are common. Adverse health outcomes associated with faecally contaminated recreational water include enteric illness, typically presenting as gastroenteritis with symptoms including vomiting, diarrhoea, stomach-ache, nausea, headache and fever. Non-gastrointestinal health outcomes (Fleisher et al. 1996; Fleisher et al. 1998) include acute febrile respiratory illness and eye, ear, and skin ailments, and infections of orifices (Fleisher et al. 1996; Fleisher et al. 1998). Refer to *Chapter 4 – Other microbial hazards* for information on microbial hazards and non-gastrointestinal illnesses associated with recreational water exposure.

Illness risk is associated with both the concentration of pathogens in the water and the degree of contact with the contaminated water (Russo et al. 2020). The risk of gastrointestinal illness and respiratory illness increases with the level of exposure and time spent in the water (Russo et al. 2020). Exposure to microbial pathogens during recreational water use may arise through:

- ingestion of water containing pathogens either incidentally through reflex swallowing, especially by children, or swallowing of water during recreational incidents/events
- aspiration of water containing microbial pathogens – water entering the nasopharynx, with most liquid subsequently being swallowed
- inhalation – breathing in aerosolised microbial pathogens such as when spray is formed
- direct body contact (dermal, ocular, mucous membrane).

The primary route of exposure to microbial pathogens are expected to be through water ingestion.

There is evidence to suggest that children ingest more water while recreating compared with other age groups because they tend to spend more time in the water. When estimating risk amongst recreational water users, it is important to integrate the amount of time spent in the water with the rate of swallowing water (DeFlorio-Barker et al. 2018; Arnold et al. 2016). Factors such as head immersion and swallowing increase gastrointestinal risk (Russo et al. 2020). See *Information sheet – Exposure assumptions* for further information.

Since the 1950s epidemiological studies conducted internationally have investigated the relationship between health risk and swimming. These epidemiological studies have investigated predominantly gastrointestinal symptoms, eye infections, skin complaints, ear, nose and throat infections and respiratory illness. These studies have concluded that the rates of symptoms were higher in swimmers compared with non-swimmers (Prüss 1998). Most studies reviewed by Prüss (1998) suggested that symptom rates were higher in younger age groups, and therefore epidemiological studies undertaken with adult participants may underestimate risks to children (Wade et al. 2008; Leonard et al. 2018).

In a recent systematic review of epidemiological studies undertaken in the freshwater context, the most frequently investigated health effects among the 35 peer reviewed studies included were gastrointestinal illness (77.1%) followed by skin rashes (37.1%), ear-related infections (34.4%), respiratory illness (31.4%) and eye-related illness (25.7%) (Adhikary et al. 2022).

Published reports from surveillance programs provide insight into the relative incidence of health outcomes in different contexts. For example, in the Netherlands, 742 disease outbreaks associated with untreated recreational water were identified between 1991-2007. Of those outbreaks, skin conditions (48%) were the most frequent followed by gastroenteritis (31%) (Schets et al. 2011).

While surveillance programs provide critical information, it is noteworthy that cases of disease attributed to exposure to pathogens in recreational water often go unrecognised. Illnesses are frequently mild and self-limiting which means that people rarely seek medical attention, and those that do may exhibit symptoms that could have been caused by one of numerous microbial agents, with a range of potential exposure pathways (i.e. food, drinking water, person-to-person etc).

3.3. Development of water quality criteria from epidemiological studies

Since the 1990s the development of water quality criteria to determine the microbial safety (or otherwise) of recreational water sites has been the focus of much research. Since it is not reasonable or practical to routinely analyse for human pathogens at recreational water sites, a surrogate water quality parameter was sought that would reflect levels of human health risk from microbial pathogens.

A series of prospective epidemiological investigations were undertaken specifically to inform the development of recreational water quality criteria (Kay et al. 1994; Fleisher et al. 1996). These studies were conducted with adults in the United Kingdom (UK) at coastal recreational water sites known to be contaminated by point source(s) of human sewage. Participants were recruited in advance and allocated on the study day to either a bathing or non-bathing group. Each bather was asked to spend at least ten minutes in the water and immerse their heads three times. Water quality monitoring was undertaken throughout the study to provide a measure of exposure. The level of reported illness associated with the concentration of faecal indicators was compared between bathing and non-bathing groups. A significant dose-response relationship between the concentration of enterococci (measured as faecal streptococci colony-forming units (cfu) per 100 millilitres (mL)) measured at chest depth, and the probability of gastroenteritis was reported (Kay et al. 1994). A significant adverse relationship was also observed for ear infections and upper respiratory tract infection (Fleisher et al. 1996). The translation of these study results into the numerical values in the water quality classification (refer to Table 3.7) is described by Kay et al. (2004).

Since the publication of these water quality criteria in 2003, many additional studies have been undertaken to inform criteria for freshwater sites and temperate locations. A description of these studies is included in the final report of technical advice provided by WHO to support the European Bathing Directive (WHO 2018), and a summary of the evidence presented in that report is given in Table 3.1.

Most of the studies undertaken since 2009 have focused on beaches affected by non-point source pollution. Typically, these studies have only shown a dose-response relationship between exposure to enterococci and health outcomes when there was an identifiable human sewage input. The presence of human faecal contamination seems to be necessary for the enterococci dose-response relationship to hold (WHO 2018a).

Table 3. 1 - Summary of evidence from epidemiological studies of illness associated with exposure to faecal indicator organisms, as described by WHO (2018a)

Susceptibility to human-derived faecal contamination	Water type	Faecal indicator organism exposure: Enterococci[1]	Faecal indicator organism exposure: *E. coli*[2]
Water site Impacted by point source(s) of sewage	Marine waters	Consistently a statistically significant relationship between enterococci and gastrointestinal illness	No statistically significant relationship
Water site Impacted by point source(s) of sewage	Freshwater	Relationship reported in first randomised control trial but outcome not replicated in subsequent studies	May be a better indicator of gastrointestinal illness in freshwater, but no statistically significant relationship.
Water sites NOT impacted by point sources of sewage	Marine waters	No statistically significant relationship	No statistically significant relationship
Water sites NOT impacted by point sources of sewage	Freshwaters	No statistically significant relationship	No statistically significant relationship

[1] Between 2009-2017 in temperate locations, nine studies in marine water, three studies in freshwater.

[2] Between 2009-2017 in temperate locations, seven studies in marine water, four studies in freshwater.

The microbial assessment categories adopted in these Guidelines for both fresh and marine recreational water bodies are therefore based on the observed relationship between enterococci and gastrointestinal illness in marine waters under the influence of sewage contamination. The dose–response model relating enterococci concentration to the probability of gastroenteritis from the randomised control trials in the UK provides the strongest evidence for a dose-response relationship. Currently, WHO considers that no statistically significant relationship has been established for *E. coli* that can support a dose-response guideline value (WHO 2021). Therefore, in the absence of a reliable dose-response relationship for *E. coli*, enterococci is the most suitable faecal indicator organism for assessing microbial risk in both marine and freshwater recreational water environments.

The consequence of applying these microbial criteria to waterways not impacted by point sources of human sewage was explored in a recent meta-analysis undertaken by Kozak et al. (2025). The authors reported that while bathers had a significantly higher risk of one or more specific illnesses than non-bathers, there was insufficient evidence to support the use of microbial measures, including faecal indicator organisms or markers, to predict human health risks in water bodies not impacted by point sources of sewage. The site specific nature of health risk drivers mean that the enterococci criteria may over- or underestimate the risk depending on the local context, and waterway managers should be aware of the potential to misclassify the microbial risk of a waterway, thus underscoring the importance of sanitary inspections.

The default microbial assessment categories in Table 3.7 provide a starting point for risk assessment. The microbial risk assessment may be refined, in consultation with the relevant health authority or regulator, by conducting a site specific microbial risk assessment particularly where there is discrepancy between the results of the microbial water quality assessment and the sanitary inspection, and follow-up of the initial classification is required (refer to section 3.5). The United States Environmental Protection Agency (US EPA 2024) provides technical guidance on deriving site specific water quality criteria for ambient recreational water bodies in which the predominant contamination is from nonhuman faecal sources.

3.4. Sources of faecal contamination and occurrence of microbial pathogens in recreational water

Assessment of the potential for health effects involves identifying sources and levels of faecal contamination (human and animals) as part of the overarching preventive risk management approach.

Recreational water bodies usually contain a mixture of faecally derived pathogenic and non-pathogenic microorganisms. Sources of faecally derived microorganisms may include sewage and wastewater effluents, recreational water users (from defecation and/or shedding), livestock (e.g. cattle, sheep, poultry), industrial processes, farming activities, domestic animals (e.g. dogs) and wildlife (most notably water birds and native animals).

The pathogens that may be transmitted through faecally contaminated recreational water are diverse and change in response to variations in human and animal populations and influences from wastewater.

Human faecal contamination of recreational water

The most important sources of faecal contamination to recreational water environments, from a public health perspective, are those derived from humans (refer to Table 3.2).

The risks will vary with local circumstances depending on the catchment and the nature of the receiving environment. For example, sewage and onsite sewage management systems effluent being discharged into an estuary with small tidal interchanges may present a greater risk than the same quantity of sewage and effluent discharged into an estuary with large tidal interchanges. Similarly, a river discharging into an enclosed bay presents a higher risk than one discharging directly into the open sea.

Table 3.2 - Sources of human faecal contamination of recreational water environments

Source	Description
Sewage discharges (including stormwater inputs in some cases due to inflow and infiltration) via outfalls, pipes, open drains, trucks and seepage through groundwater.	Sewage, treated wastewater, recycled water, faecal sludge and stormwater discharged or disposed near, upstream or directly into a recreational water environment, or through short outfall, long deep outfall.
Indirect sewage inputs via riverine discharges impacted by: - Surface run-off - Urban and rural stormwater overflows - Exfiltration from sewers - Run-off or exfiltration from onsite wastewater management systems (e.g. septic tank absorption trenches), failing and poorly managed onsite wastewater management systems. - Sewer overflows, emergency relief structures, illegal sewerage connections to stormwater - Resuspension of sediment - Open defecation e.g. from unhoused or informal settlements.	Impacted rivers discharging into water bodies used directly for recreation or discharging near to or into coastal or freshwater areas used for recreation.
Contamination from recreational water users (including bathers).	Recreational water users in direct contact with water contributing accidental faecal releases, faecal smears, vomitus, sputum and urine—particularly hazardous at high density of users relative to hydraulic turnover and recreational water body volume. Open defecation by recreational water users especially at camping grounds due to inadequate toilet facilities or inappropriate recreational behaviours.

Where multiple sources of contamination exist for a water body, all sources should be taken into consideration in determining the susceptibility to faecal influence. The most hazardous source of contamination is likely to be responsible for the classification. However, management actions should consider all sources, as faecal contamination from animals may lead to high levels of faecal indicator bacteria without posing a high risk to public health. Classification is based on a qualitative assessment of the risk of exposure under the range of conditions for which the recreational water body may be used. It also considers the operation of sewage and faecal sludge treatment plants, onsite wastewater treatment systems and faecal sludge management services, bather density, and hydrometeorological and oceanographic conditions. The most hazardous source of contamination may change according to season, weather conditions, and following events such as containment of sewage and human waste system failures.

Microbial pathogens from bathers

Bathers can influence water quality directly (Eisenberg et al. 1996), mainly through bather density and degree of dilution. Low dilution is assumed to represent no water movement (e.g. 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, or if children are among the recreational water users. Therefore, if bather density is high and no sanitary facilities are available at the recreational area, the classification should be downgraded to the next class. In contrast, if bather density is low, there are sufficient and well-maintained toilet facilities, and recreational water users are limited to adults, the risk can be retained at the same class as the broader catchment.

Loganthan et al. (2012) studied the prevalence of *Cryptosporidium* spp. in recreational versus non-recreational inland freshwater sources. The study found that *Cryptosporidium* was identified at a higher prevalence in recreational water bodies used for swimming and camping versus non-recreational water bodies. The study also found that the majority of samples from the recreational water bodies contained the human-associated *C. hominis*. Risk analysis identified increasing population as strongly correlated with an increase in the prevalence of *Cryptosporidium* in water.

Papadakis et al. (1997) collected water and sand samples from two beaches, counted the swimmers present on the beaches and tested for 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 results in microbial buildup during the day, reaching peak levels by the afternoon. Where dispersion is limited, bather-derived faecal contamination 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 faecal contamination makes in other circumstances with strong dispersal/mixing of water. Pathogens shed in urine do not correlate with faecal indicator bacteria, since in the absence of urinary tract infections, urine does not contain significant levels of such bacteria.

Sampling of faecal indicator bacteria first thing in the morning, prior to significant levels of recreational water activity, may miss the peak of faecal contamination if that peak is driven by inputs from recreational water users. For that reason, sampling is encouraged at periods of peak visitation. Another benefit of sampling at such periods is that the levels of visitors can be systematically recorded to provide more broadly useful data , and potentially data on demographics, activities and behaviours.

Microbial pathogens in general sewage/wastewater

The types and numbers of pathogens in wastewater will differ depending on the incidence of disease and carrier states in the contributing human and animal populations and the seasonality of infections. Therefore, numbers will vary greatly across different regions and times of year. For practical purposes, however, a reasonable estimate of pathogen concentrations in wastewater is required, which is based on long-term monitoring that captures those seasonal and inter-annual variations. A general indication of pathogen numbers in raw sewage from a large municipal source is given in Table 3.3, together with the health effects of these pathogens. For the *Australian Guidelines for Water Recycling* (NRMMC et al. 2006), 95th percentile concentrations of infectious human-pathogenic viruses, protozoa, and bacteria surrogates were nominally estimated at 8,000, 2,000, and 7,000 per L, respectively, based on a review of Australian data (Deere and Khan 2016). More recent evidence consistently demonstrates that the concentrations of viruses in raw sewage are typically much higher than these 2016 estimates (as indicated in the upper bounds given in Table 3.3), primarily due to elevated levels of norovirus, although there remains uncertainty and debate as to the proportion that may be infectious and the implications for public health (Clements et al. 2025).

In both marine and freshwater studies of the impact of faecal contamination on the health of recreational water users, several faecal indicator bacteria including *E. coli* (a subset of the formerly monitored thermotolerant, or faecal, coliforms) and enterococci (previously known as faecal streptococci) have been used for describing water quality. These bacteria are not postulated as the causative agents of illnesses in swimmers but correlate with disease outcomes (Prüss 1998), and thus have been used as indicators of the potential for illness.

Nonhuman faecal contamination of recreational water environments

Contamination of recreational water bodies with animal excreta presents human health risks, because some zoonotic pathogens (e.g. some zoonotic types of *Cryptosporidium parvum; Campylobacter jejuni* and *coli*; and pathogenic *Escherichia coli* such as serotype O157:H7) can be transmitted in animal faeces, particularly from intensive livestock farming to waterways (Soller et al. 2015).

Campylobacter spp. and *Salmonella* spp., of which some sequence types have been associated with gastrointestinal infections in humans, have been isolated from wet and dry sand at beaches in a number of countries (Bolton et al. 1999; Shatti and Abdullah 1999; Vieira et al. 2001; Elmanama et al. 2005; Byappanahalli et al. 2009; Yamahara et al. 2012; Khan et al. 2013). Bird faeces may be an important source of these pathogens (Whitman et al. 2014).

However, due to the 'species barrier', the prevalence and concentration of pathogens of public health importance is usually lower in animal than human excreta with some notable exceptions, such as *C. parvum* in calves and lambs. Furthermore, the less closely associated animals are with humans, the lower the probability of those animals carrying human-infectious pathogens, since pathogens evolve to circulate among closely associated hosts.

In some instances, animals (e.g. birds, livestock and domestic animals) can have a significant impact on faecal indicator bacteria used to measure microbial water quality. As a result, the use of faecal bacteria alone as an indicator of risk to human health could result in an overestimation of public health risk where the indicator organisms derive from sources other than human excreta. This could potentially result in management actions that are unnecessary (Smith et al. 2020). Possible measures to avoid this include undertaking a sanitary inspection, using microbial source tracking (MST) or undertaking further lab analysis.

Local knowledge of possible sources and environmental pathways of animal pathogens to humans should form part of the sanitary inspection, as is the case for shellfish-growing waters in many countries.

Influence of rainfall, surface run-off and stormwater on microbial loads

Following rainfall, microbial loads in water bodies may be significantly increased due to:

- surface run-off from agricultural sources and overflow of containment structures
- urban and rural stormwater overflows, including natural watercourses (torrents) that drain only stormwater
- exfiltration from sewers or onsite sewage management systems and their disposal areas
- resuspension of sediments that have accumulated pathogens.

Pathogen concentrations have been estimated in typical Australian surface waters (Deere et al. 2014; Petterson et al. 2015) and stormwater (Deere 2008) and used to derive estimates of pathogens in untreated surface waters in the *Australian Drinking Water Guidelines* (NHMRC 2011) and the *Australian Guidelines for Water Recycling* (NRMMC 2009). More recent evidence consistently demonstrates that the concentrations of viruses and bacteria in urban stormwater are typically significantly much higher than these 2008 estimates, although there remains uncertainty and debate as to the proportion that may be infectious to humans and the implications for public health (WRA 2023).

Faecal contamination levels may be elevated after rainfall and risk of illness may be higher in some coastal areas at such times. In a cohort study (Arnold et al. 2017) assessing acute illness among surfers after exposure to seawater in dry and wet-weather conditions, the authors concluded that incidence rates were higher under wet-weather conditions.

Sheltered coastal areas and shallow lakes are also subject to accumulation of sediments which may be associated with high microbial loads. These sediments can 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.

Table 3.3 - Approximate concentrations of faecal pathogens and indicator organisms in sewage

Pathogen type	Pathogen/indicator organism	Disease (health effect) or role	Microbes/L	Relevant animal source**
Virus	Adenoviruses	Respiratory disease, gastroenteritis	10^2–10^9 GC	No
Virus	Astrovirus	Gastroenteritis	10^3–10^7 GC	No
Virus	Hepatitis A virus	Various symptoms, including hepatitis	Undetected to 10^9 GC	No
Virus	Norovirus (and other caliciviruses)	Diarrhoea, vomiting	10^2–10^9 GC	No
Virus	Enterovirus	Poliomyelitis, mild febrile illness, myocarditis, meningitis	10^2–10^4 (cell culture)	No

Pathogen type	Pathogen/indicator organism	Disease (health effect) or role	Microbes/L	Relevant animal source**
Virus	Rotavirus	Gastroenteritis (Diarrhoea, vomiting)	10^2–10^8 GC	No
Virus	F+ RNA coliphages	Indicator organism	10^5–10^7 PFU	Yes
Virus	Somatic DNA coliphages	Indicator organism	10^6–10^8 PFU	Yes
Bacteria	*Campylobacter* spp.	*Campylobacteriosis,* gastroenteritis, Guillain-Barre syndrome (reactive arthritis)	10^3–10^6 MPN 10^6 GC	Yes
Bacteria	*Escherichia coli**	Indicator organism (except specific pathogenic strains[a], such as serotype 0157:H7)	10^8–10^9 CFU or MPN	Yes
Bacteria	Intestinal enterococci*	Indicator organism	10^7–10^8 CFU or MPN	Yes
Bacteria	*Salmonella* spp. (limited to non-typhoid serotypes in the Australian context)	*Salmonellosis*, gastroenteritis	Up to 10^5 MPN	Yes
Bacteria	*Shigella* spp.	*Shigellosis*, bacillary dysentery	Undetected–10^8 MPN	No
Bacteria	Vibrios such as *Vibrio cholerae* (pathogenic types are not endemic in Australia), *V. parahaemolyticus* and *V. vulnificus*	Gastroenteritis	<10-10^5 MPN	Yes
Parasitic protozoa	*Cryptosporidium* spp.	*Cryptosporidiosis*, gastroenteritis	10–10^4 oocysts	Yes
Parasitic protozoa	*Entamoeba histolytica*	Amoebic dysentery	Undetected to 100 cysts	No
Parasitic protozoa	*Giardia duodenalis*	*Giardiasis,* gastroenteritis	10–10^5 cysts	Yes
Helminths[b]	*Ascaris* spp.	Ascariasis	Undetected –450 ova	Yes
Helminths[b]	*Ancylostoma* spp. and *Necator* spp.	Anaemia	Undetected –190 ova	Yes
Helminths[b]	*Trichuris* spp.	Diarrhoea	Undetected –40 ova	Yes

CFU: colony forming unit; GC: gene copies (note that not all genome copies are necessarily infectious units); MPN: most probable number; PFU: plaque forming unit. a Croxen et al. (2013); Leonard et al. (2018). b Parasite numbers vary greatly as a result of differing levels of endemic disease in different regions. Sources: Rusinol & Girones (2017); WHO (2018b); Garcia-Aljaro et al. (2019); https://www.who.int/news-room/fact-sheets. *In this table, concentrations are expressed per L, whereas normally faecal indicator organisms are tested and reported per 100 mL. ** Relevant animal source for the Australian context.

NHMRC

3.5. Risk characterisation

A microbial-based classification approach (section 3.5.1) has been adopted to characterise microbial risk associated with faecal contamination in recreational water. There are two components to classifying a recreational water environment, including:

- sanitary inspection (with a Sanitary Inspection Category determined through assessment of the degree of susceptibility of water body to faecal contamination), described in detail in section 3.5.2
- microbial water quality assessment (with a Microbial Assessment Category determined based on counts of enterococci in water over time), described in section 3.5.3.

3.5.1. Classification matrix for faecal contamination of recreational water

Recreational water is classified by combining the sanitary inspection category with the microbial assessment category using the matrix in Table 3.4 and summarised in Figure 3.1. This results in an initial classification of the recreational water body. Further assessment (i.e. follow-up) is needed if there are discrepancies between the results of the microbial water quality assessment and the sanitary inspection.

The classification emphasises risk from human faecal contamination. Microbial risks from faecal contamination in recreational water is not static and requires active assessment and management over time. Therefore, the classification of a recreational water body may be subject to change over time, or sporadically, based on events that occur within the catchment and recreational water environment.

The assessment framework (Figure 3.1) enables local management to respond to sporadic or limited areas of contamination, and thereby upgrade the classification for a recreational water body, provided that appropriate and effective management action is taken to control exposure (refer to section 3.6). This form of classification (as opposed to a pass/fail approach) provides incentives for both local management actions and pollution abatement. It also provides a generic statement of the level of risk, which supports informed personal choice by recreational water users. It helps to identify the principal management and monitoring actions that are likely to be appropriate as described in Table 3.5, section 3.6 and Figure 3.1.

Table 3.4 - Classification matrix for faecal contamination of recreational water*

Sanitary inspection category (susceptibility to faecal contamination)	MAC** A: ≤40	MAC** B: 41-200	MAC** C: 201-500	MAC** D: >500	Exceptional circumstances
Very low	Very good	Very good	Follow up[b]	Follow up[b]	ACTION
Low	Very good	Good	Follow up[b]	Follow up[b]	ACTION
Moderate	Good[a]	Good	Fair	Poor	ACTION
High	Good[a]	Fair[a]	Poor	Very poor	ACTION
Very High	Follow up[a]	Fair[a]	Poor	Very poor	ACTION
Exceptional circumstances	ACTION	ACTION	ACTION	ACTION	ACTION

[a] Indicates possible sporadic contamination (often driven by events such as rainfall). This is typically associated with sewage overflow and/or run-off. These results should be investigated further. Initial follow-up should include verification of the sanitary inspection category and ensuring that samples recorded include event periods. Analytical results should be confirmed, and possible analytical errors reviewed (refer to 'follow-up on initial classification' below).
[b] Implies nonhuman source of faecal indicators (e.g. livestock); this should be verified (refer to follow-up on initial classification below).
[c] Exceptional circumstances relate to known periods of higher risk, such as an outbreak of a potentially waterborne pathogen in the catchment community or broader community who are potential recreational water users, or sewer rupture or wastewater treatment plant failure in the recreational water catchment. Under such circumstances, the classification matrix may not fairly represent risk (refer to 'Exceptional circumstances' below).
*In certain circumstances, there may be a risk of transmission of pathogens associated with more severe health effects through recreational and culturalwater use. The human health risk depends on specific (often local) circumstances. Public health authorities should be engaged in the identification and interpretation of such conditions.
** Microbial assessment category (95th percentiles – intestinal enterococci/100mL)

Table 3.5 - General advice for each recreational water classification

Classification	Description
Very good	Water quality monitoring and sanitary inspection indicate very good water quality. There are very few potential faecal sources. Water is considered satisfactory for swimming all the time, except under exceptional circumstances.
Good	Water quality monitoring and sanitary inspection indicate generally good water quality. On occasions (such as after high rainfall) there may be an increased risk of contamination from run-off. Water is monitored regularly throughout the recreational season and warning signs will be erected if water quality deteriorates. Water may be considered satisfactory for swimming most of the time for the general population.
Fair	Water quality monitoring and sanitary inspection indicate generally satisfactory water quality most of the time but may not be satisfactory for the young, the elderly and those with compromised immunity. Water sites receive run-off from one or more sources that may contain animal or human faecal material. Events such as high rainfall increase the risk of contamination levels from run-off. Caution should be taken during periods of high rainfall, and swimming avoided if water is discoloured. Water sites are monitored weekly during the recreational season and warning signs erected if water quality deteriorates. Water may be generally satisfactory for swimming for the general population but not the very old and those with compromised immunity.
Poor	Water quality monitoring and sanitary inspection indicate generally poor water quality. Water sites receive run-off from one or more sources that may contain animal or human faecal material. Permanent warning signs may be erected at these water sites, although responsible entities may monitor these water sites weekly and post temporary warnings. Water is generally not satisfactory for swimming for the general population. Further risk assessment may be required. Swimming should be avoided, particularly by the very young, the very old and those with compromised immunity.
Very poor	Water quality tests and sanitary inspection indicate very poor water quality. Water sites receive run-off from and direct discharges from one or more sources that may contain animal or human faecal material. Permanent signage will be erected stating that swimming is not recommended. Swimming in water should be avoided.

3.5.1.1. Initial classification

The outcome of the sanitary inspection and the microbial water quality assessment, based on Table 3.4 and Figure 3.1, is a five-level classification for recreational water environments—'very good', 'good', 'fair', 'poor' and 'very poor'. There is a requirement for follow-up where there is potential discrepancy between the results of the microbial water quality assessment and the sanitary inspection.

If the assessment shows that higher microbial contamination levels are limited to only a part of the recreational water environment (e.g. high level of contamination confined to an area near a stormwater drain), separate assessment and management are required for these areas.

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.

3.5.1.2. Follow-up of initial classification

Where the sanitary inspection and the microbial water quality assessment result in a potentially incongruent categorisation in Table 3.4, further assessment will be required. This could include re-examining the sanitary inspection (i.e. identifying further potential faecal sources in the catchment and assessing their risk) and additional analysis of microbial/water quality, with specific consideration given to the sampling protocol (spatial and temporal) and analytical methodology.

Examples of situations that may lead to potentially incongruent assessments are when:

- analytical errors have been made
- the importance of non-point sources was not appreciated in the initial sanitary inspection
- the sampling points are not representative of the influence of sewage, onsite wastewater management system effluents and faecal sludge
- important sewage overflow structures have not been identified or are present on the beach but do not discharge during the bathing season
- the assessment is based on insufficient or unrepresentative data
- extreme events arise from damaged infrastructure, or inappropriate practices for sewage or faecal sludge disposal (e.g. shipping damage to marine outfalls, illegal dumping of faecal sludge, connection to surface water of foul drains from domestic and other properties).

Where the sanitary inspection indicates low risk, but initial microbial water quality assessment indicates water of low quality, this may indicate previously unidentified sources of diffuse pollution. In this case, specific studies demonstrating the relative levels of human and nonhuman contamination (e.g. surveys of mammal and bird numbers, microbial source tracking (MST) markers) may be appropriate. Confirmation that contamination has dominant nonhuman (e.g. canine or avian) sources (Soller et al. 2015) may allow reclassification to a more favourable grading. Care is needed here as nonhuman pollution may still be a source of important pathogens (refer to section 3.4). For example, bovine sources of faecal contamination pose a potential risk to human health and therefore should not result in reclassification to a more favourable grading.

Similarly, where microbial water quality assessment indicates a very 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 may be incomplete.

3.5.1.3. Provisional classification

There will sometimes be a pressing need to issue advice on the classification of a recreational water environment when the information required in Figure 3.1 is incomplete.

Three scenarios may be envisaged:

1. No information is available on the susceptibility of the water body to new potential faecal influence (such as new developments).

2. The information available from the microbial water quality assessment and/or the sanitary inspection is incomplete.

3. There is reason to believe that the existing classification no longer accords with changed circumstances, but insufficient evidence is available to complete the classification.

In these circumstances, it may be necessary to issue a provisional classification. When such a step is taken, 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 3.1 to provide a definite classification as soon as possible.

3.5.1.4. Reclassification

In some circumstances microbiological contamination may be triggered by specific and predictable conditions (e.g. rainfall run-off) and local management actions can reduce or prevent exposure at such times. According to the Annapolis Protocol (WHO 1999), it may be reasonable to provisionally reclassify a recreational water environment provided:

- a bathing area is subject to elevated faecal contamination for a limited proportion of the time or over a limited area of the potential bathing areas; and
- the times of contamination can be predicted in some way; and
- management interventions are shown to effectively reduce or prevent exposure at these times.

This approach requires a database that allows an estimation of whether the significant faecal influence is constrained in time and whether 'predictors' can be used to determine when such conditions are likely to occur (WHO 1999). In addition, a locally applicable early warning system and subsequent management actions that can be deployed in real time must be determined (WHO 1999). Finally, for a reclassification to be applied, evidence of the effectiveness of the management action is required (WHO 1999).

However, a reclassification should initially be provisional and time limited. It may be confirmed if the efficacy of management interventions (e.g. advisories or contamination mitigation strategies) is verified during the following bathing season, otherwise it will automatically revert to its original classification (WHO 1999). Ideally, independent audit and verification should be undertaken to confirm the efficacy of management interventions.

Exceptional circumstances such as pollution incidents

Exceptional circumstances, such as pollution incidents due to sewer breaks, rainfall and flooding events should be considered as part of the site risk assessment. As part of a preventive risk management approach (see *Chapter 2 – Framework for the management of recreational water quality*), collaboration with authorities responsible for wastewater treatment, catchment management, emergency services, or local authorities should facilitate timely identification and management of events. Public health authorities should be engaged in defining triggers that are considered to constitute exceptional circumstances and incidents. This will normally require the responsibility and authority to act in response to such circumstances.

3.5.2. Sanitary inspection category

The inspection process to determine faecal contamination likelihood and impacts is called a sanitary inspection, sanitary survey or source vulnerability assessment. The aim of the inspection process should be to identify all faecal sources, although human-derived faecal contamination 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 discussed in section 3.4.

Sanitary inspections, together with microbial water quality analysis, lead to the classification of a recreational water body (section 3.5.1; Figure 3.1). Although the sanitary inspection may take many forms (e.g. US EPA 2013; EEA 2020; Deere and Billington 2021), the primary goal is to ascertain likely faecal sources to help select sampling sites, taking into account temporal and spatial variations, and to outline management actions. This includes considering human and animal inputs. The potential faecal contamination contributions of recreational activities in and around the water body should also be assessed as part of the sanitary inspection and should inform the water quality monitoring regime.

Table 3.6 provides a relative risk ranking of a recreational water body's susceptibility to faecal contamination according to potential sources. This is a qualitative assessment based on the outcomes of the sanitary inspection. The risk rating informs the sanitary inspection category.

Further information on sanitary inspections is provided in *Information sheet – Sanitary inspections* and *Chapter 2 – Framework for the management of recreational water quality*.

Table 3.6 - Sanitary inspection category – indicative descriptions for categorising the susceptibility of a water body to faecal contamination [a, b, c, d]

Sanitary inspection category (susceptibility to faecal contamination)	Potential source of faecal contamination: Wastewater/ stormwater[e]	Potential source of faecal contamination: Recreational water use[g]	Potential source of faecal contamination: Agricultural	Potential source of faecal contamination: Wildlife/ feral animals
Very low	No significant wastewater source including no sewage treatment plant discharges, no wastewater reuse, no onsite sewage management system No urban stormwater run-off	Low bather density; high dilution (e.g. < 1 bather per 1,000 square metres (sqm) [approx. 1 Olympic size municipal swimming pool]) Toilet facilities are located outside the catchment area of the water body (i.e. no risk to groundwater or surface water) No boats/vessels	No agricultural run-off or livestock	Low density of birds (e.g. waterfowl and native wildlife)
Low	Effective outfall into ocean: secondary discharge with disinfection[f] Wastewater or biosolids reuse occurs within catchment, but run-off, infiltration or discharge is unlikely to occur Indirect: run-off from low-intensity urban/rural catchment	Low bather density; low dilution or High bather density; high dilution (e.g. < 1 bather per 300 sqm [approx. 1 large municipal swimming pool]) and toilet facilities are accessible Toilet facilities comply with jurisdictional setback distances from specific water bodies, fully contained (i.e. bunded), in good condition and regularly serviced No boats/vessels moorings	Indirect: run-off from low-intensity agriculture catchment	Medium bird density Indirect: feral animals

Sanitary inspection category (susceptibility to faecal contamination)	Potential source of faecal contamination: Wastewater/ stormwater[e]	Potential source of faecal contamination: Recreational water use[g]	Potential source of faecal contamination: Agricultural	Potential source of faecal contamination: Wildlife/ feral animals
Moderate	Indirect: tertiary wastewater treatment discharges; stormwater outlets with potential sewage contamination (including emergency relief structures) Direct: Urban stormwater that is protected from sewage ingress	High bather density; low dilution and toilet facilities are accessible or High bather density; high dilution, (e.g. < 1 bather per 100 sqm [approx. 1 small municipal swimming pool]) but toilets facilities are not accessible Toilet facilities comply with jurisdictional setback distances from specific water bodies, good condition Low intensity watercraft mooring or use	Indirect: intensive use in agricultural	Indirect: significant feral animal and bird population Direct: High density of bird life on lagoons or estuaries (for example nesting area)
High	Indirect: secondary wastewater treatment plant discharge; onsite wastewater management systems; wastewater reuse discharge into water body is likely to occur once a bathing season Direct: tertiary wastewater treatment plant discharge; stormwater outlets with potential sewage contamination	High bather density; low dilution, (e.g. < 1 bather per 30 sqm [approx. 1 backyard pool or large spa pool]) but toilet facilities are not accessible Toilet facilities comply with jurisdictional setback distances from specific water bodies, but are not regularly serviced Marinas or moorings (boats)	Direct: intensive agricultural use in immediate catchment and potential for run-off from untreated animal effluent (e.g. dairying, piggeries, milking sheds) Unrestricted stock access to waterways	Dense bird population (for example nesting area) with low water flow

Sanitary inspection category (susceptibility to faecal contamination)	Potential source of faecal contamination: Wastewater/ stormwater[e]	Potential source of faecal contamination: Recreational water use[g]	Potential source of faecal contamination: Agricultural	Potential source of faecal contamination: Wildlife/ feral animals
Very High	Direct: secondary wastewater treatment plant discharge; onsite wastewater management system; wastewater reuse discharge into water body is likely to occur more than once a bathing season; High density urban stormwater with emergency relief structures	Very high bather density; low dilution, (e.g. < 1 bather per 10 sqm [approx. 1 paddling pool or small spa pool]) Toilet facilities do not comply with jurisdictional setback distances from specific water bodies Holding tanks not required for boats or no pump out facilities for boats	-	-

Notes to Table 3.6:

a) Refer to relevant state or territory guidance on conducting sanitary inspections and criteria for categorising risk.
b) Refer to relevant state or territory guidance on setback distances for potential sources of faecal contamination including wastewater discharges, wastewater reuse, onsite wastewater management systems (including for toilets in unsewered areas).
c) Direct discharge: Water quality in the recreational area is affected, or likely to be affected by discharges. Includes wastewater treatment plant discharges directly to the recreational water, or to an area where discharge water may reasonably be expected to be carried to a recreational water site by tides, currents or streams.
d) Indirect discharge: Water quality from any river or stream discharging into the recreational area is affected or likely to be affected by faecal sources.
e) Where a discharge from wastewater (including recycled water) is identified as part of the sanitary inspection, the relevant regulator should be consulted to understand how the recreational values of the water body were considered in the quantitative risk assessment in licencing the discharge and the critical controls in place. It should be noted that faecal indicator organisms are more susceptible to treatment especially disinfection, than protozoan parasites and viruses, and therefore are likely to underestimate the health risk and outcome of the microbial assessment category.
f) An effective outfall is one that is properly designed with sufficient length and depth of diffuser discharge and where the climatic and oceanic extreme conditions are considered in the design objective to ensure that treated wastewater is unlikely to reach the recreational area.
g) The bather density benchmarks are nominal values derived using quantitative microbial risk assessment based on the assumptions given in Deere and Ryan (2022) and Ryan et al. (2022), and assuming mixing in the top 2 metres of depth for the surface areas indicated.

3.5.3. Microbial assessment category

3.5.3.1. Derivation of the microbial assessment categories

The microbial assessment category approach (Table 3.7) defines a range of indicator microbial assessment categories for classifying recreational water bodies when combined with sanitary inspections. There are four microbial assessment categories (A-D) using the 95th percentile of intestinal enterococci distribution, which are used as part of the classification procedure.

Table 3.7 is derived on epidemiological data from 'healthy adult bathers' exposed to sewage-impacted marine waters in temperate waters. The values presented in Table 3.7 provide an estimated risk per exposure for gastrointestinal illness and acute febrile respiratory illness. Where there are other public health outcomes of concern, then the risks should be assessed and appropriate action taken.

The results of the randomised control trials reported by Kay et al. (1994) and Fleisher et al. (1996) underpin the microbial assessment categories in Table 3.7. The microbiological values are expressed in terms of the 95th percentile of intestinal enterococci numbers per 100 mL and represent levels of risk based on specific exposure conditions. The values may need to be adapted to take local conditions into account but, until studies suggest any change, the values should be applied for use in all recreational water bodies along with the sanitary inspection rankings.

Table 3.7 does not relate to children, the elderly or immunocompromised who may have lower immunity and require a greater degree of protection. There is no available data with which to quantify this, and therefore no correction factors are applied.

Epidemiological data on freshwaters or exposures other than bathing (e.g. high-exposure activities such as surfing, wind surfing, sailing or white-water canoeing) are currently inadequate and values based on risks cannot be derived. Thus, a single microbiological value is proposed at this time for all recreational uses of water, as the evidence to justify alternative values is currently insufficient. Nevertheless, consideration should be given, where appropriate, to making some allowance for the severity and frequency of exposure encountered by special interest groups (e.g. bodysurfers, board riders, windsurfers, scuba divers and white-water canoeists). A quantitative microbial risk assessment might be useful for this purpose.

Table 3.7 - Microbial assessment categories for recreational water bodies[1]

Microbial Assessment Category	Intestinal enterococci (95th percentile value for intestinal enterococci/100 mL (rounded values)[5]	Basis of derivation[2]	Estimated risk per exposure[3, 4, 5]
A	≤40	This value is below the NOAEL[1] in most epidemiological studies.	GI[1] illness risk: < 1% AFRI[1] risk: < 0.3% The upper 95th percentile value of 40 enterococci/100 mL relates to an average probability of approximately 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[1] for GI illness and AFRI.	GI illness risk: 1–5% AFRI risk: 0.3–1.9% The upper 95th percentile value of 200 enterococci /100 mL relates to an average probability of approximately 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 95th percentile values represents a probability of approximately 1 in 20 to 1 in 10 risk of gastroenteritis for a single exposure.

Microbial Assessment Category	Intestinal enterococci (95th percentile value for intestinal enterococci/100 mL (rounded values)[5]	Basis of derivation[2]	Estimated risk per exposure[3, 4, 5]
			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	> 500	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.

AFRI = acute febrile respiratory illness; GI = gastrointestinal; LOAEL = lowest observed adverse-effect level; NOAEL = no observed adverse-effect level. Notes to Table 3.7: 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 (refer to Note 4). 2. The 'estimated risk' refers to the excess risk of illness (relative to a group of non-bathers) 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 increase in the level of excess illness outside the range of the data (i.e. at concentrations above 158 enterococci/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. 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 lognormal distribution and a $\log_{10}$ standard deviation of 0.8103 was assumed for enterococci. If the true standard deviation for a beach were less than 0.8103, then reliance on enterococci would tend to overestimate the health risk for people exposed above the threshold level and vice versa. It is possible to calculate the risk to bathers in any waters based on knowledge of the probability density function (PDF) of enterococci at the water site and using the prevalence of gastroenteritis information from the Kay et al. (1994) study. 4. Percentile values for enterococci can be re-scaled in terms of illness risk using Wyer et al. (1999), and the standard deviation given in Note 4. See also *Information sheet – Calculation of 95th percentiles*. 5. 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. Disinfection may markedly increase the pathogen to indicator ratio (Schoen et al. 2011) 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.

3.5.3.2. Microbial water quality monitoring

It is important for the initial microbial water quality assessment to be planned so that it captures the spatial and temporal changes in enterococci that might be expected. This would ensure that locations with potentially significant faecal sources are represented as are periods after rainfall. The design of a water quality monitoring program should reflect sanitary inspection outcomes, behaviours of recreational water users and bather density.

Testing for enterococci

Testing for enterococci in water should be in accordance with standard methods (e.g. International Organization for Standardization – ISO) and conducted by laboratories that are NATA (National

Association of Testing Authorities, Australia) accredited. It is acknowledged that some freshwater sites might only have *E. coli* data available to use in the risk assessment of recreational water bodies. It is recommended that water sites that have been utilising *E. coli* as the faecal indicator organism, for the purposes of characterising microbial risk from faecal contamination, move to the use of enterococci. For an interim period, both *E. coli* and enterococci can be monitored to assist with this transition.

It is important to recognise the limitations of faecal indicator organisms. Their relative susceptibility to environmental factors compared to pathogens may underestimate risks to human health. Faecal indicator organisms also lack the host specificity required to discriminate human and animal faecal sources. Where unexpected levels of faecal indicator organisms are detected, it is important to check the sanitary inspection to ensure faecal sources have not been missed. If there is no significant source identified from the sanitary inspection then a suite of analytical methods may assist with identifying the contributing source of faecal contamination, including chemical approaches and microbial source tracking techniques (Harwood 2014) (Refer to section 3.7). Additional information on faecal indicator organisms is provided in *Information sheet –Faecal indicator organisms*.

Statistically representative samples

Collection of sufficient samples are required to enable an appropriate estimation of enterococci concentrations to which recreational water users are exposed. Classifications based on small numbers of microbiological test results are liable to considerable uncertainty.

The initial microbial water quality assessment should be based on at least 100 samples to calculate the 95th percentile. The number of results available can be increased significantly by pooling data from multiple years. This practice is justified unless catchment and local land use conditions have changed over time. For practical purposes, data from 100 samples from a 5-year period and a rolling 5-year dataset could be used for microbial water quality assessment. The data should be collected over the period of greatest recreational and cultural water use.

Calculation of 95th percentiles

There are several ways to calculate the 95th percentile. All these approaches have significant drawbacks. For example, the geometric mean provides no information on the high values at the top end of the statistical distribution that are of greatest public health concern. Much of the top-end variability in the distribution of water quality data is reflected by 95th percentiles and the 95% compliance system and are more easily understood but requires more samples to reliably determine than the geometric mean.

Calculating the illness risk for a given distribution of enterococci by the method in Kay et al. (2004) enables the recreational water concerned to be placed in its correct microbial assessment category, and its 95th percentile to be rescaled as outlined in Note 5 of the Table 3.7 (i.e. standardised on the basis of illness risk). An automated method of doing this is illustrated in *Information sheet – Calculation of 95th percentiles*, along with other methods of calculating 95th percentiles.

Data collected during or immediately following rainfall, as part of routine sampling, should be included in the calculation of the microbial assessment category. The purpose of the microbial assessment category is to give an indication of general water quality over an extended period, to allow for variations in climatic conditions. Follow-up samples from an alert or action mode response (e.g. exceptional circumstances) should not be included in the data used to generate a microbial assessment category.

The various stages involved in assessing the microbial quality of a recreational water environment are described elsewhere (Bartram and Rees 2000) and summarised in Table 3.8.

Table 3.8 - Assessing the microbial quality of a recreational water environment

Stage	Description
Stage 1	**Initial sampling to determine whether significant spatial and temporal variations exist.** 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 sources such as wastewater effluent or stormwater discharges) and maximum bather shedding (e.g. afternoon or day of peak bather numbers).
Stage 2	Assessment of spatial and temporal variations 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 and microbial water quality assessment. Microbial water quality is classified into one of four categories shown in Table 3.7, depending on the 95^{th} percentile of the intestinal enterococci distribution.
Stage 4	Definition, separate assessment, and management of affected areas, in situations where spatial and temporal variations are evident at Stage 2.
Stage 5	Confirmatory monitoring in the following year, possibly using a revised sampling regime based on the observations from the previous year.

3.6. Management and communication

Management of recreational water quality risks encompasses:

- Pollution abatement and remediation measures for managing water quality improvement
- Routine sanitary inspections and water quality monitoring to confirm the long-term classification of recreational water area
- Responding to changes to conditions and exceptions, including communication and reporting to the public.

3.6.1. Prevention and control of faecal contamination

Recreational water bodies are often polluted by effluents from wastewater treatment plants and industrial discharges, sewer overflows, leaky onsite sewage treatment systems, sewage, diffuse source pollution from agricultural areas and urban run-off as well as bather shedding and wildlife. This section describes abatement and remediation measures available for water quality improvement.

3.6.1.1. Direct point-source pollution abatement

Run-off via drainage ditches and so on is predominantly event-driven pollution that may affect recreational water areas for relatively short periods after rain.

Effective ocean outfalls are designed with sufficient length and depth of diffuser discharge to ensure a low probability of sewage or wastewater effluent reaching the designated recreational water environment. The aim is to separate the bather from human-derived faecal contamination. Long ocean outfalls can be an effective means of protecting public health by separating recreational water users from contact with faecal contamination. Screening to remove gross pollutants is the minimum treatment level required.

For nearshore discharges from large urban communities, where recreational water users may come into contact with effluent, tertiary treatment systems that include effective disinfection can be an effective means of reducing potential faecal contamination. However, public health risks will vary depending on the operation and reliability of the plant and the effectiveness of disinfection. After heavy rain, high sewer flows can lead to total or partial failure of the disinfection systems.

3.6.1.2. Non-point source pollution abatement

Run-off from rain or snowmelt via stormwater may also affect recreational water areas for short periods after rain. This is because as run-off moves over surfaces, it picks up and carries away pollutants, depositing them into lakes, rivers, wetlands, coastal waters and groundwater.

Non-point source pollution can include pathogens from livestock, pet waste and other animal sources.

Abatement options for non-point source pollution include:

- keeping litter and pet waste contained so it does not end up in street gutters and storm drains (including by making pet waste bags available in public areas and installing signs to remind owners to pick up after their pets)
- having onsite sewage management systems inspected, maintained, and pumped out regularly
- managing animal manures
- using fencing to restrict access to water bodies and riparian buffers
- providing adequate toilet facilities in recreational areas.

Nature-based solutions may provide an effective means to abate non-point sources of pollution and remediate the condition of a recreational water body. Nature-based solutions are actions that protect, manage, or restore ecosystems in ways that provide benefits to communities and ecosystems at the same time (DCCEEW 2024). For instance, nature-based solutions include the use of wetlands to reduce pathogen transport from pollution discharges into surface waters (Pastor-López et al. 2024), and minimise pathogens occurrence in both surface water reservoirs (Yu et al. 2022) and aquifers (Dillon et al. 2020). The recently emerging promotion and recognition of nature-based solutions in water supply management arises from their multiple benefits: improved biodiversity, ecosystem protection, carbon sequestration, flood mitigation (Rau 2022), and reduced treatment costs (Souliotis and Voulvoulis 2022).

3.6.1.3. Intermittent pollution abatement

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. Similarly, many onsite wastewater management systems can overflow or leach via groundwater to nearby recreational water sites in heavy rain. These may expose water users to diluted untreated human excreta. Where the sanitation system does not receive surface water after rainfall, dry-weather raw sewage overflows and unmanaged onsite wastewater management system effluent can present a direct health risk and contact with the overflow should be avoided.

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 sewage, or the effectiveness of the treatment may be lowered because of a change in the quantity and 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 options for sewage overflow structures include:

- retention tanks that discharge during periods when recreational water is not being used
- transport of sewage to locations distant from recreational areas via piped collection systems or effective outfalls
- disinfection (ozone, chlorine, peracetic acid or ultraviolet light), which may not be effective against all hazards.

These pollution abatement alternatives usually require major capital expenditure and may not be readily justifiable, especially in regional communities. An alternative are management programs that minimise recreational and cultural water use during event-driven pollution incidents.

Recycling of wastewater (e.g. for agriculture, irrigation) may divert wastewater flows away from recreational water areas to help eliminate health risks. However, during events such as heavy rainfall, wastewater run-off or discharges can enter waterways.

NHMRC

Programs to deter gulls and waterfowl away from recreational water sites, or remove seaweed, food scraps, or other detritus that may attract them, have been effective in reducing faecal indicator organism levels (Converse et al. 2012).

3.6.1.4. Catchment pollution abatement

Significant pollution sources that may present a challenge to pollution abatement include:

- upstream diffuse pollution (e.g. poorly functioning onsite wastewater management systems, local breaks in sewerage pipes and private sewer plumbing)
- point-source discharges (e.g. illegal faecal sludge disposal sites)
- animal-derived faecal contamination, especially in catchments with livestock-rearing operations
- pathogen accumulation in stream sediments and remobilisation via riverine discharges to coastal recreational areas.

Major sources of pollution should be identified and a catchment-wide pollution abatement program developed. This requires cooperation among health agencies, environmental control agencies, local authorities, users and polluters. The role of the agricultural sector in generation and remediation of pollution loadings is often crucial in catchments that are primarily affected by livestock pollution.

3.6.1.5. Enforcement of regulatory compliance

Enforcement of abatement measures to prevent point sources of pollution can be an effective tool to protecting and improving the microbial quality of recreational water bodies.

Where recreational water activities are being facilitated and promoted, it may be appropriate to base regulatory compliance on the obligation to act, including requirements to:

- implement a water quality risk management plan
- immediately consult the public health authority and to inform the public, as appropriate, when conditions are detected that are potentially hazardous to health
- take measure to improve the classification of the recreational water body.

3.6.2. Monitoring and response

Monitoring has three important phases:

1. Initial monitoring to characterise the recreational water body according to the microbial assessment category, combined with the sanitary inspection category and inform mitigation strategies (discussed in section 3.5).

2. Ongoing verification monitoring of water quality to understand variability over time and space to verify or modify the microbial assessment category and sanitary inspection category and to inform additional mitigation strategies.

3. Operational monitoring to inform a rapid response to an adverse result and inform public advisories.

3.6.2.1. Ongoing verification monitoring and inspection

Ongoing verification monitoring is required to confirm the microbial assessment category and sanitary inspection category.

Verification monitoring may use a minimum of five samples per year (to ensure that no major changes go unidentified) for recreational water areas where:

- no change to the sanitary inspection category from the annual sanitary inspection has occurred over several years
- the sanitary inspection category is “very low” or “low”
- the initial microbial water quality assessment is category A and based on at least 100 samples.

For areas where the sanitary inspection resulted in a “very high” categorisation for susceptibility to faecal contamination (where controls are effective at deterring swimming), a similar situation applies.

For intermediate-quality recreational water environments (i.e. “moderate” and “high” risk categories), an annual verification sampling program involving more frequent sampling is recommended, as shown in Table 3.9.

Table 3.9 - Recommended verification monitoring schedule

Risk category identified by sanitary inspection	Microbial sampling	Sanitary inspection
Very low	Minimum of 5 samples per year	Annual
Low	Minimum of 5 samples per year; where the microbial assessment category is category B, treat as for Moderate risk category	Annual
Moderate	Annual low-level sampling 4 sample locations x 5 occasions during swimming season Annual verification of management effectiveness Additional sampling if abnormal results are obtained	Annual

Risk category identified by sanitary inspection	Microbial sampling	Sanitary inspection
High	Annual low-level sampling 4 sample locations x 5 occasions during swimming season Annual verification of management effectiveness Additional sampling if faecal indicator organism results do not fit with sanitary inspection expectation	Annual
Very high	Minimum of 5 samples per year	Annual

Source: WHO (2021).

3.6.2.2. Operational monitoring and communication using predictive models

For short-term, routine management, a range of indicators and tools may be used for operational monitoring, including non-microbiological parameters, for example:

- detection of the release of untreated or poorly treated sewage or faecal sludge from a utility or service provider
- rainfall data that may influence run-off or release excreta from flooded onsite sewage management systems and sewers
- reports of unloading by faecal sludge trucks in coastal zones
- wind speed or direction and water temperature data as these conditions may change the dispersal of sewage, onsite sewage management system effluent and stormwater from outfalls
- operational data collected by individuals associated with a recreational water site, surveillance drones and citizen science.

The range of sources of operational data means that roles and responsibilities need to be defined during risk management planning (refer to *Chapter 2 – Framework for the management of recreational water quality*) for operational monitoring associated with faecal contamination.

The timely response and public communication to changes in recreational water quality is paramount in minimising risks to recreational water users. Predictive models can be used at bathing water areas to derive microbial water quality forecasts (e.g. daily). These can be made available to the public through means such as beach signage, websites and mobile applications. Predictive models provide water users and other beach users with near-real-time information on likely water quality conditions that are more up to date than the historical results provided by traditional analytical methods. When the results are well communicated, they allow water users to make informed choices on whether to use the recreational water site. Refer to Box 3.1 for an example of a predictive model built using real-time data. Predictive models should be validated and checked against real conditions as they may not be suitable for some beach types. Changes within beach catchments are likely to require updating of regression-based (i.e. empirical) models.

Box 3.1: Predictive modelling: the Beachwatch predictive model for New South Wales

Beachwatch, the NSW Government's recreational water quality program, uses predictive modelling to provide near real-time estimates of swimming conditions at popular locations across New South Wales. Forecasts predict the health risk to swimmers by modelling the relationship between bacterial contamination and rainfall and are informed by recent rainfall data and reported pollution events.

Beachwatch provides twice-daily forecasts for 160 monitored swim sites, classifying them as "pollution unlikely" (green), "pollution possible" (amber) or "pollution likely" (red), with recommended actions to protect public health. These classifications are based on predicted levels of microbial contamination and associated health risks, using established illness risk thresholds. Results are displayed on the Beachwatch website using a traffic-light system, enabling the public to make informed decisions on when and where to swim.

Model performance is continuously validated against routine water quality monitoring to ensure forecasts remain aligned with observed results. Annual audits assess accuracy, identify areas for refinement, and maintain transparency. In 2025, the Beachwatch predictive model achieved 93% overall accuracy. Ongoing tracking ensures forecasts remain reliable. When prediction accuracy at a swim site declines, models are reviewed and adjusted to reflect changes in water quality patterns. Recalibration ensures the models adapt over time as conditions change and new monitoring data become available. Source: http//www.beachwatch.nsw.gov.au

3.6.2.3. Assessing and acting on single and/or high analytical results

All results should be reported to relevant authorities, who should set trigger values for being alerted to results of concern.

Alert levels include results that would be considered unusual or unexpected, or that exceed the microbial assessment category. This requires an investigation of the cause of the elevated levels and increased sampling to enable the risks to bathers to be more accurately assessed. To help determine what is unusual or unexpected for the water site, responsible agencies should ensure that they are fully informed of any sanitary inspection information for the water site and any past records of water quality, and that they have undertaken a reasonably recent visual inspection so that results can be interpreted in context. Care should be taken in interpreting single results or low numbers of samples. It is important that sufficient samples are collected to enable an appropriate estimation of the faecal indicator organism densities to which recreational water users are exposed.

The circumstances that may lead site management agencies to consider issuing an advisory notice of likely adverse water quality include:

- Climatic conditions, such as high rainfall, leading to elevation of faecal indicator organisms in recreational water bodies. This information should be communicated to the public through signage, and to tourist information centres and the news media via electronic means. The water quality levels at which such an advisory might be prudent will depend on local circumstances.

- A rare or extreme event causing gross pollution of the bathing water. These events may include floods, fires and power outages. Often, the first evidence of such an event will be visual reports of gross pollution, indicated by high turbidity, water discoloration and/or associated sanitary wastes from sewer overflow, and/or overflow debris from rivers and drains discharging into the bathing water. A protective advisory notice informing the public of potentially adverse water quality should be issued on first observation of the evidence. Microbiological testing to confirm adverse water quality (high microbial concentrations) could provide a yardstick for a return to more normal water quality for the affected water site.
- Sewer debris is reported in the bathing water but is not explained by weather events. This may indicate a gross malfunction or leakage of the sewerage system or private sewer plumbing. An advisory notice to inform the public of the risk should be posted. The notice should only be removed when the new source of gross pollution has been rectified.

Although uncommon, for water sites where environmental *E. coli* blooms are suspected and *E. coli* is still used as part of the microbial monitoring program, it is important to obtain evidence that the *E. coli* are environmental in origin and not associated with faecal sources. Precautionary signs should be erected while a sanitary inspection is undertaken to identify potential sewer leaks and other sources. Simultaneous monitoring for enterococci and *E. coli* may assist in strengthening the evidence of a non-faecal (environmental) source (i.e. low numbers of enterococci as compared with *E. coli*). Discounting of results should only be considered when the evidence for their occurrence is clear and in consultation with the relevant health authority or regulator. Even in the confirmed presence of an environmental *E. coli* bloom, it is likely that *E. coli* that are faecal in origin will also be present at lower concentrations; this could present a health risk. Further details on the management of environmental *E. coli* is available in Sinclair (2019).

3.6.3. Public health advisories and warnings

Recreational water managers may take steps to identify periods when microbial 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 reducing risks to public health and, in many circumstances, allows an area's classification to be modified. It can also facilitate the use of areas, for a specified period of time, that might otherwise be considered unsuitable.

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 source of faecal contamination, 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 and cultural water use, for example, by fencing, signposting or changing the location of car parks, bus stops and toilets (Bartram and Rees 2000).

See *Information sheet – Preparing a risk communication plan* and *Risk communication planning checklist.*

3.6.4. Public health surveillance and risk communication

3.6.4.1. Public health surveillance

Surveillance systems are essential for detecting and investigating outbreaks of waterborne illnesses associated with recreational water. However, there are limitations to current surveillance systems including:

- the retrospective nature of outbreak surveillance can make it difficult to obtain samples needed to measure water quality parameters and provide laboratory confirmation of disease aetiology
- counts of outbreaks and cases are likely to underestimate actual disease incidence due to under reporting for mild cases of illness, variations in public health capacity and reporting requirements.

Despite these limitations, the systematic documentation of surveillance data on outbreaks and national health data reports associated with recreational water activities can provide important insights into exposure scenarios, trends and the health impacts of exposure to recreational water bodies. Responsible authorities should periodically consider whether any new pathogens or diseases should be included on the National Notifiable Disease Surveillance System to improve reporting.

3.6.4.2. Public health risk communication

Public health risk communication entails the provision of information on the appropriate uses of a recreational water body based on its classification, near-real-time information to reflect day-to-day water quality conditions generated using predictive models, and issuing of warnings and advisories in accordance with incident and emergency management protocols.

Good-quality and near-real-time public information describing the recreational water environment is important to enable people to make informed choices. Communication options include short-term advisory notices with clear public visibility at key water access locations, digital information platforms such as smartphones, websites and social media, informed by predictive models (WHO 2021).

Communication strategies and messages should be tested prior to deployment to ensure their effectiveness. When deployed, a process to monitor user understanding and adherence should be implemented. See *Information sheet – Preparing a risk communication plan* and the *Risk communication planning checklist*.

3.7. Research and development

3.7.1 Temporal and spatial variability of empirical sampling data

High quality studies gathering empirical sampling data from research in the UK and the US have revealed very high intra-day temporal and fine-scale spatial variability, of the order 2–4 $\log_{10}$, in regulatory faecal indicator organism concentrations (Fleisher 1985; Wyer et al. 1999).

In the UK studies, this pattern was evident at seven marine beaches sampled at 30-minute intervals for 12 hours over 60 bathing season days, with triplicate analyses to increase the precision of single-sample bacterial enumeration. The inherent assumption that the compliance sample set (one sample on the compliance sampling day) represents the water quality on the bathing day was therefore not validated, and this has implications for design of predictive modelling protocols. Further similar studies at other water sites are warranted to better understand how variable faecal indicator organism concentrations are in other settings.

In the interim, it is important to be cognisant of this high level of variability when estimating health risks or undertaking modelling exercises. It would be beneficial to test this intra-day temporal and fine-scale spatial variability at specific water sites to help inform local understanding of contaminant variability and potential risk. In the absence of such local evidence, faecal indicator microbial results from only a few samples should be assumed to be indicative rather than precise measurements of the true concentration, and hence the concentration should be assumed to be highly variable.

3.7.2 Epidemiological studies to derive microbial water quality guideline values

Although still relevant, the epidemiological studies underpinning water quality guideline values are temporally dated, and are limited in terms of recreational activities, exposure types, geography, and subpopulations studied. New, high quality epidemiological studies in a variety of locations, with subjects from the general population as well as subpopulations of interest (e.g. children, immunocompromised people, the elderly, elite sportspeople), as well as a variety of activities and exposure scenarios, would enable future validation and updates to guideline values.

Epidemiological data is especially needed on younger bathers, especially given that children are likely exposed to longer contact times and more likely to ingest recreational water.

Epidemiological studies are also needed to study the association between alternative faecal indicator organisms and symptoms following bathing or other exposures in recreational water bodies. This includes *Clostridium perfringens* as a faecal indicator organism for tropical waters (Vierheilig et al. 2013); coliphage as a faecal indicator organism that may correlate better than bacteria with pathogenic viruses (McMinn et al. 2017; US EPA 2017); and various MST (molecular) markers.

3.7.3 Developing site specific microbial water quality criteria

When sewage is not a dominant faecal source within a catchment, there may be value in investing in a research program to develop site specific microbial water quality criteria. In addition to site specific water quality monitoring, tools such as quantitative microbial risk assessment (QMRA), in combination with microbial source tracking (MST) have been used for this purpose in many recreational contexts (Federigi et al. 2019).

MST methods remain primarily a research and investigation tool to help identify the dominant faecal source for a sampled body of water. MST uses genetic markers or microorganisms in excreta that are strongly associated with a specific host (e.g. humans, livestock, dogs, waterfowl; Wiedenmann et al. 2006; Reischer et al. 2011; Harwood et al. 2014). Genotypic methods differentiate sources through genetic patterns of bacteria in the source sample. An ideal MST marker should meet certain performance criteria, i.e., it should be highly specific to its host and broadly distributed in the faeces of individuals within an animal group. The concentration of the marker should be high enough, and it should be evenly distributed in the faeces of the host with little or no temporal or geographical variations. The persistence of the marker in the environment should be similar to faecal indicator bacteria and pathogens, and the presence should be correlated with human health risks. Host specificity, or the prevalence of the marker in faeces/waste from the target host, is necessary for confidence that absence of the marker is indicative of the absence of a faecal pollution source. This can vary widely depending on the type of waste assessed and the geographic location.

More information regarding the development of alternative criteria to address nonhuman faecal sources and the related research needs can be found in US EPA (2024).

Research needs to improve confidence in site specific tools include reliable and robust microbial pathogen data in various recreational water environments, harmonisation of monitoring and analysis for microbial pathogens, improved understanding on the fate of microbial pathogens in the environment, improved exposure assessments and refinement of dose-response models for various pathogens to improve the accuracy of risk estimates.

Box 3.1: Quantitative Microbial Risk Assessment (QMRA) and microbial source tracking for assessing risks to recreational water users in Port Phillip Bay

EPA Victoria (2021) used quantitative microbial risk assessment (QMRA) to improve its understanding of recreational water quality in Port Phillip Bay. Microbial source tracking (MST) techniques were used to identify human sewage, canine and avian sources of microbial contamination and assess risks to recreational water users.

The study measured enterococci concentrations. Source tracking was performed using qPCR marker *Bacteroides* HF183/BacR287, as an indicator of human sewage, and 16S rRNA gene sequencing. The study found a significant correlation between the proportion of the microbial communities that were like human sewage microbial communities and the qPCR marker ($p=0.008$) and enterococci ($P<0.001$).

Similarly, a significant relationship was reported between enterococci concentrations and the total proportion of faecal microbial communities ($p<0.001$), indicating that enterococci provided an estimate of the overall level of faecal contamination.

Further information is available at https://www.epa.vic.gov.au/about-epa/publications/2007.

3.7.4 Environmental proliferation of faecal indicator organisms

Further research is also needed to understand the sanitary significance of environmental proliferation of faecal indicator organisms, particularly in submerged vegetation compared with faecal contamination derived from human and animal faeces, and the consequences for monitoring and interpretation of results. Blooms of faecal indicator organism *E. coli*, for instance, have been reported in recreational water environments (Power et al. 2005). Blooms of enterococci have also been reported in tropical areas and may occur in temperate climates during summer, for example in river embankments rich in organic matter (Byappanahalli et al. 2012).

3.8. Supporting tools and information

Information sheet - Sanitary inspections

Information sheet – Faecal indicator organisms

Information sheet – Calculation of 95th percentiles

Information sheet – Exposure assumptions

Information sheet – Preparing a risk communication plan

Risk communication planning checklist

3.9 References

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4. Other microbial hazards

Guideline recommendation

Recreational water users and responsible entities should be aware that serious infections can result from exposure to microbial hazards that are naturally present in surface waters, especially among immunocompromised individuals.

Site specific risks should be assessed as part of a preventive risk management approach. Where the risk assessment of a water site identifies that the local environment supports the presence of microbial hazards, the emphasis should be on managing the risk of exposure and raising public awareness of the risks and opportunities to take personal preventive measures.

Where environmental conditions at a water site potentially support *Naegleria fowleri*, health advice should include information to help recreational water users understand the elevated risk associated with activities where water is likely to enter the nasal passage.

4.1. Overview

Recreational water bodies may contain a wide range of endemic microbial hazards, including some free-living and opportunistic human pathogens.

This chapter describes microbial hazards where there is an association between human cases of disease and water related activities. Understanding their presence and the conditions that influence their occurrence can assist in identifying and managing any risks to water users.

Given the potential health significance of *Naegleria fowleri* (*N. fowleri*) and *Burkholderia pseudomallei* (*B. pseudomallei*) in Australian waters, an independent review of the evidence on these organisms in recreational water was commissioned by NHMRC. The review included studies published between 2004 to 2021, and informs the guidance included in this chapter. For more detailed information from this review, readers are encouraged to view the evidence evaluation report conducted by Puzon et al. (2024) which is included as a background document to these Guidelines. Content on other organisms in this chapter has been informed by WHO (2021) and Australian publications.

For guidance on microbial pathogens introduced to recreational water bodies through human or animal faecal contamination, refer to *Chapter 3 - Microbial pathogens from faecal sources*. For guidance on managing potential health risks associated with cyanobacteria and algae, refer to *Chapter 5 - Harmful algal and cyanobacterial blooms.*

4.2. Health effects of microbial hazards, occurrence and exposure

Microbial hazards present in untreated waters have been associated with a range of mild to severe health effects, including localised to serious life-threatening systemic infections (refer to Table 4.1). These microorganisms include some free-living organisms and opportunistic human pathogens.

Near-drowning episodes or significant aspiration can create opportunities for infection by many opportunistic microorganisms (Sympardi et al. 2020; Baumgardner 2017). Eye, ear and skin infections are commonly associated with recreational water exposure as summarised below.

Infections of the eye include conjunctivitis that affects the clear film covering the white part of the eye and keratitis that affects the cornea. Microbial keratitis is a serious infectious disease that can lead to vision loss and ophthalmic morbidity; however, it is rare in the absence of predisposing factors. Wearing contact lenses increases the risk of microbial keratitis associated with recreational water exposures (Arshad et al. 2019). In Australia keratitis is predominantly caused by *Pseudomonas aeruginosa* (Stapleton et al. 2007). Fungi (Chew and Woods 2018; Kim et al. 2024) and Acanthamoeba (Höllhumer et al. 2020) are less prevalent but important waterborne agents.

Infection of the external ear canal (otitis externa) is a very common disease in Australia and overseas, with 10% of people thought to be affected at some time (Hajioff et al. 2015). Usual symptoms are mild pain and itching around the ear. Pain may become more severe if the infection progresses to involve deeper tissues. The most frequent bacterial pathogens are *Pseudomonas aeruginosa* and *Staphylococcus aureus.* Fungal overgrowth (e.g. *Aspergillosis* and *Candida* species) is common especially following prolonged antibiotic treatment (Hajioff et al. 2015).

The incidence of otitis externa is more common among swimmers and in warmer, more humid environments (Wijesekera et al. 2024) and can be an important contributor to disease burden. While predominantly thought to be linked only with swimming pools and hot tubs, untreated waters are also an important contributor to infection. Wade et al. (2013) estimated that more than 916,000 earaches per year were attributable to swimming in natural waters in the United States (based on the 2011 population).

Malignant otitis externa or necrotising otitis externa is a rare invasive form of external otitis, characterised by progressive spread of infection from the external auditory canal to involve the temporal bone and skull base. Malignant otitis externa occurs primarily in immunocompromised individuals, particularly those with diabetes. A retrospective analysis in the Northern Territory revealed that among nine patients with necrotising otitis externa, six were Aboriginal patients, all of whom were diabetic and aged around 16 years younger than non-Aboriginal patients (Loh et al. 2019). The mean age at diagnosis was, respectively, 54.2 +/- 11.1 years and 69.9 +/- 8.3 years.

Surfer's Ear (external auditory canal exostoses) are localised bony growths that form in the ear canal and are common among surfers in Australia. There is a recognised association between time spent surfing and the presence and severity of surfer's ear, with risk increasing after only 5 sessions per month (Alexander et al. 2015). Simas et al. (2021) reported a prevalence of 71.8% among 85 surfers on the Gold Coast, QLD. Surfer's ear is not caused by any microbial agent, however, surfer's ear can increase an individual's susceptibility to pathogens as water can be trapped within the ear canal leading to recurrent otitis externa (Taylor et al. 2022).

Any break in the skin barrier can become infected by a range of microbial hazards potentially present in recreational water bodies. For immunocompromised individuals, those infections can lead to serious health outcomes (Chaúque et al. 2022), including necrotising fasciitis associated with *Vibrio vulnificus* (Bermingham et al. 2025). Allergic reactions including swimmer's itch (described below) have also been associated with certain recreational water sites.

The global rise in antibiotic resistance poses a significant threat to public health. Several of the bacterial and fungal agents described in this chapter are listed as priority pathogens by the World Health Organization (WHO) for research given their public health importance, including the bacteria *Pseudomonas aeruginosa* and *Staphylococcus aureus* and the fungi *Candida spp*., *Aspergillus fumigatus* and *Cryptococcus spp*. (WHO 2022, 2024). Infections with these agents may become increasingly difficult to treat with the increasing prevalence of resistant strains.

Table 4.1 - Microbial hazards of potential concern found in recreational water bodies[a]

Organism type	Organism	Disease (health effect) or role	Exposure pathway	Relevant advisory
Bacteria	*Aeromonas* spp.	Skin and wound infections, pneumonia, gastroenteritis and systemic blood infection (i.e. bacteraemia). Increased susceptibility in immunocompromised.	Wound or trauma.	Cover wounds with waterproof dressing
Bacteria	*Burkholderia pseudomallei*	Melioidosis (A diverse spectrum of clinical presentations and severity, most common presentation is pneumonia with or without bacteraemia. Almost any organ can be involved) People with underlying medical conditions (e.g. diabetes, renal and liver disease) are at increased risk of infection.	Wound, inhalation, or ingestion.	Cover wounds with waterproof dressing
Bacteria	*Chromobacterium violaceum*	Wound infections, abscesses and systemic blood infection (i.e bacteraemia). Invasive disease is more likely in immunocompromised.	Wound or trauma.	Cover wounds with waterproof dressing

Organism type	Organism	Disease (health effect) or role	Exposure pathway	Relevant advisory
Bacteria	*Leptospira* spp.	Leptospirosis (Variable presentation from nonspecific illness with fever to Weil's disease which is severe and can lead to jaundice, kidney failure, psychological symptoms and bleeding into the lungs). Infection risk is associated with adventure travel and recreational water sports.	Mucous members, wound or trauma.	Cover wounds with waterproof dressing
Bacteria	*Pseudomonas aeruginosa*	Skin, ear, and eye infections. In immunocompromised individuals, infections of the lungs, urinary tract and gastrointestinal tract can occur.	Skin, ear, and eye.	Cover wounds with waterproof dressing
Bacteria	*Shewanella* spp. (*Shewanella algae* and *Shewanella putrefaciens)*	Skin, ear, and wound infections and systemic blood infections (i.e. bacteraemia). Invasive disease is more likely in immunocompromised.	Skin, wound and ear.	Cover wounds with waterproof dressing
Bacteria	*Staphylococcus aureus*	Skin, ear, and wound infections.	Skin, wound and ear.	Cover wounds with waterproof dressing
Bacteria – noncholera vibrios	*Vibrio alginolyticus*	Ear infections, soft tissue infections. Comorbidity (hepatic disease) increases the risk of severe outcome.	Wound, trauma or ear.	Cover wounds with waterproof dressing. Wash cuts sustained in water thoroughly with clean water and soap.
Bacteria – noncholera vibrios	*Vibrio cholerae* non-O1/O139	Gastroenteritis, ear and wound infections. Comorbidity (hepatic disease) increases the risk of severe outcome.	Ingestion, wound or trauma.	Cover wounds with waterproof dressing. Wash cuts sustained in water thoroughly with clean water and soap.

Organism type	Organism	Disease (health effect) or role	Exposure pathway	Relevant advisory
Bacteria – noncholera vibrios	*Vibrio parahaemolyticus*	Wound infection, pneumonia. Comorbidity (hepatic disease) increases the risk of severe outcome.	Ingestion, wound or trauma.	Cover wounds with waterproof dressing. Wash cuts sustained in water thoroughly with clean water and soap.
Bacteria – noncholera vibrios	*Vibrio vulnificus*	Severe wound infection. Comorbidity (hepatic disease) increases the risk of severe outcome.	Wound or trauma.	Cover wounds with waterproof dressing. Wash cuts sustained in water thoroughly with clean water and soap.
Mycobacterium	*Mycobacterium avium*	Complex lung disease. Increased susceptibility in immunocompromised.	Inhalation of water.	Cover wounds with waterproof dressing
Mycobacterium	*Mycobacterium marinum*	Skin and soft tissue infection, nodular granuloma	Wound or trauma. Handling of fish.	Cover wounds with waterproof dressing
Mycobacterium	*Acanthamoeba spp.*	Amoebic keratitis, Granulomatous amoebic encephalitis (GAE)	Existing injury to cornea. Increased risk associated with wearing contact lenses in water.	Remove contact lenses
Mycobacterium	*Naegleria fowleri*	Primary amoebic meningoencephalitis (a rare but almost always fatal infection of the brain)	Water sports, diving, jumping, and immersing the head increase the risk of the amoeba entering via the nose.	Prevent water going up the nose by avoiding head emersion and using nose clips)
Helminths	Schistosomes	Swimmer's itch	Allergic reaction to skin penetration by cercariae.	Not applicable
Yeast and Fungi	*Candida* spp.	Ear infections, skin infections	Water is swallowed or enters the nasal passages, ears, or cuts on the skin during activities like swimming or diving.	Not applicable

Organism type	Organism	Disease (health effect) or role	Exposure pathway	Relevant advisory
Yeast and Fungi	*Aspergillus* spp.	Ear infections, aspergillosis and allergy	Water is swallowed or enters the nasal passages, ears, or cuts on the skin during activities like swimming or diving.	Not applicable
Yeast and Fungi	Dermatophytes	Onychomycosis and tinea Increased susceptibility in immunocompromised.	Contact with contaminated water or surfaces such as sand.	Not applicable
Yeast and Fungi	*Cryptococcus* spp.	Cryptococcal meningitis, pneumonia, systemic infection Increased susceptibility in immunocompromised.	Contact with contaminated water or surfaces such as sand.	Not applicable

Source: [a]Adapted from WHO (2021).

4.2.1. Burkholderia pseudomallei

B. pseudomallei is a Gram-negative, soil-dwelling bacteria endemic in tropical and subtropical regions of the world especially south-east Asia and Australia. In Australia, *B. pseudomallei* is most commonly found north of latitude 20°S, and is endemic in the Northern Territory, far north Queensland, and parts of Western Australia (Smith et al. 2018). *B. pseudomallei* is known to be part of the natural environment, and in Australia has been detected in soils, rural water supplies, groundwater and groundwater seeps (Baker and Warner 2016).

Frequency of detection in environmental samples increases under certain climatic conditions including increased dew point, cloud cover, rainfall, and maximum temperature (Kaestli et al. 2016). Although typically considered to only occur in tropical regions, *B .pseudomallei* has been detected in south-western Australia (Golledge et al. 1992) and south-east Queensland (Queensland Health 2017, 2023), with an outbreak of 14 melioidosis cases in southern Queensland in April 2021 – June 2022 (Gassiep et al. 2023). Consistent with the environmental occurrence of *B. pseudomallei*, most cases of melioidosis occur during the wet season after heavy rain or flooding (refer to Box 4.1). However, Smith et al. (2023) describe an outbreak of melioidosis among children following a Queensland sporting event, which involved crawling through a mud pit, that took place in a tropical region during the dry season (refer to Box 4.2).

Human infection from *B. pseudomallei*, referred to as melioidosis, occurs from direct contact with water or soil via skin cuts and abrasions, inhalation, or eyes. Infection by ingestion is considered unusual, although outbreaks caused by contaminated drinking water supplies have occurred. Symptoms vary greatly among cases ranging from localised wound infections to pneumonia and blood infections. Pneumonia is the most common presentation of melioidosis in Australia (Meumann et al. 2012).

Melioidosis cases are more common in people with underlying medical conditions, such as diabetes, alcoholism, or chronic renal disease (Inglis and Sousa 2009). Aboriginal and Torres Strait Islander peoples are disproportionately affected and bear the greatest burden of the disease. The mortality rate is about 14% in northern Australia (Kaestli et al. 2016). The northern Aboriginal and Torres Strait Islander population is noted to account for 30% of overall melioidosis cases but comprise 67% of cases presenting at the intensive care unit (Stephens et al. 2016).

For additional information on *B. pseudomallei*, refer to Puzon et al. (2024).

Box 4.1 Queensland melioidosis death toll climbs after floods spread bacteria

In early 2025, Queensland experienced severe flooding due to prolonged heavy rainfall and tropical low-pressure systems. These events led to widespread inundation across the state's northeast. The floods triggered unprecedented case numbers of melioidosis and associated fatalities. The flooding brought *B. pseudomallei*, usually found in deep soil, to the surface, increasing human exposure through contaminated water and soil. Queensland Health intensified surveillance efforts, leading to timely identification and reporting of new cases. Public health campaigns were launched to educate residents about melioidosis, emphasising the importance of protective measures during flood clean-up activities. General practitioners were advised to remain vigilant for melioidosis symptoms, especially in patients with recent exposure to floodwaters or soil. This outbreak of melioidosis underscores the need for increased community awareness of the risks from contact with surface waters and mud following extreme weather events which are expected to become more frequent with climate change.

Sources: Melioidosis surveillance | Queensland Health (accessed 16 June 2025); Be melioidosis aware | Torres and Cape Hospital and Health Service (accessed 16 June 2025); Murray B (27 February 2025) Queensland floodwaters stir up deadly melioidosis outbreak - ABC News (accessed 16 June 2025).

Box 4.2 An outbreak of melioidosis among children after a sporting event

While predominantly associated with vulnerable populations, in certain contexts melioidosis risk should be considered for the entire population including children.

In late 2022, an outbreak of limited cutaneous melioidosis occurred among seven healthy children following a Queensland sporting event. The event, which included crawling through a mud pit, took place in a tropical region during the dry season. *Burkholderia pseudomallei* was isolated in soil samples from the mud pit and genomically linked to *B. pseudomallei* isolated from cutaneous lesions on 7 children who participated in the event and had melioidosis diagnoses.

Smith et al. (2023) describe the clinical features, environmental sampling, genomic epidemiologic investigation and public health response to the outbreak.

This outbreak of melioidosis highlights the need for people participating in recreational activities involving mud play to be aware of the possible increased risk of melioidosis, and to take appropriate action with any subsequent skin infections.

Source: Smith et al. (2023).

4.2.2. *Leptospira*

Leptospirosis is a bacterial zoonosis, in other words it can infect both humans and animals. *Leptospira* spp. are shed in the urine of infected hosts, and if able to persist in the environment can cause new infections via cuts and abrasions or mucous membranes (including eyes, mouth or genital surfaces). Warm, nutrient-rich environments favour their persistence; hence leptospirosis is more common in tropical and subtropical areas with high rainfall. In Australia, leptospirosis is most common in north-eastern NSW and Queensland (Goarant et al. 2019; NSW Health 2021), and associated with agricultural practices (particularly dairy) in other states. Studies investigating the occurrence of *Leptospira* spp. in environmental samples, indicate that detections are more frequent in soil than water, suggesting that soils may be protective of *Leptospira* spp. persistence. Furthermore, detections were also associated with turbid waters following rainfall events, particularly where animal excreta are washed into waterways (Bierque et al. 2020).

Infections are often subclinical. Symptoms include fever, headache, muscle pain, chills, red eyes, abdominal pain, jaundice, haemorrhages in skin and mucous membranes, vomiting, diarrhoea and skin rash. In extreme cases illness may progress to kidney or liver failure, aseptic meningitis, or pulmonary bleeding. Approximately 10% of cases develop severe disease (Cagliero et al. 2018).

Leptospirosis is difficult to diagnose as quick and simple diagnostic tests are not readily available (Picardeau 2013). Diagnosis is based on clinical suspicion and laboratory confirmation (Ahmed et al. 2020). The Queensland Health Leptospirosis Reference Laboratory provides expertise in testing and advice to support public health across Australia.

Leptospirosis is a notifiable disease in all States and Territories of Australia. The annual national notification rate per 100,000 from 2010 to 2024 varied between 0.3 and 1.0 or between 72 and 251 reported cases (DH 2025). In tropical regions, epidemiological clusters are observed following storms and hurricanes. In temperate climates, leptospirosis is commonly linked to occupational activities or recreational water activities (WHO 2025a).

Internationally, cases have been linked to recreational activities in surface waters, especially after rain and when muddy (Monahan et al. 2009). Recreational swimming in freshwater presents obvious risks for contracting leptospirosis and a common source outbreak was identified on the Waimea River on southwestern Kauai, Hawaii in July 1987 when three youths were hospitalised with suspected leptospirosis after swimming regularly in the river (Katz et al. 1991).

Outbreaks have been linked to rafting or kayaking (Agampodi et al. 2014; Guillois et al. 2018; Boland et al. 2004; Reisberg et al. 1997). Three cases were documented among individuals surfing on a river in Switzerland (Schreiber et al. 2015). Several outbreaks linked to triathlons have been reported in Europe (Brockmann et al. 2010; Radl et al. 2011), the USA (Guarner et al. 2001) and Reunion Island (Pagès et al. 2016).

Risk factors for potential leptospirosis transmission include muddy turbid water following rainfall. Recreational water users need to be aware of the risk and cover cuts and abrasions to minimise their exposure.

Flooding serves to wash contaminated mud and soils into larger water sources and increase the likelihood of host interactions. During times of flooding, education of the general population and awareness of the risks of leptospirosis may help reduce infection rates, particularly in areas where flooding occurs frequently or seasonally. Local inhabitants should be advised to use appropriate protective measures, such as covering skin abrasions, wearing suitable footwear, avoid water splashes, ingestion and direct contact with potentially contaminated water (Monahan et al. 2009).

Adventure sporting events is an increasing area of potential exposure risk. Following the Eco-Challenge-Sabah 2000 multisport endurance race that took place in Borneo, Malaysia in August to September 2000, initially approximately 20 cases of acute febrile illness were reported. Of the 304 athletes who competed in the race, 189 were subsequently contacted. Eighty (42%) met the case definition and 29 (36%) were hospitalised; none died (Sejvar et al. 2003). Race activities associated with water contact included jungle trekking, swimming and kayaking, caving, sailing, climbing and mountain-biking. A retrospective epidemiological survey of the area where the race took place pointed to a number of risk factors for infection, including contact with water in the Segema river, a jungle trek where participants suffered wounds to the skin and increased monthly rainfall in the region prior to the race (Sejvar et al. 2003).

Case studies have shown that outbreaks associated with endurance races in tropical and nontropical climates can result in large outbreaks of leptospirosis and water sport event organisers should have protocols to contact participants in the event of an outbreak, as well as participant education to highlight risks prior to competition. Information sessions on prevention of disease including the option to wear additional protective clothing such as foot and hand protection, as well as the use of chemoprophylaxis, would be advised.

4.2.3. Pseudomonas aeruginosa

P. aeruginosa is an aerobic, Gram-negative rod-shaped bacteria, commonly present in the environment. *P. aeruginosa* is frequently associated with hospital acquired infections and due to its importance in that setting has been extensively studied. In immunocompetent people, the *P. aeruginosa* has been associated with skin rashes (folliculitis), and eye and ear infections. In immunocompromised individuals, infections of the lungs, urinary tract and gastrointestinal tract can occur.

P. aeruginosa has frequently been identified in disease outbreaks associated with untreated recreational water use (Schets et al. 2011; van Asperen et al. 1995; Craun et al. 2005; Wade et al. 2013) including skin, eye and ear infections.

The sources of *P. aeruginosa* in surface waters is the matter of some scientific debate, as the organism has commonly been considered to be ubiquitous in the environment with soil and water part of its natural habitat. In a meta-analysis including a total of 64 articles, Crone et al. 2020 showed that the occurrence of *P. aeruginosa* was significantly higher in environments with intense human activity than those without human contact, suggesting that human faecal contamination may lead to increased numbers in natural recreational water bodies.

4.2.4. *Staphylococcus aureus*

S. aureus is an opportunistic non-faecal human pathogen frequently found in fresh and marine waters used for recreational and cultural activities.

S. aureus is commonly present in the skin, nose, ears and/or mucous membranes of humans without causing any health impacts. Over time, 20% of the population will almost always be colonised with *S. aureus*, 60% of the population will be colonised with *S. aureus* off and on, while another 20% are almost never colonised with *S. aureus* (SA Health 2016). Under certain circumstances, especially in the presence of skin trauma, *S. aureus* can cause infection. Typically presenting as skin and soft-tissue infections, severe cases can be life-threatening especially when resistant to methicillin (methicillin-resistant *S. aureus* or MRSA infections).

Humans are an important direct source of *S. aureus* to surface waters. Bathers have been shown to shed around 10^6 CFU/person in the first 15 minutes of swimming (Elmir et al. 2007). Overcrowding of water sites can be expected to increase the risk of *S. aureus* infection. Increased foot infections in people with diabetes following flood events is also a potential risk.

Other important reservoirs include domestic animals (Boost et al. 2008) and birds (Gilmore 2012) and therefore *S. aureus* can enter recreational water bodies from urban runoff. Furthermore, *S. aureus* concentrations in fresh, brackish and marine waters are positively correlated with turbidity (Steadmon et al. 2023).

4.2.5. VACS (Vibrio, Aeromonas, Chromobacterium violaceum and Shewanella)

The term 'VACS' refers to a group of environmental Gram-negative, oxidase-positive bacteria naturally found in aquatic environments (fresh, brackish and marine waters). They are recognised as important causes of water-associated infections, predominantly from exposure of skin wounds, and typically share susceptibility patterns and clinical presentations (McAuliffe et al. 2015).

In two separate reviews undertaken in the Northern Territory (442 patients from 2000-2013 (McAuliffe et al. 2015); 317 patients from 2015-2022 (Campbell et al. 2024)), *Aeromonas* was most commonly isolated (67%, 63%) followed by *Vibrio* spp. (15%, 19%), *Shewanella* spp. (13%, 13%) and *C. violaceum* (5%, 5%). The most common clinical presentations were skin and soft tissue infections on the lower limbs, consistent with exposure during water-associated activities.

Non-*cholerae Vibrio*

Although there are several pathogenic *Vibrio* species, the following four species have primarily been associated with recreational water infections: *V. alginolyticus*, *V. vulnificus*, *V. parahaemolyticus* and non-O1/O139 *V. cholerae*.

Vibrios have been isolated in waters showing a broad range of salinities and pH values. However, *V. cholerae* and *V. mimicus* are the only species found in freshwater. The species preferentially proliferate in warm (>20°C), saline aquatic environments. There appears to be a positive correlation between water temperature and the number of human pathogenic vibrios isolated, as well as the number of reported infections. Seasonality is especially noted for *V. vulnificus* and *V.*

parahaemolyticus in the marine environment (Vezzulli et al. 2012; Baker-Austin et al. 2017), and nontoxigenic *V. cholerae* in freshwater (Kirschner et al. 2008).

Wound infections, particularly those caused by *V. vulnificus*, can be very serious, especially if the patient has an underlying health condition (Menon et al. 2014). Such infections are almost always associated with contact with seawater (especially through cuts sustained on reefs or other rocks) and/or consuming shellfish.

V. parahaemolyticus is most often associated with food poisoning but can cause wound infections and has been associated with pneumonia following inhalation of contaminated aerosols. Wound infections tend to be more severe (requiring antibiotic treatment) than self-limiting gastrointestinal manifestations (Baker-Austin et al. 2017).

Cases from freshwater sites are mainly associated with non-O1/O139 *V. cholerae,* manifest mainly as otitis media or soft tissue infections (Maraki et al. 2016). Underlying liver conditions (liver cirrhosis, chronic liver disease) and alcohol abuse are the most common comorbidities for *V. cholerae* wound infection (Maraki et al. 2016). Marine nontoxigenic *V. cholerae* has also been associated with pneumonia (Marinello et al. 2017).

Aeromonas spp.

Aeromonas spp. are ubiquitous in aquatic environments (Janda and Abbott 2010), only some of which have potential human health significance. In surface water, aeromonads show characteristic seasonality, with increased numbers in the warmer months of the year.

Serious wound infections have been associated with exposure to *Aeromonas* spp. in recreational water. Skin trauma (such as an open wound or penetrating injury) is typically required for wound infection. An Aeromonas wound infection outbreak associated with a muddy football game occurred in Australia and affected 26 people that received game-related scratches and abrasions that became infected when exposed to the mud irrigated with river water (Vally et al. 2004).

Respiratory tract infections of *Aeromonas* in near-drowning patients and bacteraemia have also been observed. Pneumonia has been reported following aspiration of contaminated water and near-drowning incidents (Gonçalves et al. 1992; Ender et al. 1996; Vally et al. 2004).

Chrombacterium violaceum

Chrombacterium violaceum infection is rare with only 154 cases reported in the literature. In the Australian setting, an increased frequency of asymptomatic colonisation and less severe clinical spectrum of disease has been observed (Lin et al. 2016).

Location data available for 143 cases reveal a worldwide tropical distribution (Lin et al. 2016). Published cases often described severe sepsis and high case fatality rates (up to 60%) (Lin et al. 2016; Yang and Li 2011).

Shewanella spp.

Shewanella spp. infections are uncommon and are often described in relation to chronic wound infections and patients with diabetes. They favour warm ambient temperatures of tropical and subtropical climates, and summers of temperate climates (McAuliffe et al. 2015). In 2017, various media outlets reported a case of *Shewanella* infection in South Australia, which was presumed to occur following exposure to Murray river water through broken skin (see ABC News).

Shewanella spp. have been associated with a range of infections including ear infections, skin and soft tissue infections and bacteraemia following water exposure (Janda and Abbott 2012; Brulliard et al. 2017; Allou et al. 2018). There is increased risk of invasive disease in those with underlying medical conditions or the elderly (Laupland et al. 2022).

4.2.6. Mycobacterium

The "typical" species of mycobacteria, such as *M. tuberculosis*, *M. bovis*, *M. africanum* and *M. leprae*, have only human or animal reservoirs and are not transmitted by water. In contrast, the atypical or non-tuberculous species of Mycobacterium are natural inhabitants of a variety of water and soil environments.

Atypical *Mycobacterium* spp. including *Mycobacterium avium complex* and *Mycobacterium marinum* are waterborne. Despite the widespread prevalence of the organism, disease is relatively infrequent.

Mycobacterium avium complex are a rare cause of complex lung disease after inhalation of infected water, air or soil. It mainly affects middle-aged and elderly people with underlying chronic lung conditions. *Mycobacterium marinum* is found mainly in marine water (Iredell et al. 1992; Ang et al. 2000) and is associated with skin infections and nodular granuloma that may ulcerate and cause nodular lymphangitis. Infection is usually on the extremities and is associated with water contact with an existing wound or trauma.

Risk prevention measures include covering cuts and sores with waterproof dressings and being aware of the risk of infection in water bodies.

4.2.7. Free-living amoebae

Free-living amoebae are common in most soil and aquatic environments. Only four genera are known to contain species that infect humans: *Acanthamoeba*, *Balamuthia*, *Sappinia* and *Naegleria* (Visvesvara et al. 2007; Diaz 2011). Only members of the genus *Acanthamoeba* and *N. fowleri* are known to be important in natural recreational water bodies (Health Canada 2023). Both organisms are frequently isolated from warm freshwaters (Siddiqui and Khan 2014; Çamur et al. 2016; Abdul Majid et al. 2017; Değerli et al. 2020), including surface waters in tropical and subtropical climates, and thermal springs or water bodies receiving cooling water discharge in temperate regions (Behets et al. 2007; Zbikowska et al. 2013; Montalbano et al. 2017). However, the incidence of infection associated with these waters is extremely low.

Acanthamoeba

Acanthamoeba are single-celled free-living amoebae commonly found in freshwater and soil. Rayamajhee et al. (2023) reported on the incidence of *Acanthamoeba* in coastal lagoons in Australia, with higher concentrations during summer, when recreational activities are likely to be at their highest.

Acanthamoeba can cause three types of disease. In immunocompetent individuals, the most common disease is an eye infection known as acanthamoebic keratitis. Symptoms of acanthamoebic keratitis include inflammation of the cornea, blurred vision, ulceration and blindness.

In immunocompromised individuals, *Acanthamoeba* has also been associated with granulomatous amoebic encephalitis and cutaneous infections. Clinical symptoms of granulomatous amoebic encephalitis are similar to other forms of meningitis and include headache, fever, lethargy, stiff neck, confusion, irritability and death. The lack of distinguishing features of granulomatous amoebic encephalitis makes diagnosis difficult.

Symptoms of cutaneous infections include skin lesions and nodules or sinus lesions and sinusitis. In addition, disseminated disease can develop when infection spreads from the primary source of infection, usually the skin, to other organs and tissues.

Naegleria fowleri

Naegleria are a free-living amoeba commonly found in warm freshwater and soil.

There are more than 30 species of *Naegleria*, but only one, *Naegleria fowleri* (*N. fowleri*), has been isolated from human cases of disease, although infection is rare. *N. fowleri* is thermophilic and grows at temperatures between 25°C and 42°C by feeding on bacteria in water and soil; it does not grow below 20°C (WHO 2025b). Most cases of disease are associated with recreational exposure to warm freshwater (e.g. lakes, rivers, heated swimming pools, thermal waters) and contaminated drinking water in warm climates (De Jonckheere 2011; Cope and Ali 2016; Cope et al. 2018; Cope et al. 2019).

N. fowleri is commonly found in tropical and subtropical freshwaters, hot springs including artificially heated habitats such as geothermal hot springs and water bodies impacted by cooling tower effluent (Martínez-Castillo et al. 2016).

Infection with *N. fowleri* is called primary amoebic meningoencephalitis (PAM), is a very rare but almost always fatal infection of the brain. *N. fowleri* is sometimes referred to as a 'brain-eating amoeba' due to the consequences of PAM.

When water containing *N. fowleri* is allowed to enter the nose, amoeba can cross the olfactory mucosa of the upper nasal cavity and directly infect the brain resulting in PAM. Initial symptoms of PAM are similar to other forms of meningitis (headache, fever, nausea and vomiting); however, once established the infection progresses rapidly. Recent reports of *N. fowleri* infections in Kerala, India have suggested that rapid clinical interventions may improve the survival rate from PAM (Ghosh et al. 2025).

Naegleria fowleri infections in Australia are rare. There have been five confirmed cases and one probable case documented in Queensland since the year 2000, but none of these have been related to recreational water exposures (QLD Health 2025).

The following observations are made from globally reported cases linked to recreational and cultural activities:

- accurate diagnosis of PAM is difficult and often delayed as symptoms are similar to any type of meningitis, hence under reporting in many contexts is likely. The incubation period varies from 2 to 15 days (WHO 2021)
- the median age for *N. fowleri* infections has been reported to be 14 years old (n=381, ranging from 1-month old to 85 years old) with 75% of cases being male and 25% female (Gharpure et al. 2021) (noting the reported median age may change if the age distribution for recreational versus cultural activities is taken into account)
- *N. fowleri* cases have occurred in recreational water bodies with reported water temperatures between 22°C and >30°C (Puzon et al. 2024)
- 85% of all reported PAM cases occur during warm, hot, or summer seasons (Gharepure et al. 2021a)
- swimming is the most common recreational activity linked to *N. fowleri* infections (Gharepure et al. 2021a)
- recreational activities that involve water being forced up the nose (e.g. water skiing, diving, jumping in water) may present a higher risk
- cultural practices including full emersion baptism (Barnett et al. 1996) and ritual ablution (Siddiqui and Khan 2014) have been associated with cases of PAM.

For additional information on *N. fowleri*, refer to Puzon et al. (2024).

4.2.8. Cercarial dermatitis (swimmer's itch)

Schistosoma (commonly known as blood flukes) are parasitic blood trematodes with worldwide distribution. The larvae form of these parasites, called cercariae, are released by infected aquatic snails and can burrow into the skin of people swimming or wading in the water. There are no human infectious Schistosoma endemic in Australia. However, cercariae of non-human infectious schistosomes can cause an inflammatory response (allergic reaction) when they attempt to penetrate human skin, especially in people that have been exposed previously (Kolářová et al. 2012). The resulting papular rash is known as cercarial dermatitis or 'swimmer's itch'.

Different species have diverse (human or animal) host specificity, but all require snails as intermediate hosts. The nature and severity of the infection depend mainly on the causative agent. The cercariae of avian schistosomes are thought to be responsible for the majority of cases of cercarial dermatitis in water users (Loker et al. 2022).

Most reports are related to freshwater lakes, but some brackish waters and seawaters can also be a source of infection (Kolářová et al. 2012; Sangiorgio et al. 2024). Most swimmer's itch from recreational exposure is attributed to *Trichobilharzia* spp., especially in temperate climates (Horák et al. 2015).

Swimmer's itch is thought to be relatively uncommon in Australia, however, under-reporting rates are likely to be high. Cases have been reported in Queensland, New South Wales, Western Australia and Victoria in freshwater, brackish water and saltwater (Frew et al. 2016; Appleton and Lethbridge 1979; Hurley et al. 1994; Sangiorgio et al. 2024). A case report by Sangiorgio et al. (2024) describes a severe case of swimmer's itch with a bullous (blister-like) eruption associated with swimming at a marine sanctuary in Victoria. The marine sanctuary provides a coastal habitat for a wide range of marine and bird life (including marine snails), and is subject to episodes of brackish water due to freshwater runoff from a creek and stormwater drains.

Risk factors for swimmer's itch include bathing in warm, shallow water with dense vegetation, where aquatic snails are likely to live. Personal swimming behaviour (especially swimming duration) is expected to affect the likelihood and severity of symptoms (Selbach et al. 2016). Although cercarial dermatitis affects all age groups, children are at higher risk because they tend to spend more time in shallow water (Horák et al. 2015).

4.2.9. Yeast and fungi

Yeast and fungi, including *Aspergillus* spp., *Candida* spp., *Cryptococcus* spp. and dermatophytes have been found in sand/sediment and water environments (Brandão et al. 2021). Whilst infections from recreational water exposure are rare, these opportunistic pathogens can pose a risk and be difficult to treat, particularly in immunocompromised individuals (Yee et al. 2016).

Swimming was found to be a risk factor for otomycosis (Gharaghani et al. 2015), and for keratitis when wearing contact lenses (Zimmerman et al. 2016; Ahmad 2018).

4.2.10. Vector-borne pathogens

Some water environments used for recreational activities can provide a habitat for insect vectors such as mosquitoes and ticks that harbour and transmit a range of disease causing pathogens. For example, vector-borne diseases that pose public health risk from transmission from mosquitoes include Ross River virus, Barmah Forest virus, Murray Valley encephalitis virus, Japanese encephalitis virus and West Nile virus – Kunjin strain. Advice to the public on how to protect themselves from insect vectors is available from the relevant health authority in each state and territory. See *Information sheet – Resources on water quality and other hazards*.

4.3. Assessment of risk

Although infection with some of these microbial hazards via recreational water may be severe or even life-threatening, little is known about the specific drivers that influence human health risk. It is therefore not possible to define quantitative guideline values for individual microbial agents.

4.3.1. Occurrence of microbial hazards in water environments

When assessing the human health risk associated with non-faecal microbial hazards at a specific recreational water site, the climatic and water quality conditions should be assessed to determine the potential for organisms to be present (refer to Table 4.2). For those microorganisms identified as potentially supported by the local environment, any hazardous events likely to influence their occurrence should be identified. If necessary, monitoring may then be undertaken to further assess the occurrence of specific microbial hazards.

Table 4.2 - Potential climatic and water quality conditions that influence the occurrence of specific microbial hazards in water environments [a]

Type of Organism	Organism	Source and specific risk factors	Climate (indicative water temperature): Temperate (>15°C)	Climate (indicative water temperature): Subtropical (>20°C)	Climate (indicative water temperature): Tropical (>25°C)	Water environment: Freshwater	Water environment: Marine
Bacteria	*Aeromonas* spp.	Environment. Infected gastropods (e.g. snails, leeches).		☑	☑	☑	☑
Bacteria	*Burkholderia pseudomallei*	Environment (soil and water). Infected animals including sheep, goats, horses, pigs and rodents can transfer bacteria to the environment. [b, c] Tropical storms and extreme weather.			☑	☑	
Bacteria	*Chromobacterium violaceum*	Environment (soil and water).		☑	☑		☑
Bacteria	*Leptospira* spp.	Environment (soil and water). Animal hosts with access to water. Warm nutrient rich water.	☑	☑	☑	☑	
Bacteria	*Pseudomonas aeruginosa*	Environment. Infected animals, particularly in agricultural areas (e.g. poultry).	☑	☑	☑	☑	☑
Bacteria	*Shewanella* spp. (*Shewanella algae*	Environment.		☑	☑		☑

Type of Organism	Organism	Source and specific risk factors	Climate (indicative water temperature): Temperate (>15°C)	Climate (indicative water temperature): Subtropical (>20°C)	Climate (indicative water temperature): Tropical (>25°C)	Water environment: Freshwater	Water environment: Marine
	and *Shewanella putrefaciens)*						
Bacteria	+*Staphylococcus aureus*	Shed by humans and warm-blooded animals. Bather loading.	☑	☑	☑	☑	☑
Bacteria - noncholera vibrios	*Vibrio alginolyticus*	Environment.		☑	☑		☑
Bacteria - noncholera vibrios	*Vibrio cholerae* non-O1/O139	Environment.		☑	☑	☑	☑
Bacteria - noncholera vibrios	*Vibrio parahaemolyticus*	Environment. Migratory bird activity near waterways.		☑	☑		☑
Bacteria - noncholera vibrios	*Vibrio vulnificus*	Environment.		☑	☑		☑
Mycobacterium	*Mycobacterium avium*	Environment. Infected avians near waterways.				☑	☑
Mycobacterium	*Mycobacterium marinum*	Environment, fish, amphibians.			☑	(✓)	☑
Free-living amoebae	*Acanthamoeba* spp.	Environment.	☑	☑	☑	☑	
Free-living amoebae	*Naegleria fowleri*	Environment . High nutrient, stagnant waters. Thermal pollution.		(✓)	☑	☑	
Helminths	*Cercariae of Schistosomes*	Snails. Dense vegetation.	☑	☑	☑	☑	☑
Yeast and Fungi	*Candida* spp.	Environment (water and sand). Shed by humans and warm-blooded animals.		☑	☑	☑	☑

Type of Organism	Organism	Source and specific risk factors	Climate (indicative water temperature): Temperate (>15°C)	Climate (indicative water temperature): Subtropical (>20°C)	Climate (indicative water temperature): Tropical (>25°C)	Water environment: Freshwater	Water environment: Marine
Yeast and Fungi	*Aspergillus* spp.	**Environment (water and sand).**		☑	☑	☑	☑
Yeast and Fungi	Dermatophytes	Environment (water and sand). Shed by humans and warm-blooded animals.		☑	☑		☑
Yeast and Fungi	*Cryptococcus* spp.	Environment (water and sand). Decaying vegetable matter and bird droppings.		☑	☑	☑	

Source: [a]Adapted from WHO 2021, [b]Queensland Health (2023), [c]Sprague (2022).

Notes to table: ☑ Favourable condition ✓ possibly favourable condition.

4.3.2. Influence of climate change on microbial hazards

Natural water environments, including recreational water bodies and sand/sediments, are expected to undergo major changes as a result of climate change resulting in increasing water temperature, sea level, precipitation and waves (Brandão et al. 2022). Table 4.2 shows that several microbial hazards prefer warm temperatures. The prevalence of these microbial hazards and the infections they cause may increase under conditions of global warming. For example, increasing sea surface temperatures (>18°C) is likely to increase proliferation of vibrios (Schets et al. 2011). *N. fowleri* also prefers warm water environments. Climate change also increases favourable conditions for *B. pseudomallei* (Birnie et al. 2022).

Leptospirosis may also increase under conditions of climate change, because the survival of leptospires outside the host depends on humid and warm conditions. Increased rainfall and temperatures, along with a likely increase in recreational water activity, may affect the incidence of this disease (Brockmann et al. 2010; Hartskeerl et al. 2011; Effler 2020). Extreme weather events, such as flooding, also contribute to higher host interactions (Monahan et al. 2009).

Schistosomes are sensitive to changes in temperature as cercarial production and emission rates are both temperature dependent (Soldánová et al. 2013). Climate change may also allow an extension of the seasonal window for parasite transmission (Horák et al. 2015) and change host distribution by modifying waterfowl migration pathways (Gordy et al. 2018).

4.4. Risk management

In most cases for the microbial hazards outlined in this chapter, the initial risk assessment and any associated monitoring program should be based on an understanding of the recreational water catchment, seasonal and annual variability of potential risk factors and indictors relevant for the specific microbial hazard (refer to Table 4.2).

Authorities should be aware of the potential hazards posed and act using a risk-based approach. If the risk assessment, based on assessing environmental factors, identifies that the local environment supports a specific microbial hazard, the emphasis should be on managing the risk of exposure.

Relying on environmental testing of specific microbial hazards may underestimate the risk. This is because the location and number of microbial hazards can vary over time within the same body of water and therefore a negative result does not necessarily mean the water is free of the specific microbial hazard. In most cases, the sample volume and number of samples required to be representative of a recreational water body would be impractical.

If the prevalence of a microbial hazard is strongly dependent on environmental factors, site specific indicator values for these environmental factors can be developed to trigger intervention (e.g. water temperature as a warning sign for vibrios) (Semenza et al. 2017).

Box 4.3 provides an example of indicators to assess the potential increased risk for *N. fowleri*.

Box 4.3 Indicators of increased risk of *N. fowleri*

The initial risk assessment of *N. fowleri* should be based on an understanding of the recreational water environment and whether it is able to support thermophilic *N. fowleri*. This includes understanding the potential abiotic and biotic factors, including synergistic effects, affecting the distribution and abundance of *N. fowleri.* Although the impacts of some abiotic factors remain poorly investigated or inconclusive, *N. fowleri* appears to have a wide pH range, low salinity tolerance and thermophilic preference, and preferentially feeds upon bacteria (Stahl and Olson 2021).

Potential considerations and factors indicating increased risk of *N. fowleri* include:

- temperature: This includes the temperature profile of the water body throughout the year and presence of hot springs or artificially heated habitats such as geothermal hot springs. Given the range of reported water temperatures associated with *N. fowleri* cases (section 4.2.6), it is difficult to specify a definitive trigger for temperature. However, water bodies that seasonally exceed 30°C or that continually exceed 25°C support the growth of *N. fowleri* (NHMRC 2011). The risk of exposure to *N. fowleri* can be considered greater for these water bodies requiring an increased emphasis on risk minimisation (section 4.4.5).
- presence of thermal pollution sources: Even if ambient water temperatures are lower, a source of heated water (such as discharge of cooling waters from a power station, or inflow from a geothermally heated stream) could present a risk to water users under certain conditions.

- salinity: Higher salt concentrations negatively impact the viability and growth of *N. fowleri* (Arberas-Jiménez et al. 2024; Lam et al. 2019).

Climate change may be a contributing factor. As air temperatures rise, water temperatures in lakes, ponds, and other freshwater also rise. These conditions provide a more favourable environment for *N .fowleri* to grow (US CDC 2025).

4.4.1. Site management

4.4.1.1. Animal control

Where animal carriers play a role in disease transmission (Table 4.2), the recreational water site should be managed, as far as possible, to control these animals. In the case of leptospirosis, for example, providing adequate litter control and other measures to minimise the rodent population can be effective (Mohan 2006).

4.4.1.2. Advisories

Where a water site has been linked to infection or has conditions that are suitable for microbial hazards, this information should be made available to water users to allow them to make an informed decision. If an increase in pathogen concentrations or disease incidence is linked to certain environmental conditions (e.g. water temperature, sediments/mud, precipitation, time of day), advisories should be issued accordingly. Signage can be posted onsite or made available online. Advisories should also include advice on appropriate water user behaviour and specific risks for vulnerable groups, particularly immunocompromised people.

4.4.2. Operational monitoring of environmental factors

Relying on direct routine monitoring of recreational water bodies for microbial hazards to ensure safety is not recommended as this may underestimate the risk; it is more important to consider the environmental conditions that support their growth and abundance. For example, *N. fowleri* concentrations can change relatively quickly due to amoeba population growth, and the concentration may vary spatially within the water body.

Since many of these microbial hazards are endemic or persistent in water environments and not related to faecal pollution, monitoring of faecal indicator organisms cannot predict their occurrence.

For microbial hazards whose prevalence is strongly dependent on environmental conditions, indirect operational monitoring of environmental conditions and water quality (e.g. temperature, turbidity) should be considered within the risk management plan. Operational monitoring during periods when microbial hazard concentrations may be higher than normal may help to mitigate potential risks. An understanding of the recreational water catchment and how it might be subject to change can, potentially, act as an early warning system. Pertinent questions include:

- Are water temperatures increasing which might allow the proliferation of microbial hazards (e.g. vibrios and *N. fowleri*)?
- Are waterbirds encroaching on a water site?
- Has there been heavy rainfall, which might increase the risk of microbial hazards (e.g. leptospirosis or *B. pseudomallei)*?

Given that climate change is impacting surface water environments, periodic reassessment of the temperature profile should be undertaken.

Under particular circumstances, such as the organisation of a water sports event, it may be useful to take environmental samples (e.g. mud or water samples) before and after the event to assist in identifying pathogens in the event of an infection (DeNizio and Hewitt 2019).

4.4.3. Targeted microbial monitoring

Targeted screening for easily detectable microbial hazards can be useful for investigative and research purposes (Kirschner et al. 2008; Strathmann et al. 2016; Rudko et al. 2018). Detection techniques are available for most microbial hazards including culture methods, polymerase chain reaction (for quantitative determination) and phylogenetic analysis. For species-level identification in the case of schistosomes, see Horák et al. (2015). Molecular methods provide fast screening tools for most of the organisms described in this chapter.

Identifying free-living organisms can be challenging and may require specialised knowledge and equipment. In many cases, it may be necessary to consult with a specialist or send samples to a laboratory for identification.

4.4.4. Illness surveillance

Disease surveillance at a national level allows information on symptoms, severity, pre-existing conditions and the source of infection to be examined. Where potentially fatal infections (e.g. *Naegleria* infection, severe leptospirosis) are suspected to be linked to a specific water site, this information should be conveyed to local authorities and site managers.

Although many of the infections outlined in this chapter are currently considered rare, this may be partly due to underdiagnosis, misdiagnosis and lack of reporting (Heggie 2010; ECDC 2018; Gordy et al. 2018). Responsible authorities, including health departments, should periodically consider whether any new pathogens or diseases should be included on the National Notifiable Disease Surveillance System to improve reporting.

4.4.5. Awareness and personal preventive measures

Raising the awareness of recreational water users, at-risk groups and medical professionals means that people can take personal preventive measures. Where these fail, medical help can be sought, and the infection can be recognised as quickly as possible.

4.4.5.1. Recreational water users

Similarly to managing risks from microbial risks from faecal sources (see *Chapter 3 – Microbial pathogens from faecal sources*), recreational water users can be made aware of the risks of swimming after rainfall events, when turbidity and surface run-off is the highest.

Users of recreational water can also take several precautions against infections (especially wound infections). Existing skin lesions should be covered with waterproof dressings before the person enters the water. If an injury is sustained while in the water or at the recreational water site, the wound should be washed thoroughly with soap and water. It is good practice to remove wet swimwear, shower and towel dry after water exposure (Gordy et al. 2018; Graciaa et al. 2018). For example, vibrios can be present on the skin after water contact, and washing with soap is efficient in removing them (Shaw et al. 2015). Similar measures should be taken in the event of exposure to mud and sediments around a water body, and care should also be taken when entering and leaving a water site to minimise contact with these potential sources of exposure.

Showering and towelling are also advised to prevent swimmer's itch, although the impact might be limited, as cercariae/larvae can enter the skin within minutes. Avoiding high-risk areas (shallow water with dense vegetation) and high-risk periods (early morning, when cercaria densities are the highest) has been reported to reduce exposure (Rudko et al. 2018).

Recreational water users are encouraged to remove contact lenses prior to participating in water-based recreation to avoid microorganisms that may infect the eyes.

Recreational water users should familiarise themselves with the possible risks and symptoms of infection. If symptoms develop after recreational water exposure, medical help should be sought as quickly as possible and the water contact explained to the medical provider—that is, location of the water site, type of water (fresh or marine) and details of any incident.

Adventure travellers should be aware of the specific pathogens that occur in the area. For water sports, protective clothing is advisable where the risk of infection is high. Chemoprophylaxis against leptospirosis has been suggested for participants in water sports events or adventure travellers in endemic areas (Sejvar et al. 2003).

People should assume that any warm freshwater lake, river and hot spring could contain *N. fowleri*. The only known pathway of infection from *N. fowleri* is across the olfactory mucosa. If water that contains *N. fowleri* can be prevented from entering the nose (e.g. behaviour modification, nose clips), the risk of infection is mitigated. To minimise the risk of *N. fowleri* infection from the use of freshwater sites such as hot springs and other warm waters, there are a wide range of behavioral precautions that recreational water users can take. Practices for reducing the risk from *N. fowleri* in warm freshwater include:

- avoiding water-related activities, especially jumping and diving or water sports involving a high degree of water contact such as waterskiing
- avoiding putting the head under water, especially in hot springs and other geothermal waters
- using nose clips or holding the nose closed while taking part in water-related activities
- avoiding digging in, or stirring up, the sediment while taking part in water-related activities

- avoiding using the water for any form of nasal irrigation or nasal lavage.

4.4.5.2. At-risk groups

Many of the infections listed in this chapter (notably leptospirosis and wound infections) are associated with pre-existing wounds or skin lesions. People with wounds should avoid water contact or take appropriate care to cover skin lesions.

For some of these infections, most notably *V. vulnificus* wound infections, but to some extent all vibriosis, people with underlying medical conditions (especially hepatic disease or other chronic illness) are at an increased risk of severe illness and death. Such at-risk groups should limit their exposure to brackish water or seawater (CDC 2017). In general, immunocompromised people are at higher risk of contracting infection from opportunistic pathogens.

Travellers should be aware of diseases endemic to an area and seek medical advice, especially if they plan to engage in recreational water activities (Bourque and Vinetz 2018).

4.4.5.3. Advice to medical professionals

Delays in diagnosis can seriously impact health outcomes for infected individuals. Medical professionals such as general practitioners or emergency department doctors will often be the first to be informed of any symptoms. As well as being aware of any local cases or outbreaks, establishing the patient's history of recreational water contact, especially for wound infections, acute febrile illness and suspected meningitis, may allow more rapid and accurate diagnosis of infections (Perkins and Trimmier 2017). Practitioners should pay attention to risk behaviours such as travel to endemic areas, adventure travel and extreme water sports (Bourque and Vinetz 2018; Mavridou et al. 2018).

4.5. Research and development

Epidemiological evidence on the dose–response relationship for infections caused by the microorganisms discussed in this chapter is scarce. More data are needed to better understand risks to the health of recreational water users.

A crucial problem in controlling for these other microbial hazards is the lack of quantitative data to inform decisions. In the absence of guideline values, research is needed on monitoring and management approaches for detection of these species (or sentinel species), as well as proxies such as the geographic range of the host species and conditions that favour proliferation. Research to link catchment characteristics (including surrounding land use) and health outcomes is also needed to assist with decision making.

In addition, for most pathogens, available research is from temperate climates (with the exception of leptospirosis). More data are needed on the prevalence of these hazardous microorganisms and their associated infections in subtropical and tropical areas. As surface water temperatures increase with climate change, it is likely that these organisms will pose a greater threat to human health, suggesting that identifying the abiotic and biotic factors which are associated with their presence is crucial for surveillance and management.

Follow-up studies on the efficiency of various management practices, including communication campaigns to reduce infections, should be developed.

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5. Harmful algal and cyanobacterial blooms in freshwater and marine waters

Guideline recommendation

Effective management oversight and public communication should be adopted to minimise exposure to harmful algal and cyanobacterial blooms in recreational water environments to reduce risks to public health.

Consistent with a preventive risk management approach, a situation assessment and alert level framework should be implemented to facilitate a proactive and staged response to the presence and development of harmful algal and cyanobacterial blooms.

As part of determining appropriate actions using an alert level framework, recreational water bodies should not contain:

- ≥ 20 µg/L of anatoxins
- ≥ 6 µg/L of cylindrospermopsins
- ≥ 8 µg/L of microcystin-LR* or other microcystins and nodularin toxins
- ≥30 µg/L of saxitoxins
- biovolume equivalent of ≥ 3 mm^3/L for the combined total of all cyanobacteria
- chlorophyll *a* of ≥ 8 µg/L (with a dominance of cyanobacteria)
- cyanobacterial or algal scum** or visible presence of cyanobacteria or algae with visibility <1 metre
- *Moorea producens* (formerly *Lyngbya majuscula*) and *Microcoleus* (formally *Phormidium*) in high abundance.

*This guideline value represents the sum value of all microcystins and nodularin toxins present. A toxicity equivalence factor of one should be used for all microcystin and nodularin congeners.

**Algal scum: dense accumulation of cyanobacterial or algal cells at or near the surface of the water forming a layer of distinct discolouration (green, blue, brown or red).

5.1. Overview

This chapter describes the health effects of human exposure to harmful algal and cyanobacterial blooms through possible ingestion of water, dermal contact and inhalation, and the assessment and management of risks associated with these harmful blooms. It is known that some algal and cyanobacterial blooms produce toxins responsible for shellfish poisoning from eating contaminated shellfish; however, these Guidelines do not address dietary exposure to these toxins.

Harmful algal and cyanobacterial blooms are the rapid proliferation of algae and cyanobacteria in water that can produce toxins harmful to people, animals and the environment. They can adversely affect water quality through scum formation, discolouration, odour production and oxygen depletion.

Algae and cyanobacteria are both groups of planktonic microscopic organisms that are ubiquitous in aquatic ecosystems. Cyanobacteria are a type of photosynthetic bacteria that exhibit algae-like characteristics—like bacteria, their cells have no nucleus and like all algae, they contain a green pigment (chlorophyll *a*). Algae, sometimes termed 'microalgae', include species of diatoms and dinoflagellates. A subset of these organisms can produce potent toxins and therefore have the potential to become harmful when they accumulate in high concentrations to form blooms.

Although the species associated with harmful blooms in fresh and marine waters are usually different, they can overlap in estuarine settings. Blooms in freshwater and brackish water bodies are frequently caused by cyanobacteria. Blooms in estuarine and marine water environments can be caused by a range of algal species, including dinoflagellates and diatoms, as well as some marine species of cyanobacteria.

In both fresh and marine water environments, harmful blooms growing on sediments and surfaces are cyanobacteria—in freshwater they grow either directly as mats on the sediment, rocks, or on the surface of submerged aquatic plants. In marine subtropical and tropical coastal areas, large filaments of cyanobacteria grow in mats or clumps on the sediment.

The most commonly occurring harmful algal and cyanobacterial blooms in Australia are (Hallegraeff et al. 2021):

- Freshwater: *Umezakia* (formerly *Chrysosporum* spp)., *Dolichospermum* spp., *Microcystis* spp., and *Raphidiopsis* spp.
- Estuarine: *Nodularia spumigena*
- Marine: *Moorea producens*, *Trichodesmium* spp., *Gymnodinium*, *Karenia* spp., *Heterosigma*, *Alexandrium*, *Chatonella*, *Pseudo-nitzschia*.

The formation of harmful algal and cyanobacterial blooms is a natural phenomenon caused by various environmental conditions. However, over recent decades their frequency, intensity and geographic distribution appear to have increased in inland water bodies and the ocean (Chorus and Welker 2021; Glibert et al. 2018). Factors that underlie this increase include increasing pollution of rivers and oceans, particularly nutrient enrichment (eutrophication) and water temperature increases including sea surface warming associated with climate change (Flynn et al. 2018; Glibert et al. 2018; NRC 2000).

The content of this chapter has in parts been adapted from the World Health Organization (WHO) *Guidelines on recreational water quality. Volume 1: coastal and fresh waters* (WHO 2021) and has been informed by a review of the evidence base in the Australian context (Burch 2021). The World Health Organization (WHO) guidebook *Toxic cyanobacteria in Water (TCiW)* (Chorus and Welker 2021) provides a comprehensive overview of the information and expertise needed to assess the risk of cyanotoxin occurrence and provides further context for guideline recommendations.

5.2. Health effects of harmful algal and cyanobacterial blooms

Harmful algal and cyanobacterial blooms are a public health concern as they can produce harmful toxins but may also cause adverse effects unrelated to the toxins themselves such as discoloured water and unpleasant odours. Harmful algal and cyanobacterial blooms can result in widespread mortality of fish and other aquatic organisms directly through exposure to toxins or indirectly through the depletion of oxygen in water.

Depending on the level of exposure and the type of algal or cyanobacterial toxin, human health consequences may range from mild to severe to, in extreme cases, fatal. Recreational exposure may be to whole algal or cyanobacterial cells, lysates, dried cells or mixtures of these forms.

Exposure to harmful algal or cyanobacterial blooms during recreational water use may arise through:

- ingestion of water that contains cells and toxins either incidentally from reflex swallowing especially by children, or swallowing of water during recreational accidents
- aspiration of water that contains cells and toxins—water entering the nasopharynx and subsequently being swallowed
- inhalation—breathing in aerosolised toxins such as when spray is formed (e.g. through wave action, waterfalls, fountains, aerators), and droplets contain cells (e.g. during waterskiing or jet skiing) or when dried scums present on the beach are raised as dust
- direct body contact (dermal and mucous membrane) with scum, dislodged material from benthic mats or vegetation with attached algae or cyanobacteria floating in swimming areas or accumulated on beaches.

Although there are several routes of exposure, the most likely route of exposure to toxins from harmful algal blooms is expected to be through incidental water ingestion during recreational activities. Exposure through inhalation of aerosolised cyanobacteria may also be significant in conditions where sprays and aerosols are present (Facciponte et al. 2018; Graham 2023; Lim et al. 2023).

5.2.1. Harmful effects of cyanobacterial toxins in freshwater and brackish water

Cyanobacteria are persistent prokaryotic organisms that occur naturally (Pilotto et al. 1997) and can cause cyanobacterial blooms. They have many characteristics of bacteria and some of algae. Like bacteria, their cells have no nucleus. Like algae, they contain a green pigment (chlorophyll *a*) with which they can perform photosynthesis and as such their growth is favoured by warm water, adequate sunlight, and calm stable weather conditions (Pilotto et al. 1997). Unlike other algae, cyanobacteria also contain blue pigment (phycocyanin), which is mostly visible when cells in scums die and lyse, releasing the pigment into the water. Intact cells and blooms of cyanobacteria usually look green, but some species look greenish bluish; this has led to the popular term blue-green algae. Others appear olive coloured, reddish, purple, brown or bright green.

Cyanobacterial blooms can produce intracellular cyanotoxins. They can also potentially produce cell-surface endotoxins, although this is not well understood and more research is needed.

Most cyanobacteria in water are not toxic most of the time. However, there is no simple way to determine whether the cyanobacteria present contain the specific genes that support toxin production, or whether those genes are active. Toxic and nontoxic strains can be distinguished using molecular testing such as tests for the presence of toxin producing genes. However, the presence of toxins can only be determined using chemical analyses, which should be regarded as the gold standard for risk assessment when making decisions that may have social or economic impacts (e.g. closure of a water site).

There are several known intracellular cyanotoxins:

- anatoxins are alkaloids that target the nervous system (neurotoxins)
- cylindrospermopsins are alkaloids that affect the liver and a wide range of other organs especially the kidneys (hepatotoxin, cytotoxic)
- microcystins and nodularins are cyclic peptides that affect the liver (hepatotoxins)
- saxitoxins are alkaloids that target nerve and muscle cells (neurotoxins).

Table 5.1 provides an overview of currently known cyanotoxin groups, the frequently occurring genera in freshwater and brackish water bodies that produce them, their associated mechanisms of toxicity and reported health effects in humans and other animals (adapted from WHO 2021).

The uptake of cyanobacteria involves a risk of intoxication by the cyanotoxins listed in Table 5.1. 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.

Human fatalities are known only from exposure to microcystins in drinking water (with possible cylindrospermopsin co-exposure) via haemodialysis (Jochimsen et al. 1998). Severe heptatoenteritis has been linked to *Raphidiopsis raciborskii* (formerly *Cylindrospermopsis*) via exposure to drinking water (Byth 1980).

A small number of severe health effects have been plausibly attributed to recreational exposure that can be linked to microcystin exposure (Giannuzzi et al. 2011; Vidal et al. 2017). Vidal et al. (2017) reported a case of recreational exposure to cyanobacteria and cyanotoxins, suffered by a family (three adults and a 20-month-old child). The adults had only self-limiting gastrointestinal symptoms while the child had more severe gastrointestinal condition resulting in acute liver failure requiring liver transplant. Histological studies and microcystin determination confirmed the presence of microcystin toxins in the liver. During the exposure period blooms of mainly *Microcystis* were observed and microcystins were detected in the water.

In other cases, severe symptoms such as abdominal pain, headache, sore throat, vomiting and nausea, dry cough, diarrhoea, blistering or numbness around the mouth, and pneumonia have been reported following exposure to cyanobacterial blooms. These are not the symptoms expected from the currently known cyanotoxins listed in Table 5.1, and other causative agents, possibly associated with the bloom, cannot be excluded.

Allergic reactions to cyanobacteria are reported anecdotally from eutrophic bathing waters but are rarely investigated in scientific studies or published in peer-reviewed journals (Stewart et al. 2006). The results of clinical investigations relating to cutaneous and respiratory reactivity to cyanobacteria confirm that certain freshwater cyanobacteria can elicit hypersensitivity reactions in some individuals (TCiW, Chorus and Testai 2021). Chorus and Testai (2021) reviewed epidemiological studies conducted between 1990 and 2011. This included Australian studies by Pilotto et al. (1997) and Stewart et al. (2006) that investigated acute illness including cutaneous and systemic reactions following recreational exposure to freshwater cyanobacteria. Chorus and Testai (2021) concluded that the levels of exposure were usually poorly characterised, and that these studies are inadequate for risk assessment purposes. If individuals experience allergic skin reactions after swimming in the presence of blooms they should avoid further contact with them.

A compound that has generated interest and concern is β-methylamino-L-alanine (BMAA). BMAA is reported to be found in some cyanobacteria and it has been suggested as a causal factor for neurological diseases. The significance of understanding the importance of BMAA has been difficult due to challenges in accurately measuring BMAA and other considerations under active research (Chernoff et al. 2017; Dunlop et al. 2021). The link between BMAA and neurodegenerative disease is not supported by WHO (2021) based on a comprehensive review by Chernoff et al. (2021) which contended that there is a lack of clear evidence for the “BMAA-neurodegenerative disease hypothesis at the present time” (Chorus and Welker 2021). This review points out that several inconsistencies must be clarified before the role of BMAA in human disease can be assessed with more certainty.

Dislodged benthic mats of cyanobacteria or underwater vegetation with epiphytic toxic cyanobacteria may contain high levels of cyanotoxins, and the death of pet dogs that have ingested such material has triggered concern in communities. There is a large body of evidence confirming the relationship between dog deaths and exposure to both freshwater benthic and planktonic cyanobacteria. *Nodularia spumigena*, the first cyanobacterium recognised to cause animal deaths (Francis 1878) can be a problem in both freshwater and estuarine environments. Ingestion of toxic *N. spumigena* has been the documented cause of multiple dog deaths. There have also been multiple dog deaths linked to the ingestion of benthic mats of the cyanobacterium *Microcoleus* (formerly *Phormidium)* which produces anatoxins (potent neurotoxins) causing rapid and severe poisoning, leading to symptoms such as muscle paralysis and respiratory failure in dogs (Puddick et al. 2017; Wood et al. 2017).

These multiple dog deaths trigger concern about the risks posed to recreational water users. Adults are highly unlikely to ingest such material although infants may be more inclined to put such material in their mouths. Careful management is required at these water sites to ensure recreational water users avoid direct contact and keep some distance from such material, and that young children are supervised (TCiW, Chorus and Testai 2021).

Table 5.1 - Cyanotoxins in freshwater and brackish water relevant to human health worldwide[a]

Toxin and type of chemical	Genera[b] that commonly produce the toxins (note not all present in Australia)	Mechanism of toxicity[a]	Acute health effects and comments[c]
Anatoxin-a and its analogues (ATXs) Amine alkaloid	*Anabaena, Aphanizomenon, Chrysosporum, Cuspidothrix, Dolichospermum, Lyngbya, Microcoleus, Moorea, Oscillatoria, Phormidium, Planktothrix, Raphidiopsis* (formerly *Cylindrospermopsis*), *Tychonema*	Neurotoxic, pre- and post-synaptic depolarisation	Tingling, burning, numbness, drowsiness, incoherent speech, salivation, respiratory paralysis leading to death (experimental animals). Scum ingestion has caused numerous deaths of dogs, livestock and waterfowl; animal deaths can also be due to ingestion of detached lumps of benthic cyanobacteria or submerged vegetation with attached cyanobacteria beached on shorelines.
Anatoxin-a(S) (ATX(S)) (guanitoxin) Organophosphate	*Anabaena, Dolichospermum*	Neurotoxic; inhibits acetylcholinesterase	Occurrence sparsely documented. Anatoxin-a(S) (ATX(S)) is, despite the similarity of the names, not structurally related to anatoxin-a. The “S” in the name denotes a characteristic symptom of exposure in mammals: “salivation”. Recently, also named guanitoxin (Fiore et al. 2020).
Cylindrospermopsins (CYNs) Alkaloids with tricyclic guanidino moiety and uracyl	*Anabaena, Aphanizomenon, Chrysosporum, Dolichospermum, Oscillatoria, Raphidiopsis* (formerly *Cylindrospermopsis*), *Umezakia*	Cytotoxic; act predominantly on the liver, kidneys, erythrocytes	Fever, headache vomiting, bloody diarrhoea following exposure via drinking water. More frequent in northern regions of Australia. Concentrations of dissolved CYN are often as high as, or higher than, those of cell-bound CYNs and can persist for weeks even after the producing organism is no longer present .

Toxin and type of chemical	Genera[b] that commonly produce the toxins (note not all present in Australia)	Mechanism of toxicity[a]	Acute health effects and comments[c]
Microcystins (MCs) Cyclic heptapeptides with specific amino acid Many congeners (>250). A small number occur commonly	*Anabaena, Dolichospermum, Microcystis, Nostoc, Planktothrix*	Inhibit protein phosphatases Hepatotoxic; act predominantly on the liver	The cyanotoxins most frequently found at hazardous concentrations. Numerous animal deaths. Occur largely cell bound, accumulating in scums; concentrations dissolved in water are usually low. Occur widely in freshwater and sometimes in brackish areas.
Nodularins (NODs) Cyclic heptapeptides with specific amino acid	*Nodularia, Nostoc*	Inhibit protein phosphatases Hepatotoxic; act predominantly on the liver	Reports of fatal dog poisonings. Like MCs but occur predominantly in brackish water (*Nodularia occurs* extensively in the Baltic Sea although first described as toxic in Lake Alexandrina, South Australia). Frequent occurrence in Gippsland Lakes and along the Ninety Mile Beach in Victoria.
Saxitoxins (STXs) Also termed paralytic shellfish toxins, known from toxic marine algae accumulated in shellfish Alkaloids Many analogues	*Anabaena, Aphanizomenon, Chrysosporum, Cuspidothrix, Dolichospermum, Lyngbya, Microcoleus, Oxynema* (formerly *Phormidium*), *Planktothrix, Raphidiopsis* (formerly *Cylindrospermopsis*), *Scytonema*	Neurotoxic; block Na^{+} channels in neuronal cells, and Ca^{2+} and K^{+} channels in cardiac cells	Paralytic shellfish poisoning. Animal deaths have been attributed to STX in planktonic freshwater cyanobacteria. Known from paralytic shellfish poisoning but also produced by some freshwater cyanobacteria. Freshwater mussels and crustaceans can contain STXs.

[a] Source: WHO (2020).

[b] Many genera were recently reorganised and are still undergoing reorganisation; new names rarely correspond fully with old names.

[c] Dietary exposure to toxins is outside the scope of these recreational Guidelines. These Guidelines are concerned with exposure through possible ingestion of recreational water bodies, dermal contact, and inhalation of sea-spray aerosols.

5.2.2. Harmful effects of cyanobacterial and algal toxins in marine water

Marine harmful algal and cyanobacterial blooms may become a problem if human exposure occurs. For example, toxins can bioaccumulate in shellfish and occasionally in fish that are subsequently eaten by humans. Many of the toxins are named by the syndromes they cause, such as paralytic shellfish poisoning, diarrhetic shellfish poisoning, amnesic shellfish poisoning, neurotoxic shellfish poisoning and ciguatera fish poisoning. These Guidelines, however, do not address dietary exposure to toxins.

These Guidelines are concerned with exposure through possible ingestion of marine water, dermal contact and inhalation of sea-spray aerosols. Dermatotoxins and other irritant toxins are more common in marine waters than in freshwaters; however, dermal and other irritant effects in humans resulting from these exposures have had limited scientific investigations. Several health effects relating to dermal and respiratory irrigations have been reported in association with many toxic species of dinoflagellates, diatoms, nanoflagellates and cyanobacteria in the marine waters. Organisms and genera that commonly produce toxins of concern are discussed below and summarised in Table 5.2. With the exception of saxitoxin, there is insufficient data to develop guideline levels for human health.

5.2.2.1. *Karenia mikimotoi*

Karenia mikimotoi (*K. mikimotoi*) is a marine dinoflagellate species from the genus *Karenia*.

Blooms of *K. mikimotoi* have been observed in marine waters across the world, being first recorded in the 1930s. They have caused mass mortalities of fish, shellfish, and other invertebrates in the coastal waters of many countries.

The direct effects of *K. mikimotoi* blooms on human health have rarely been reported (Li et al. 2019). *K. mikimotoi* does not produce a toxin that is harmful to humans and does not cause long term harmful effects (SA Health 2025). *K. mikimotoi* is susceptible to damage by wave action releasing algal particles. Human exposure to these particles in surf spray and other aerosols can cause eye irritation and respiratory symptoms such as coughing and shortness of breath. Skin irritation has been reported by people swimming in water containing the algae, while ingestion could cause stomach upsets or flu-like symptoms (EPA SA 2025; SA Health 2025).

However, *K. mikimotoi* is toxic to marine life. Although this species is haemolytic and cytotoxic, and generates reactive oxygen species, none of the isolated toxins or lipophilic extracts have toxic effects as extreme as those of the intact algal cells (Li et al. 2019). *K. mikimotoi* has been reported to damage the gills and gill structures of marine life, resulting in substantial mortalities (Li et al. 2019; EPA SA 2025).

Box 5.1 describes the significant marine algal bloom of in the coastal waters of South Australia in 2025 in which *Karenia* spp. were present and resulted in widespread mortalities of marine life.

Box 5.1 South Australia *Karenia spp.* harmful algal bloom

In March 2025, a significant bloom was detected off the Fleurieu Peninsula in South Australia, with signs including discoloured water, thick sea foam and dead marine life washing up on shore. The bloom expanded throughout South Australia to Yorke Peninsula, Kangaroo Island, Gulf St Vincent, and parts of the Spencer Gulf, and persisted through winter.

Satellite measurements of chlorophyll *a* levels showed that the bloom covered an estimated 4,500 square kilometres, caused mass mortalities of fish and invertebrate marine species and disrupted marine industries. Early water testing initially identified *Karenia mikimotoi* as the dominant species, which was then shown to change over time and with location. The presence of brevotoxins was also detected for the first time in Australian waters, providing evidence that other *Karenia* species were most likely present. Recent reports indicate that *K. cristata* as the species producing the brevetoxins (Murray et al. 2025 *under peer review*).

The harmful algal bloom was believed to be influenced by environmental conditions, including marine heatwaves under drought conditions and relatively calm weather conditions, although it was highlighted that further research was needed to better understand drivers. Nutrients from the Murray River Floods in the summer of 2022/2023 and a sustained upwelling event in the summer of 2023/2024 were also thought to be contributing factors.

Surfers, beachgoers and coastal residents reported illnesses ranging from skin and eye irritation and respiratory symptoms such as coughing and shortness of breath. Public health advice was issued to avoid affected waters and foams generated by the bloom and seek care if symptomatic. Testing of commercially harvested oysters, mussels, cockles and scallops was undertaken with some harvesting areas temporally closed as a precaution to uphold food safety standards.

Source: SARDI (2025); Murray et al. (2025) (*under peer review*).

5.2.2.2. *Moorea producens* (previously *Lyngbya majuscula*)

Moorea producens is a toxic marine cyanobacterium found mainly in tropical waters. Their former genus *Lyngbya* has now been reorganised, with species now belonging to the genera *Moorea* and *Okeania.* Further research is needed in Australia to confirm the species present.

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 been reported in Moreton Bay near Brisbane in Queensland (Dennison et al. 1999; Osborne et al. 2007).

Moorea producens has been shown to produce more than 70 biologically active compounds, many of which have been shown to be toxic including 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 *M. producens* was present in the water
- driving on the beach covered by *M. producens* on Fraser Island, Australia
- cleaning fishing nets and crab pots in Moreton Bay, Australia and in Hawaii.

Severe blistering may also result if *M. producens* is trapped under the clothing (particularly wetsuits) of swimmers.

In Queensland's coastal environment, *M. producens* growing attached to seagrass, seaweed, and rocks in clumps or mats of fine, dark cotton wool like strands 10 to 30 cm long have been identified. Mats of *M. producens* 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 (e.g. itchy or painful rash), people should avoid areas affected by *M. producens* if possible. People should also avoid direct contact with material washed up onto the beach. This includes swimming or wading in areas where *M. producens* is growing or floating in the water. Where *M. producens* has washed onto beaches it should be cleared as soon as possible by local councils. In these circumstances it is important to take precautions to minimise contact with *M. producens* during collection, transit and disposal operations. People with any of the symptoms listed above who have been in an area affected by *M. producens* should consult a doctor.

5.2.2.3. *Ostreopsis*

Ostreopsis, a genus of benthic dinoflagellates, are known for producing palytoxin and related compounds. *Ostreopsis* spp. are increasing their biogeographic distribution from tropical to more temperate waters and causing recurrent blooms in certain coastal areas (Pavaux et al. 2020). Some reports have noticed the expansion of Ostreopsis spp. in coastal waters of Australia including from north Queensland to Tasmania (Verma et al. 2016; Pavaux et al. 2020).

Blooms of the dinoflagellate *Ostreopsis* spp. have been accompanied by reports of respiratory and skin irritation in people exposed to sea spray (Tichadou et al. 2010; Vila et al. 2016; Medina-Pérez et al. 2021). Although most symptoms were mild, a respiratory syndrome including fever, sore throat, cough and shortness of breath has been seen in people who spent time at or near beaches during *Ostreopsis ovata* bloom events.

5.2.2.4. *Trichodesmium*

Trichodesmium, filamentous marine cyanobacteria, are found worldwide in surface waters of tropical and subtropical oceans, but are particularly abundant around Australia. *Trichodesmium* are well known to form blooms around the tropical Australian coast from Western Australia to Queensland, but have been found nearly everywhere around Australia (Blondeau-Patissier et al. 2018; Davies et al. 2020; Qi et al. 2023).

Trichodesmium is known for forming buoyant colonies on the ocean surface due to its abundant gas vesicles, which give it a yellowish or brownish appearance and the common names 'sea sawdust' or 'red tide'. Whilst blooms are typically a rusty-brown colour, some variations in colour may occur with grey, green and purple streaks being observed. The blooms of *Trichodesmium* can be mistaken for oil slicks or foamy pollution, especially when washed up on beaches. Where *Trichodesmium* becomes stagnant, a toxin may be released. This release is indicated by a change in colour of the *Trichodesmium* filaments from a rusty brown colour to a green hue accompanied by the release of a pigment which will colour the water pink.

Many types of toxins are reported to be produced by *Trichodesmium* spp. (e.g. Gupta et al. 2014; Pelin et al. 2016; Shunmugam et al. 2017). Some strains of *Trichodesmium* 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 have potential to cause irritation, it is advisable that 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.

Table 5.2 - Marine cyanobacterial and algal toxins relevant to human health

Toxin	Organism and genera that commonly produce the toxin	Mechanism of toxicity[a]	Health effects and comments
Aplysiatoxin, Debromoaplysiatoxin	Benthic cyanobacteria: *Lyngbya, Phormidium/Schizothrix*	Irritant and tumour promotor via activation of protein kinase C	Swimmer's itch or seaweed dermatitis.
Azaspiracid[a]	Dinoflagellate: *Protoperidinium*	Inhibits hERG voltage-gated potassium channels	Azaspiracid shellfish poisoning, known from eating contaminated seafood.
Brevetoxins	Dinoflagellate: *Karenia*	Activate voltage-gated sodium channels in nerve cells	Respiratory irritation from inhaling contaminated aerosols. Neurotoxic shellfish poisoning known from eating contaminated shellfish.
Ciguatoxins[a]	Epibenthic dinoflagellate: *Gambierdiscus*	Promote opening of excitatory sodium channels in the nervous system including the brain	Ciguatera fish poisoning known from eating contaminated finfish.
Domoic acid[a]	Diatom: *Pseudo-nitzschia*	Activation of glutamate receptors in the brain	Amnesic shellfish poisoning (ASP) known from eating contaminated shellfish.
Lyngbyatoxin-a	Benthic cyanobacteria: *Lyngbya* (Cardellina et al. 1979)	Irritant and tumour promotor via activation of protein kinase C	Swimmer's itch or seaweed dermatitis, eye irritation.

Toxin	Organism and genera that commonly produce the toxin	Mechanism of toxicity[a]	Health effects and comments
Nodularins	*Nodularia, Nostoc*	Inhibit regulatory protein phosphatases involved in controlling a range of cellular processes	Reports of fatal dog poisonings; refer to Table 5.1.
Oakadaic acid, dinophysistoxin[a]	Dinoflagellate*: Dinophysis, Prorocentrum*	Inhibit regulatory protein phosphatases involved in controlling a range of cellular processes	Diarrheic shellfish poisoning (DSP) known from eating contaminated shellfish.
Palytoxins	Benthic dinoflagellate *Ostreopsis*	Potent vasoconstrictor via opening of the sodium-potassium pump protein	Respiratory and skin irritation from exposure to aerosols, particularly when handling aquarium corals.
Saxitoxins[a]	Dinoflagellate: *Alexandrium, Gymnodinium, Pyrodinium*	Neurotoxic; block Na^+ channels in neuronal cells, and Ca^{2+} and K^+ channels in cardiac cells	Paralytic shellfish poisoning, known from eating contaminated shellfish.

[a] Dietary exposure to toxins is outside the scope of these recreational Guidelines. These Guidelines are concerned with exposure through possible ingestion of water, dermal contact, and inhalation of aerosols.

5.3. Assessment of risks associated with harmful algal and cyanobacterial blooms in recreational water

The assessment and management of potentially harmful algae and cyanobacteria blooms requires a basic understanding of their properties, their behaviour in natural ecosystems and the environmental conditions that support their excessive growth.

Harmful algal and cyanobacterial blooms can look like foam, scum, mats, or paint on the surface of the water. A bloom can change the colour of the water to green, blue, brown, red, purple or another colour. Some blooms may not be visible.

For a specific harmful bloom, whether toxins reach health-relevant concentrations depends on the taxonomic (and genotypic or clonal) composition of the phytoplankton and characteristics of the biomass. A bloom may be present without producing toxins, and conversely, toxins can be present both before and after blooms are visible.

In the case of saxitoxins, not all saxitoxins producers form surface scums or strong discolouration; those that do not may be overlooked. Therefore, if the presence of cyanobacteria is suspected, microscopic examination for the presence of cyanobacteria that could potentially produce saxitoxins is important.

It is also important to understand the characteristics of the various harmful algal and cyanobacterial blooms. For example, unlike planktonic cyanobacteria, benthic cyanobacteria may not always appear as an extensive area covered by a layer of biomass. Instead, benthic cyanobacteria often are growing as small distinct mats that may be present over a large area. Detached mats often accumulate at the banks of rivers, streams, and lakes where animals are much more likely to consume them. Furthermore, benthic cyanobacteria typically occur in very clear, shallow water with low nutrient concentrations.

Assessing risks for human health in situations with observed animal deaths including pets and wildlife, especially when water appears clear and toxin concentrations are low or nondetectable, is challenging.

For effective risk assessment, it is important to select parameters that indicate a harmful bloom or toxin occurrence and to define the levels at which they trigger specific actions.

5.3.1. Exposure assessment

A surveillance strategy should be developed for recreational water sites, and where there are numerous recreational water sites the strategy should prioritise those most likely to be relevant to public health.

Criteria for determining these priorities are:

- the likelihood of harmful algal or cyanobacterial blooms occurring
- the pattern of use of the recreational water body.

Assessing the likelihood of harmful algal or cyanobacterial blooms can be based on:

- existing information about the occurrence and amounts of algae and cyanobacteria, trophic state and hydro-physical conditions
- a targeted program of site inspection, sampling and analyses. Algal or cyanobacterial biomass or indicators of high biomass can serve as triggers for action, which may, if appropriate and possible, include toxin analyses.

The conditions determining the potential for blooms tend to be more stable over time than the blooms themselves. Once a basic understanding of the conditions in a water body has been established, it may be sufficient to check the key environmental conditions only periodically—for example, only during the expected bloom season or when peak blooms are expected (spring or late summer/early autumn in temperate climates, depending on the type of algae or cyanobacteria).

A list of considerations to assist with assessing the likelihood of exposure to harmful algal or cyanobacterial blooms that could be adapted to local circumstances is provided in Box 5.2.

Table 5.3 (Part A) provides a summary of conditions affecting or indicating the likelihood of high cyanobacterial biomass in freshwater including total phosphorus, hydro-physical conditions, temperature, transparency, pH and whether there have been historical blooms of cyanobacteria. Phosphorus levels in water can be an important indicator of potential for cyanobacterial growth; however, some species are efficient scavengers of phosphorus, meaning low concentrations do not necessarily indicate an absence of cyanobacteria, and therefore, phosphorus should not be used as the sole parameter for assessment. In some environments, nitrogen may be the limiting factor.

It is difficult to provide generic parameters that favour harmful algal and cyanobacterial blooms in marine environments.

Box 5.2: Example questions to support assessment of likelihood of exposure to harmful algal or cyanobacterial blooms

- Is information available to indicate the likelihood of bloom occurrence (e.g. from catchment characteristics and land uses that affect nutrient loads, from trophic status, or from direct observations of algae and cyanobacteria and/or water body characteristics; Table 5.3, part A)?
- If not, or the information is insufficient, how can an initial assessment of the likelihood of blooms be developed?
- If scums occur, are there bays and shorelines where they tend to accumulate? If so, how do these areas relate to the recreational water sites?
- How intensively is the water site used (refer to Table 5.3, part B)? Does use individuals occur occasionally, or are the same people exposed frequently (e.g. almost daily, weekly)?
- Are water users likely to be receptive to information and to adapt their activities at the site accordingly? If not, what measures can be put in place to restrict access?
- Are site operators or users likely to be willing to engage in initiatives to assist surveillance (e.g. by scum scouting, or checking turbidity and reporting observations)? Can citizen science be developed for this purpose, or can lifeguards be trained to recognise blooms?
- Are water or beach quality information systems in place that can be adapted to include harmful algal and cyanobacterial blooms?
- If the water body is also used for drinking-water supply and/or irrigation water, has an assessment been made for water quality managers that could inform recreational exposure assessment?

(adapted from TCiW, Chorus and Testai 2021)

Table 5.3 - Criteria to prioritise water bodies for cyanobacterial bloom monitoring

Part A: Susceptibility to cyanobacterial bloom

Intensity of monitoring and intervention based on susceptibility	Total phosphorus[b,c]	Hydro physical conditions	Temperature[d]	Transparency	pH
High	>50 µg/L	Stagnant, depth >5–10 m, with stable thermal gradients: favours scum-forming taxa (e.g. *Microcystis*, *Dolichospermum*, *Aphanizomenon*) Stagnant, shallow and well mixed: favours non-scum-forming taxa and other fine filamentous forms (e.g. *Limnothrix, Raphidiopsis*)	>25°C	Low; Secchi depth often <1 m	>7
Moderate - High	>20 to <50 µg/L	Stagnant, deeper than 10 m, stratified: potential for mass development of filamentous cyanobacteria which accumulate at the metalimnion	>25°C	Moderate; Secchi depth: 1–3 m	≥7
Low - Moderate	>10 to <20 µg/L	Fast-flowing river Lake or reservoir with water residence time <1 month	20-25°C	High; Secchi-depth: 3–7 m	6–7
Low	<10 µg/L	Mountain stream or brook Lake or reservoir with water residence time <1 month	<20°C	Very high – clear water; Secchi depth often >7 m	<6

Note: Exception - cyanobacteria attached to surfaces

Source: Adapted from TCiW, Burch et al. (2021). Notes to Table 5.3: a) The history of cyanobacterial blooms is a key component in determining susceptibility of a water body to cyanobacterial blooms and should be considered in combination with the relevant environmental conditions. Historical cyanobacterial monitoring results should be examined. b) In the presence of efficient scavengers, low concentrations of phosphorus do not necessarily indicate an absence of cyanobacteria. c) In some environments, nitrogen may be the limiting factor. d) 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.

Part B: Recreational use patterns of water bodies prone to algal or cyanobacterial blooms

Intensity of monitoring and intervention	Water body use pattern
High	Almost daily exposure during the bloom season (e.g. at lakeside holiday homes, caravan parks and campsites). Use of recreational water sites by a large number of people occasionally (e.g. weekends).
Moderate - High	Water sports with high probability of immersion of the head and/or oral uptake of bloom material. Lakeshore bathing sites with diving boards or rafts, water slides or other attractions leading to immersion of the head are likely to increase the probability of incidental oral uptake.
Low - Moderate	Water sites used by only a small number of people and only occasionally or discontinuously.
Low	Water users who are receptive to information on blooms, how to recognise them and how to respond to them. Water users who are willing to engage in initiatives to assist surveillance (e.g. by scum scouting and checking turbidity, reporting observations to the responsible authority and triggering targeted surveillance).

Source: Adapted from TCiW, Chorus and Testai (2021).

5.3.2. Dose-response

For many species of toxic cyanobacteria and algae, there are limited data on dose-response relationships associated with toxicity, making it difficult to identify a safe level of exposure to the toxins. Where animal or human data are available, guideline values for cyanotoxins have been derived (see Table 5.4 and *Information sheet – Derivation of guideline values for cyanotoxins in recreational water*).

It is challenging to establish cause–effect relationships between toxins and symptoms from existing case reports and epidemiological data. Exposure is usually poorly characterised and the presence of the causative hazard may not have been recognised. This is partly due to lack of awareness of toxins, and to the delay between exposure and symptoms (symptoms such as liver damage cause no pain until damage is substantial). Limited data on some routes of exposure, especially inhalation exposure from aerosolisation of toxins makes this even more difficult.

Cyanotoxins are considered among the most toxic naturally occurring compounds (Chorus and Welker 2021). Epidemiological studies have reported symptoms in human populations exposed to cyanotoxins. For those studies there is a lack of data on the dose to which the population was exposed and a lack of clarity on the adjustment for potential confounding factors (e.g. other pathogenic microorganisms).

However, the numerous cases of poisoning of farm or wild animals caused by cyanotoxins demonstrate their toxic potential (Wood 2016; Svirčev et al. 2019) and suggests that animal illnesses and deaths are sentinel events for human health risks (Hilborn and Beasley 2015). A large body of evidence from experimental studies with laboratory animals has elucidated their mode of action: some cyanotoxins are highly neurotoxic and others can damage the liver, kidney or other organs when ingested (Chorus and Welker 2021).

The guideline values in Table 5.4 for cyanotoxins, except saxitoxins, are based on animal studies, despite these having many limitations. Saxitoxins are an exception due to the rapid onset of highly specific diagnostic symptoms of human poisoning following the consumption of STX-contaminated seafood and the availability of extensive data on exposure levels and health outcomes (EFSA 2009).

Guideline values for microcystins/nodularins, cylindrospermopsins, saxitoxins and anatoxins, adapted to the Australian context from guideline or reference values derived by WHO (2021), can be used to assess the likely risks to human health from recreational exposure to cyanotoxins as part of an alert level framework (see section 5.4.2). Refer to WHO (2020a, b, c, d) and *Information sheet – Derivation of guideline values for cyanotoxins in recreational water* for the derivation of the guideline values in Table 5.4.

Nodularin, primarily produced by *Nodularia spumigena*, is structurally similar to microcystins and exerts similar toxicity to microcystin-LR at its main target site in the liver (NHMRC 2011). There is insufficient toxicological and epidemiological data to establish a separate action level for nodularin. However, given nodularin has an identical mode of action to microcystins in animals and is considered to present at least the same risk to human health as microcystin if ingested, the action level for microcystin-LR can be considered relevant for nodularin.

The cyanotoxin guideline values in Table 5.4 are based on a worst-case scenario of a young child playing in a bloom-infested water; taking into account the higher total exposure of children due to their likely longer playtime in recreational water environments and greater accidental ingestion. Children are particularly vulnerable because of their smaller body weight, which increases their relative dose of toxin. Toddlers are at even greater risk, as they are prone to ingesting water and putting materials, such as dislodged bloom mats, into their mouths. Consuming even a small amount can cause serious harm. Consistent with WHO (2021), the default bodyweight of a young child and the volume of water unintentionally swallowed are 15 kg and 250 mL, respectively (WHO 2003; WHO 2021) (refer to *Information sheet – Exposure assumptions*).

All of the cyanotoxin groups in Table 5.4 are composed of a range of analogues with similar but variable structures that result in differences in their toxic potencies. For example, more than 250 different analogues of microcystins have been described (Spoof and Catherine 2017; Bouaïcha et al. 2019), although only a few analogues occur commonly or at any one time. Microcystin-LR is one of the most potent analogues and the only one with enough toxicology data to support the derivation of a guideline value. In most cases, summing the quantities of all microcystin analogues detected for comparison with the guideline value will be protective of water users. The number of analogues in each of the other cyanotoxins groups is smaller, but generally the same principal applies. For example, 7-deoxy-CYN and 7-epi-CYN should be summed with CYN, anatoxin-a, homoanatoxin-a, and the dihydro derivatives of these should be summed, as should all STX analogues detected.

Table 5.4 - Cyanotoxin guideline values to support an alert level framework (see section 5.4.2)[a]

Cyanotoxin	Guideline value	Basis of derivation[c]
Anatoxins (ATXs)	20 µg/L ATX equivalence	Experimental animal study (Fawell et al. 1999a) (adapted from WHO 2020a)
Cylindrospermopsins (CYNs)	6 µg/L CYN equivalence	Experimental animal study (Humpage and Falconer 2003) (adapted from WHO 2020b)
Microcystins (MC)[b]	8 µg/L MC-LR equivalence	Experimental animal study (Fawell et al. 1999b) (adapted from WHO 2020c)
Saxitoxins (STXs)	30 µg/L STX equivalence	Case reports on human poisoning (EFSA 2009) (adapted from WHO 2020d)

[a] In the absence of oral toxicity data for other congeners, the guideline values apply to total ATXs, total CYNs, total MCs and total STXs as gravimetric or molar equivalents, based on the worst-case assumption of the congeners having similar toxicity. [b] A toxicity equivalence factor of one should be used for all microcystin and nodularin congeners unless new oral toxicity information becomes available. [c] For more information see *Information sheet – Derivation of guideline values for cyanotoxins in recreational water*.

5.3.3. Risk characterisation

Assessing the risks of harmful algal and cyanobacterial blooms to human health for a given recreational water body requires the integration of information on the likelihood of blooms, the pattern of recreational and cultural water use, and data on parameters that indicate harmful blooms or toxin occurrence.

The alert level framework described in section 5.4.2, adapted from WHO (2021), promotes a proactive approach for responding to harmful algal and cyanobacterial blooms to minimise public health risk. The alert level framework has been specifically designed for managing blooms associated with planktonic cyanobacteria. The alert level framework is based on an assessment of the likelihood that a water body will contain sufficiently high levels of toxic cyanobacterial biomass to cause health risks, combined with the intensity of recreational and cultural use of the water body.

The alert level framework approach does not consider the assessment of risks from detached mats of benthic cyanobacteria or from toxic cyanobacteria attached to underwater vegetation or the assessment of harmful marine blooms. The exception to this is if toxin concentrations in the water are measured, in which case toxin testing can provide an indication of plankton and benthic cyanotoxin loading to a recreational water site. Section 5.4.3 describes an approach for responding to benthic cyanobacteria.

The alert level framework can be adapted to marine algae, provided that suitable indicator parameters can be found to trigger responses (refer to section 5.4.4).

Challenges for developing recreational guideline values for cyanotoxins in marine environments and benthic mat-forming cyanobacteria include monitoring techniques for aerosolised toxins and toxins that irritate skin via contact, sampling approaches for benthic marine blooms and mat-forming cyanobacteria, and the ability to accurately quantify toxins in various matrices (Smith et al. 2024).

5.4. Management and communication

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. These arrangements need to be clarified in the site management plan or Water Quality Risk Management Plan (refer to *Chapter 2 - Framework for the Management of Recreational Water Quality*).

The site management plan or Water Quality Risk Management Plan should encompass a monitoring program for harmful algal and cyanobacterial blooms and risk management interventions including:

- longer-term measures to prevent or reduce bloom occurrence (section 5.4.1)
- immediate response actions to minimise human exposure to harmful algal blooms using an alert level framework (refer to sections 5.4.2, 5.4.3 and 5.4.4).

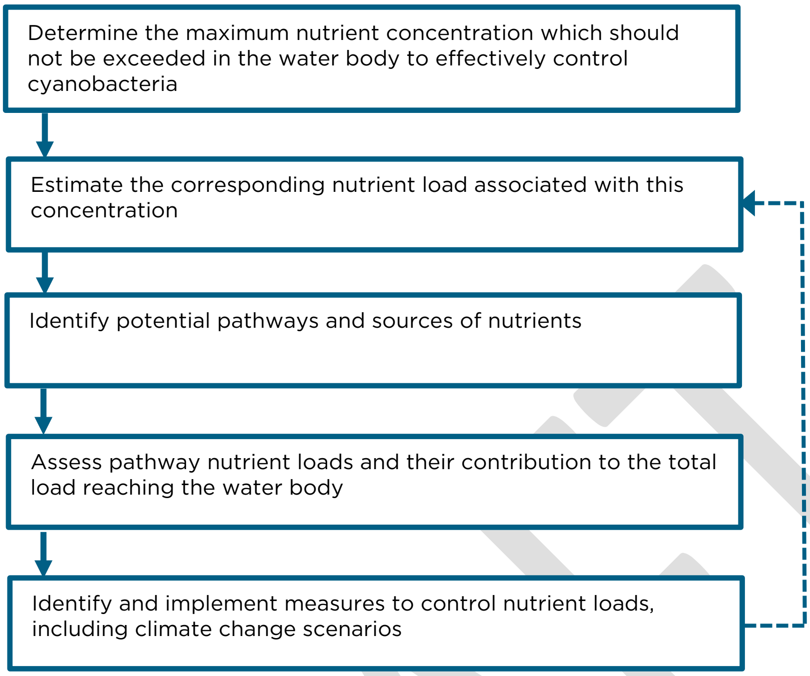
5.4.1. Prevention and reduction control measures

There are several human-induced and environmental conditions that have been found to promote harmful algal and cyanobacterial blooms including nutrient enrichment, temperature, pH, hydro-physical conditions, and seasonal patterns and variations such as warmer months, drought or periods of increased rainfall and runoff. The impact of these conditions and their significance will vary for each water body. To remediate or prevent occurrence of harmful algal blooms, a concerted effort is needed to understand these conditions for a specific water body.

5.4.1.1. Catchment management to reduce nutrient loads

Nutrient enrichment is a key contributor to promoting the dominance of harmful algal and cyanobacterial blooms. The most sustainable approach for controlling blooms is to reduce nutrient loads from the catchment to the water body (refer to Figure 5.1). The type of nutrient (i.e. phosphorus, inorganic nitrogen, organic nitrogen) can differentially impact species and strains. The sources of these nutrients are often from human activities such as agricultural runoff, stormwater runoff, sewage discharge and industrial wastewater.

Figure 5.1 - Identification of control measures to reduce catchment nutrient load



Source: Adapted from Chorus and Zessner (TCiW 2021)

Human-related activities such as agricultural runoff, inadequate wastewater treatment, septic tank effluent, stormwater runoff from urban catchments and golf courses have led to excessive eutrophication of many water bodies (van Dolah 2000) which can lead to proliferation of blooms. Eutrophication can be mitigated by reducing nutrient loads, particularly nitrogen and phosphorus in human and animal wastes and fertilisers, which travel from catchments to rivers and from there to coastal waters (Anderson and Garrison 1997; Park et al. 2013; Yu et al. 2017).

Higher nutrient concentrations and more turbid water tend to favour the growth of cyanobacteria (TCiW, Burch et al. 2021). Note: this does not apply to cyanobacteria growing on submerged surfaces since they require clear water for light penetration. Gas bubbles can lead to benthic cyanobacteria floating up to the surface and accumulating along shorelines.

Among the nutrients determining the amount of biomass that can form, total phosphorus has a key role in many water bodies: blooms of significance to recreational exposure usually require total phosphorus concentrations above 20–50 µg/L. In general, total phosphorus concentrations below 20 µg/L will not support a high biomass per unit water volume, so blooms are only likely to form if buoyant cyanobacteria at low cell density can rise to the surface in a large water body and become concentrated by wind along a shoreline or in a bay. This may result in visible scums, which are typically thin and transient because they quickly disperse if buoyancy of the cells or wind direction changes.

As cyanobacterial growth rates are relatively slow, planktonic cyanobacterial blooms do not form within the water of rapidly flowing rivers, although toxic benthic mats are known to form in such conditions. They proliferate much more quickly in tropical water temperatures relative to temperate lakes or reservoirs. Water body mixing is well tolerated by many cyanobacteria, but deep and strong mixing can suppress the proliferation of scum-forming cyanobacteria.

Whilst management strategies typically focus on phosphorus limitation, strategies to reduce nitrogen loading is also required as nitrogen dynamics in aquatic systems play an important role in influencing harmful algal and cyanobacterial bloom biomass and potential toxicity. Nutrient enrichment, specifically with nitrogen, can promote the dominance of toxic strains over non-toxic strains in cyanobacterial genera including *Microcystis* spp., *Planktothrix* spp. and *Raphidiopsis raciborskii* (Suominen et al. 2017; Davis et al. 2009; Davis et al. 2010; Lei et al. 2015; Gobler et al. 2016). Furthermore, the type of nutrient can differentially impact strains. For example, one study found that the growth of a toxic *Microcystis* strain can be stimulated by inorganic nitrogen rather than organic nitrogen, whereas the opposite was observed in a non-toxic strain of *Microcystis* (Gobler et al. 2016).

Catchment inspections and satellite imagery may assist in identifying potential land uses and the condition of the landscape that may significantly contribute nutrient input into recreational water bodies.

Practical catchment management interventions to minimise nutrient transfer to water bodies include:

- redirecting or treating point sources of pollution, including treating urban stormwater discharges
- sewerage treatment plant upgrades
- construction/remediation of wetlands
- incentivising best practice nutrient management within the catchment
- stabilising of streambank and gully erosion and restoration of riparian buffers
- managing grazing to limit erosion of soil and groundcover destruction and restrict access to waterways by providing stock watering and shade away from drainage lines.

5.4.1.2. Responding to the impacts of climate change

Climate change is predicted to impact algal and cyanobacterial blooms; however, whether the changing conditions will lead to proliferations will depend on the local conditions and the characteristics of a waterbody (Chapra et al. 2017; Ibelings et al. 2021b).

Conditions linked to climate change that can support an increase of algae and cyanobacteria include:

- more extreme precipitation (causing increased erosion and nutrient input)
- drought
- more stable thermal stratification of the water body beginning earlier in the year
- higher carbon dioxide concentrations (Visser et al. 2016; Chapra et al. 2017).

However, these conditions can also be less favourable for harmful algal and cyanobacterial blooms. Drought can prevent sufficient water exchange, but it can also reduce erosion. Increasing frequency of storm events can disrupt dominance of a species (Turner et al. 2015), and it can take time for a bloom to build up again after such events. The way in which climate change influences conditions for harmful blooms strongly depends on the conditions of the specific water body along with local conditions. Predicting future impacts of climate change on harmful blooms requires regional and local assessments.

5.4.2. Alert level framework for monitoring and managing cyanobacteria

Alert level frameworks are used internationally to monitor and manage harmful algal and cyanobacterial blooms (WHO 2021; NZ 2024). The alert level framework in Figure 5.2 has been developed using guideline values and biomass triggers developed for the Australian context (see *Information sheet – Cyanobacterial biomass triggers supporting the alert level framework* and related evidence to decision tables in the Administrative Report).

The alert level framework (Figure 5.2) is based on an assessment of the likelihood that a water body will contain sufficiently high levels of toxic cyanobacterial biomass to cause health risks, combined with the intensity of recreational and cultural use of the water body. The recommended actions within the alert level framework can be adapted for local conditions if required in consultation with the relevant health authority. The alert level framework provides a staged response to the presence and development of a harmful bloom associated with cyanobacteria. Toxins found at levels above the guideline values in Table 5.4 activate a public health response, such as continued monitoring or issuance of public health notices.

Figure 5.2 – Alert level framework for monitoring and managing cyanobacteria

Site risk assessment for elevated risk of blooms and cyanotoxin exposure

- Total phosphorous concentrations >20 µg/L and/or historical detections of cyanobacteria (including public reports)
- Intensive recreational activity

Alternative or complementary entry point for assessment at intervals of about 2 weeks

ALERT LEVEL FOR CYANOBACTERIA RISK ASSESSMENT PATHWAY			ACTIONS
Assessment by visual site inspection	Assessment by visual and field measurements	Assessment supported by laboratory analysis	
SURVEILLANCE LEVEL (Triggered when cyanobacteria has been first detected at low levels)			
Observations: - fairly clear water, slightly turbid, - water discoloration (predominantly greenish in most cases) Secchi disc transparency >2 metres	Observations and Secchi disc transparency (>2 metres) as per assessment by visual site inspection CHLA probe or benchtop testing kit: <1 µg/L chlorophyll *a* with dominance of cyanobacteria Toxic species are not detected through field test kits (e.g. ELISA toxin testing or PCR/qPCR)	Microscopy indicates <0.4 mm³/L total biovolume for all cyanobacteria or <1 µg/L chlorophyll *a* with dominance of cyanobacteria	• Weekly sampling and/or visual inspections.
ALERT LEVEL (Established cyanobacterial population with potential risk to public health)			
Observations: - pronounced turbidity - water discoloration (predominantly greenish in most cases) - unable to observe water undersurface (i.e. bathymetry) from shoreline - possibly minor thin green film or streaks on part of the surface Secchi disc transparency >1-<2 metres	Observations and Secchi disc transparency (>1-<2 metres) as per assessment by visual site inspection CHLA probe or benchtop testing kit: ≥1 to <8 µg/L chlorophyll *a* with dominance of cyanobacteria Toxic species are detected through field test kits (e.g. ELISA toxin testing or PCR/qPCR)	Microscopy indicates ≥0.4 to <3 mm³/L total biovolume for all cyanobacteria or ≥1 to <8 µg/L chlorophyll *a* with dominance of cyanobacteria If toxins analysed: toxin concentrations are less than guideline values in Table 5.4.	• Increase sampling frequency and/or visual inspections to twice weekly at representative locations to establish population growth and spatial variability in the water body. • Decide on the requirements for toxicity assessment or toxin monitoring. • Notify agencies as appropriate including public health authorities. • Inform site users to watch for scums and avoid activities that can lead to uptake through mouth or nose, particularly children; if this cannot be controlled, keep children out of the water.
ACTION LEVEL (Established harmful algal bloom with restrictions required to minimise risk to public health)			
Visible thick cyanobacterial scum covering most of the water surface in areas used for recreation Secchi disc transparency <1 metre	CHLA probe or benchtop testing kit: ≥ 8 µg/L chlorophyll *a* with dominance of cyanobacteria Toxic species are detected through field test kits (e.g. ELISA toxin testing or PCR/qPCR) Cyanobacterial scums are consistently present Consider moving to for more definitive public health assessment	Microscopy indicates ≥3 mm³/L total biovolume for all cyanobacteria or ≥8 µg/L chlorophyll *a* with dominance of cyanobacteria Cyanobacterial scums are consistently present Toxin concentrations are greater than guideline values in Table 5.4	• Immediate action to prevent contact with scum; possible temporary prohibition of swimming and other water contact activities. • Inform site users to stay out of the water and to avoid sports that can lead to scum contact; particularly update through mouth or nose; keep children out of scum. • Inform relevant authorities. • Public health follow up investigation. • Continue monitoring as for alert level. • Samples should be tested for toxin-production genes or cyanotoxins to continue growing knowledge on toxin-producing cyanobacteria in Australia.

Notes:

- Laboratory analysis includes microscopy,
- Results from field testing kits such as ELISA should be interpreted with caution. Analytical testing such as molecular analysis should be sought wherever possible, particularly if the results will be used to support decision making that may have social or economic impacts (i.e. from closure of water sites).
- Secchi disks should be locally calibrated to account for any local water quality conditions that would affect the visual results.
- The recommended actions within the alert level framework can be adapted for local conditions if required in consultation with the relevant health authority. 'Cyanobacterial scums are consistently present' 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 visual when there is a high population, as cells may mix down with wind and turbulence and then reform later when conditions become stable.
- Not all species of planktonic cyanobacteria form visible blooms or scums.
- Clear water bodies with far lower plankton biomass may harbour toxic cyanobacteria growing on surfaces such as sediments and submerged plants as mats, which can detach and float in the water or be washed ashore.
- Chlorophyll *a* requires a qualitative check by microscopy of whether chlorophyll a is largely from cyanobacteria.
- Cell count can continue to be used as a local indicator of the presence and amount of potentially toxic cyanobacteria provided it is calibrated with occasional toxin analyses.

An accessible version of Figure 5.2 is below.

Figure 5.2 - Alert level framework for monitoring and managing cyanobacteria (Accessible)

Site risk assessment for elevated risk of blooms and cyanotoxin exposure • Total phosphorus concentrations >20 µg/L, and/or historical detections of cyanobacteria (including public reports) • Intense recreational activity
Alternative or complementary entry point for assessment at intervals of about 2 weeks

Alert level for cyanobacteria risk assessment pathway	Assessment by visual site inspection	Assessment by visual and field measurements	Assessment supported by laboratory analysis	ACTIONS
SURVEILLANCE LEVEL (Triggered when cyanobacteria has been first detected)	Observations: - fairly clear water, slightly turbid - water discolouration (reddish/brown/greenish in most cases) Secchi disc transparency >2 metres	Observations and Secchi disc transparency (>2 metres) as per assessment by visual site inspection CHLA probe or benchtop testing kit: <1 µg/L chlorophyll a with dominance of cyanobacteria Toxic species not detected through field test kits (e.g. ELISA toxin testing or PCR/qPCR)	Microscopy indicates <0.4 mm^3/L total biovolume for all cyanobacteria or <1 µg/L chlorophyll a with dominance of cyanobacteria	Weekly sampling and/or visual inspections

Alert level for cyanobacteria risk assessment pathway	Assessment by visual site inspection	Assessment by visual and field measurements	Assessment supported by laboratory analysis	ACTIONS
ALERT LEVEL (Established cyanobacterial population with potential risk to public health)	Observations: - pronounced turbidity - water discolouration (predominantly greenish in most cases) - unable to observe water undersurface (i.e. bathymetry) from shoreline - possibly minor thin green film or streaks on part of the surface Secchi disc transparency <1->2 metres	Observations and Secchi disc transparency (>1–<2 metres) as per assessment by visual site inspection CHLA probe or benchtop testing kit: ≥1 to <8 µg/L chlorophyll *a* with dominance of cyanobacteria Toxic species are detected through field test kits (e.g. ELISA toxin testing or PCR/qPCR)	Microscopy indicates ≥0.4 to <3 mm^3/L total biovolume for all cyanobacteria or ≥1 to <8 µg/L chlorophyll *a* with dominance of cyanobacteria If toxins analysed: toxin concentrations are less than guideline values in Table 5.4.	• Increase sampling frequency and/or visual inspections to twice weekly at representative locations to establish population growth and spatial variability in the water body. • Decide on the requirements for toxicity assessment or toxin monitoring. • Notify agencies as appropriate including public health authorities. • Inform site users to watch for scums and avoid activities that can lead to uptake through mouth or nose, particularly children; if this cannot be controlled, keep children out of the water.

Alert level for cyanobacteria risk assessment pathway	Assessment by visual site inspection	Assessment by visual and field measurements	Assessment supported by laboratory analysis	ACTIONS
ACTION LEVEL (Established harmful algal bloom with restrictions required to minimise risk to public health)	Visible thick cyanobacterial scum covering most of the water surface in areas used for recreation Secchi disc transparency <1 metre	CHLA probe or benchtop testing kit: ≥8 µg/L chlorophyll *a* with dominance of cyanobacteria Toxic species are detected through field test kits (e.g. ELISA toxin testing or PCR/qPCR) Cyanobacterial scums are consistently present Consider moving to for more definitive public health assessment	Microscopy indicates ≥3 mm³/L total biovolume for all cyanobacteria or ≥8 µg/L chlorophyll *a* with dominance of cyanobacteria Cyanobacterial scums are consistently present Toxin concentrations are greater than guideline values in Table 5.4	• Immediate action to prevent contact with scum; possible temporary prohibition of swimming and other water contact activities. • Inform site users to stay out of the water and to avoid sports that can lead to scum contact; particularly uptake through mouth or nose; keep children out of scum. • Inform relevant authorities. • Public health follow-up investigation. • Continue monitoring as for alert level. • Samples should be tested for toxin-production genes or cyanotoxins to continue growing knowledge on toxin-producing cyanobacteria in Australia.

Notes

- Laboratory analysis includes microscopy.

- Results from field testing kits such as ELISA should be interpreted with caution. Analytical testing such as molecular analysis should be sought wherever possible, particularly if the results will be used to support decision making that may have social or economic impacts (i.e., from closure of water sites).
- Secchi disks should be locally calibrated to account for any local water quality conditions that would affect the visual results.
- The recommended actions within the alert level framework can be adapted for local conditions if required in consultation with the relevant health authority.
- 'Cyanobacterial scums are consistently present' 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 visual when there is a high population, as cells may mix down with wind and turbulence and then reform later when conditions become stable.
- Not all species of planktonic cyanobacteria form visible blooms or scums.
- Clear water bodies with far lower plankton biomass may harbour toxic cyanobacteria growing on surfaces such as sediments and submerged plants as mats, which can detach and float in the water or be washed ashore.
- Chlorophyll a requires a qualitative check by microscopy of whether chlorophyll a is largely from cyanobacteria.
- Cell count can continue to be used as a local indicator of the presence and amount of potentially toxic cyanobacteria provided it is calibrated with occasional toxin analyses.

Source: Adapted to Australian conditions from Chorus and Testai (2021).

5.4.2.1. Approaches for assessing and monitoring a harmful cyanobacterial bloom

The alert level framework for cyanobacteria comprises three approaches for assessing and monitoring a harmful bloom:

- assessment by visual site inspection only
- assessment by visual site inspection supported by field tests
- assessment supported by laboratory analysis including toxin testing.

All three approaches have their limitations and advantages. For water bodies with intensive recreational activity and elevated risk of cyanobacteria blooms, assessment supported by laboratory analysis is considered best practice and should be undertaken wherever possible.

For water bodies in remote areas that do not have timely access to analytical capability, assessment by visual site inspection and field measurements may be the most practical option. However, findings from these kinds of assessments should be interpreted with caution. Analytical testing should be sought wherever possible, particularly if the results will be used to support decision making that may have social or economic impacts (i.e. from closure of water sites). Additionally, testing samples for toxin-producing genes or new cyanotoxins supports improving the state of knowledge on toxin-producing cyanobacteria in Australia.

5.4.2.2. Alert levels for triggering a short-term response

The alert level framework in Figure 5.2 assesses the development of a bloom through a monitoring program, with actions in three stages linked to different alert levels: **Surveillance level, Alert level, Action level**. These are described below.

For effective risk assessment, it is important to choose parameters that indicate cyanotoxin occurrence and to define the levels at which they trigger specific actions. Depending on the approach selected for assessing and monitoring the bloom, the triggers for surveillance, alert and action levels are based on alert levels for the following parameters and indicators:

- the guideline values of cyanotoxins in water (microcystins/nodularins, cylindrospermopsins, anatoxins and saxitoxins (refer to Table 5.4)
- concentration of cyanobacterial biomass indicators (biovolume and chlorophyll *a*) in water correlated to microcystin-LR
- observational parameters including scum and reduced transparency measured by Secchi disc.

It should be noted that Secchi disc reading should be interpreted with caution, particularly in the presence of suspended or dissolved inorganic particles such clay turbidity, which is often found in Australian water bodies. Secchi disks should be locally calibrated to account for any local water quality conditions that would affect the visual results.

Depending on the species, visual monitoring alone may well suffice to trigger a specific action. Visual signs of a cyanobacterial bloom include:

- surface water discolouration (e.g. a green, white, brown, or blue tint)
- reduced transparency
- thick, mat-like accumulations of scum on the shoreline and surface
- unfavourable odour compounds.

Some cyanobacterial blooms may be present without producing cyanotoxins, and conversely, cyanotoxins can be present both before and after blooms are visible. Therefore, it is best practice that cyanotoxin levels be confirmed through laboratory testing of water. Microscopic phytoplankton identification can provide information when blooms are present and not visually apparent.

It should be noted that clear water bodies with far lower plankton biomass may harbour toxic cyanobacteria growing on surfaces such as sediments and submerged aquatic plants as mats, which can detach and float in the water or be washed ashore.

When using laboratory analysis, it is important to interpret the laboratory data in conjunction with visual information (from site inspection, observation of scums and water transparency, and qualitative microscopy).

A measure of biomass is best for triggering action—either biovolume or the concentration of chlorophyll *a* (the latter needs to be combined with a brief visual assessment by microscopy to check whether this mainly represents cyanobacteria, or whether eukaryotic algae dominate). This is because of the pronounced differences in the cell sizes of cyanobacterial species. This approach also encompasses nonspecific health impacts associated with the presence of cyanobacterial cells but not with any specific known cyanotoxin.

Unlike NHMRC (2008), these guidelines do not provide triggers for cyanobacterial cell counts. Cyanobacterial biovolume (i.e. cells/L multiplied by mean cell volume of the species) is a more accurate indicator of planktonic cyanobacterial biomass than total cyanobacterial cell counts since this measurement accounts for the surface area of the cell, as well as the mass of all cellular material, or cellular biomass (Saccà 2016). Microcystin-LR concentrations have been found to relate more directly to cellular biomass than to cell numbers (Ibelings et al. 2021).

Cell counts can nonetheless continue to be used, as can any other locally convenient indicator of the presence and amount of potentially toxic cyanobacteria (e.g. *in situ* fluorescence, turbidity, satellite data), provided that such a parameter is calibrated with occasional toxin analyses. 'Potentially toxic' means that while some strains of cyanobacteria are known to carry toxin-producing genes, further analysis (e.g. ELISA, toxin testing) is required to determine whether they are actually producing toxins or what those toxins are. Such a calibration is generally valuable: although literature data can be used for setting threshold values to trigger action, these provide worst-case estimates and tend to overestimate the risk, as most blooms contain a lower share of toxin-producing genotypes.

Periodically calibrating whichever indicator is used with toxin analyses of local samples is likely to allow lower values to be set for the indicator chosen, which may avoid undue restrictions on water site use. The cyanotoxin guideline values for recreational exposure in Table 5.4 may be used for such calibration.

The alert levels adopted for biovolume and chlorophyll *a* are based on correlations with microcystin-LR and therefore conservative for most cyanotoxins. Periodically calibrating them against data obtained for the specific water body, and the toxins that commonly occur there, may allow use of higher thresholds for triggering action to prevent exposure to health-adverse levels of cyanobacteria.

However, cylindrospermopsins are more readily mobilised to outside of the cells (species dependent), and may be an exception due to their relatively higher proportion of toxin dissolved in water. In the recreational context the cell-bound material will still be the primary concern in situations where exposure to scums may arise.

The derivation of trigger levels for biovolume and chlorophyll *a* is described *in Information sheet – Cyanobacterial biomass triggers supporting the alert level framework*.

Depending on access to laboratory capacity, cyanotoxin analyses may be readily available and may be the most practical local approach; toxin analyses may also be used directly for triggering action. However, it is important to use microscopy for a brief qualitative assessment of the key genera of cyanobacteria in the sample to understand the development of the bloom situation (refer to TCiW, Padisak et al. 2021, for information on laboratory methods).

One of the challenges with biovolume monitoring, particularly in regional areas, is the requirement for locally available competent and experienced analysts with suitable laboratory equipment along with an accurate and ideally site or regionally relevant cell biovolume library. Therefore, an alert level framework that uses simpler metrics can be used to help focus where biovolume monitoring efforts should be targeted, or to help identify where alternative monitoring methods can be utilised.

Enzyme-linked immunosorbent assay (ELISA) toxin testing methods are commercially available as field testing kits and provide direct evidence of the presence or absence of cyanotoxins. However, findings from these assessments should be interpreted with caution. If the presence of cyanotoxins are detected, these finding should trigger further investigations and repeat analysis, with analytical testing sought wherever possible to confirm the findings. Conventional polymerase chain reaction (PCR) or quantitative real–time PCR (qPCR) analysis to detect the presence of toxin-producing genes is also becoming more readily accessible with benchtop instruments increasingly available.

The following discussion of the alert levels and corresponding actions is adapted from TCiW (Chorus and Testai 2021).

Surveillance level

Surveillance level is indicative of when cyanobacteria are first detected at low levels either through visual observations, field-based measurement or analytical measurement, signalling the early stages of possible bloom development. Measurements indicate:

- the presence of potentially toxic species are not detected through ELISA toxin testing
- <1 µg/L chlorophyll *a* (with a dominance of cyanobacteria)
- <0.4 mm^3/L total biovolume of all cyanobacteria.

Visually, water appears fairly clear but may be slightly turbid with water discolouration (green is the most common colour expression). Transparency determined with a Secchi disc will usually be >2 m.

Because of the potential for rapid increase or even scum formation, it is appropriate to intensify surveillance and inform water users about the potential for cyanobacteria to increase to higher levels. 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.

Monitoring and sampling should be undertaken weekly to fortnightly at representative locations in the water body where the known toxigenic species (e.g. *Microcystis aeruginosa, Dolichospermum circinale* (formerly *Anabaena circinalis), Raphidiopsis* (formerly *Cylindrospermopsis) raciborskii, Umezakia* (formerly *Chrysosporum) ovalisporum, or Nodularia spumigena*) are present. Fortnightly to monthly sampling frequency may be appropriate where other types are present, and the risk is perceived to be lower. A single water site that is representative of the recreational area may be acceptable but multiple water sites are warranted if the area is large.

Surveillance is particularly relevant for water bodies with total phosphorus concentrations well above 20 µg/L (provided nitrogen is not reliably limiting; for determining this, refer to TCiW, Chorus and Zessner 2021) because cyanobacteria, once dominant, may reach a higher biomass within a few days. It is also relevant for very large water bodies because they have a potential for scum formation even at these rather low biomass levels, as scums can accumulate from very large water volumes. It is good practice to visually inspect waters regularly under calm conditions even when the risk is considered low.

Alert level

Alert level is triggered when measurements indicate:

- the presence of potentially toxic species are detected through ELISA toxin testing
- >1 µg/L – <8 µg/L chlorophyll *a* (with a dominance of cyanobacteria)
- >1 – <3 mm^3/L total biovolume of all cyanobacteria.

Under this scenario, cyanobacteria are clearly visible when inspecting the water site, particularly as greenish turbidity or discolouration and possibly also as minor green streaks or specks floating on parts of the water surface, but not as scum covering major parts of the surface area. Secchi disc transparency may indicate <2 - >1 metres or even less (Figure 5.3).

This level indicates an established cyanobacterial population, with the potential for localised high numbers that could pose a potential hazard.

In such a situation, cyanotoxin concentrations can reach potentially hazardous levels even without scums, but typically they do not, and recreational and cultural use may be continued without exposure to cyanotoxins exceeding the guideline values. This is particularly the case for scum-forming microcystin-producers such as *Microcystis*, *Dolichospermum,* or *Anabaena*, which may be visible as slight streaks or small specks between which water is fairly clear. However, water users should be informed.

This alert level also 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.

Determining biomass and possibly toxin concentrations provide more precise information and is important in water bodies with a history of supporting the proliferation of non-scum-forming species of cyanobacteria.

Informing water users to avoid exposure to high densities of such evenly dispersed cyanobacteria is less straightforward than informing them to avoid scums because the situation is harder to describe.

Where data from visual inspection and quantifying cyanobacterial biomass can be supported by cyanotoxin analyses, this can avoid undue restrictions on recreational water site use in situations where cyanobacterial biomass is high, but toxin content is low (below Alert Level).

At Alert Level, the cyanobacteria present may well increase to a heavy bloom within a few days if conducive conditions prevail in the water body. Watching out for scums and increased surveillance may therefore be appropriate, particularly for heavily used recreational water sites.

Depending to some extent upon the sensitivity and usage of the area, sampling frequency should be increased to twice weekly where the known toxigenic species is dominant in the total cyanobacterial biovolume. For example, twice-weekly sampling may be justified where there is a pressing need to issue advice for ongoing use if the water site is being used heavily by recreational water 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 water sites should be sampled at representative locations to rapidly detect if the situation escalates to Action level.

Action level

Action level is defined by:

- exceedances of guideline values for cyanotoxins (refer to Table 5.4)
- the presence of potentially toxic species are detected through ELISA toxin testing
- ≥8 µg/L chlorophyll *a* (with a dominance of cyanobacteria)
- ≥3 mm^3/L total biovolume of all cyanobacteria.

Action level describes a situation with scums or very high cell density leading to substantial turbidity. While scums can be thick in parts of the water body, other parts may still show a Secchi disc transparency up to about 1 m. If scum material is both very thick and highly toxic, 100 – 200 mL ingested by a toddler can contain an acutely hazardous dose. The presence of substantial cyanobacterial scums is a readily observable indicator of a high risk of adverse health effects. Cyanotoxin analysis can be used to confirm or downgrade the alert level status.

Action Level situations call for immediate action to avoid scum contact and oral uptake. At this alert level 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. Refer to *Information sheet – Preparing a risk communication plan* and *Risk communication planning checklist*.

Temporary prohibition of recreational activities may be appropriate alongside more intensive monitoring for confirming or downgrading the alert level status. Providing information to water users is important to achieve an understanding of the hazard and improving compliance. Measures to reduce exposure that can be implemented quickly may include installation of floating physical barriers to prevent the scum from being driven into the swimming area, provided that surface scums are the key issue (rather than dispersed, suspended cells or colonies). If scums typically accumulate at certain water sites while other water sites largely remain unaffected, directing recreational and cultural use to another water site may be an option. Removing drying scum accumulated on beaches may be necessary to avoid the development of dust (using personal protective equipment if scum is already dry).

The monitoring of the bloom should continue as for Alert Level to determine when the bloom is in decline so that normal recreational and cultural use can resume.

As discussed above, misconceptions about what constitutes a scum are common for large, deep and usually clear lakes with low nutrient concentrations. In such lakes, cyanobacteria may become transiently dominant in the phytoplankton, but only at low concentrations. Cells from the large water volume may rise to the surface and be swept into a downwind bay where they may form a surface film, typically thin and with cyanotoxin concentrations well below hazardous levels. Water users not accustomed to any visible phytoplankton on the surface may interpret even a very thin and locally limited film as scum and be unduly concerned, and advisories may need to explain what amounts to a sufficiently pronounced scum to cause concern. Local information may be appropriate to dispel such concerns.

Rescinding warnings

The alert level should not be changed from a higher to a lower level (e.g. from Action Level to Alert Level) until two successive lower results from representative samples at multiple locations have been recorded.

Importantly, the half-life of toxins can extend beyond the collapse of a bloom. 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 half-life of toxins varies (from a few hours to several months) depending on the specific toxin and environmental conditions (Chorus and Welker 2021). In most cases toxicity testing is usually only warranted at 7–10 day intervals or less often.

Figure 5.3 - Alert Level conditions observed as streaks, specks and Secchi disc transparency

Source: reproduced from WHO (2021).

5.4.3. Responding to benthic cyanobacteria

In the case of benthic cyanobacteria, a similar alert level framework can be adopted, with benthic mat abundance and detachment of mats as the triggers for changes in thresholds. For tropical/subtropical beaches with filamentous cyanobacteria (e.g. *Moorea*, formerly *Lyngbya*) growing on surfaces, this can include removing detached filaments accumulating on beaches and providing information to water users.

During stable flow conditions (in streams and rivers) cyanobacteria mats can proliferate, at times forming expansive black-brown leathery mats across large expanses of river substrate. Flow conditions, substrate, water chemistry and species composition can influence the macroscopic appearance of benthic cyanobacterial mats, and at times they may easily be confused with other algal groups (e.g. diatoms or green algae). Microscopic confirmation should be undertaken.

Under certain environmental conditions, or as they become thicker (and bubbles of oxygen gas become entrapped within them), mats will detach from the substrate and may accumulate along the edge of the water body or shorelines.

During these events the risk to human and animal health is higher due to the accessibility of the cyanobacterial mats to recreational water users. The highest risks to users are likely to be ingestion of and/or direct contact with these cyanobacterial mats, as the toxin concentrations in the mats can be very high (with evidence of dog deaths due to consumption of cyanobacterial mats) (Gugger et al. 2005; Puschner et al. 2010; Wood et al. 2017). Although it is not expected that an adult would intentionally consume the cyanobacterial material, there is a real possibility that a child playing at the water's edge or shoreline might do so. There is also a risk around recreational managers and park rangers interacting with the material when cleaning the beach.

Not all cyanobacterial mats are toxic, and where access to cyanotoxin analysis is available, data on cyanotoxin concentrations in such material are the best basis for assessing whether such situations require warnings and, if so, regarding which types of water-related activity. Sampling involves collecting grab samples of sediment or floating scums, or biofilm scrapes (Gaget et al. 2020). During these investigations, water users should be advised to avoid contact with the toxic material (clumps that are either floating in the water or beached along the shoreline).

An example of an alert level framework for the management of Moorea blooms is provided in Box 5.3. The *Aotearoa New Zealand guidelines for cyanobacteria in recreational freshwaters* provide an alert-level framework for benthic *Microcoleus* in rivers and streams (NZ 2024), refer to Box 5.4.

Box 5.3 Management of *Moorea* blooms in Queensland, Australia

Moorea producens (formerly *Lyngbya majuscula*) is a benthic marine cyanobacterium that forms distinctive dark-green weed-like mats that grow on sediments or loosely attached to seagrass. Mats can detach and drift onshore, and filaments can be released by strong currents or storm events. Public health issues—mainly acute dermatitis (seaweed dermatitis or swimmer's itch)—can arise from contact with *Moorea* filaments through recreational use of affected water bodies. In Moreton Bay, Queensland, monitoring for Moorea blooms included monthly visual inspections from boats, combined with shore-based inspections for deposited material.[a]

Moreton Bay Regional Council published a Harmful Algal Bloom Response Plan in 2018, with a focus on management of *Moorea* blooms. The plan included monthly monitoring of northern Moreton Bay for blooms and a three-level response plan, as shown in the table 5.5 (below box). A management plan has since been published.[b]

[a] Monitoring updates: *Lyngbya* blooms in Moreton and Deception bays, https://www.qld.gov.au/environment/coasts-waterways/marine-habitats/monitoring-updates, accessed 29 May 2021)[b] Kingston P, McGregor G, Smit R, Witte C, Burford M, Sendall B, Ormerod R (2023). Sea wrack at Wynnum foreshore: A study of causes, impacts and management: Department of Environment and Science, Queensland Government.

Table 5.5 – Three-level response plan for blooms in northern Moreton Bay

Level	Detection	Response
Level 1	Small to moderate bloom material at locations away from developed areas.	No action required to remove material, but signs to inform public of the presence of a potentially harmful algal bloom may be appropriate. Activate stakeholder communications.
Level 2	Large quantities of bloom material washing ashore or forming rafts adjacent to developed areas or areas of high public use.	Activate or install signs immediately. Issue media release. Physically remove material from foreshores.
Level 3	Very large quantities of material washed ashore or beginning to form large rafts adjacent to developed areas or areas of high public use.	Same response as for Level 2, but closure of beaches may also be required, particularly where large amounts of blooms are growing close to the water's edge.

Box 5.4 Alert-level framework for benthic *Microcoleus* in rivers, Aotearoa New Zealand

Alert-Level[a]	Actions
Surveillance level (green mode) **Situation 1:** Up to 20% coverage[b] of *Microcoleus* attached to the river substrate.	Undertake fortnightly surveys between spring and autumn at representative locations in the water body where known mat proliferations occur and where there is recreational use.
Alert level (amber mode) **Situation 1:** 20–50% coverage[b] of *Microcoleus* attached to the river substrate.	Increase monitoring frequency to at least weekly.[c] Notify public health staff. Consider erecting a sign that provides the public with information on the appearance of mats and the potential risks. Consider increasing the number of survey sites to enable risks to recreational users to be more accurately assessed. Consider testing samples for cyanotoxins or toxin-production genes.[d]
Action level (red mode) **Situation 1:** Greater than 50% coverage[b] of *Microcoleus* attached to the river substrate; or **Situation 2:** Up to 50% coverage,[b] but *Microcoleus* mats are visibly detaching from the substrate, accumulating as scums along the river's edge or becoming exposed on the river's edge as the water level decreases.	Continue monitoring as for Alert Level (amber mode).[c] Immediately notify public health staff. Notify the public of the potential risk to health. Consider testing samples for cyanotoxins or toxin-production genes.[d]

a. The alert-level framework is based on an assessment of the percentage of riverbed that Microcoleus mats cover at each site. However, local knowledge of other factors that indicate an increased risk of toxic cyanobacteria (for example, human health effects, animal illnesses and prolonged low flows) should be used when assessing a site status and may, in some cases, lead to an elevation of site status (for example, from Surveillance Level to Action Level), irrespective of mat coverage.

b. This should be assessed by undertaking a site survey as documented in section 4.4.

c. Benthic Microcoleus proliferations can grow rapidly in some water bodies, hence the recommended weekly sampling regime.

d. Cyanotoxin and toxin-production gene testing is useful to provide further confidence on potential health risks when a health alert is being considered.

Source: Reproduced from [Aotearoa New Zealand Guidelines for Cyanobacteria in Recreational Freshwaters]

5.4.4. Responding to harmful blooms associated with marine algae and cyanobacteria

The alert level framework can be adapted to managing harmful blooms associated with marine algae and cyanobacteria, noting that suitable parameters are needed to trigger a response. A three-level response plan could comprise:

- Surveillance level: At surveillance level the water body has the potential for algal growth and regular sampling and monitoring should be carried out.

- Alert level: Alert level is triggered when marine algae are clearly visible. It is necessary to 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 and, importantly, on the sensitivity and usage of the recreational water area. Increased surveillance may be appropriate, particularly for heavily used recreational water sites, to rapidly detect if the situation escalates to Action level.
- Action level: Action level is triggered with scums or very high algal density. Action level situations call for immediate action to avoid exposure through dermal contact and inhalation. Temporary banning of water use may be appropriate, and intensified monitoring may be important to either confirm or revert to alert level status, in order to not unnecessarily restrict use. Providing information to water users is important to achieve an understanding of the hazard and improving compliance.

Further research is needed to establish appropriate indicators for the development of marine harmful algal blooms to support robust risk management frameworks.

5.4.5. Monitoring

In areas subject to harmful algal or cyanobacterial blooms, adequate monitoring is required to prevent human exposure to affected areas. The monitoring program should be included as part of the overall risk management plan for a recreational water area.

It is not feasible to monitor for harmful algal and cyanobacterial blooms in all water bodies that are used for recreational and cultural activities. Instead, responsible authorities can use criteria to identify the areas that are at greater risk for bloom formation. This information is then used to prioritise areas for management including monitoring. Monitoring programmes should be adaptive, so that sampling and analysis are increased when there is evidence of increasing amounts of algae or cyanobacteria.

The aim of monitoring should be specified, for example:

- for an initial assessment of the likelihood of blooms in the context of risk assessment
- for triggering immediate responses in the context of an Alert Level Framework
- for validating measures implemented to control blooms
- for regular verification that a bathing site is safe to use.

This determines both when and where to sample, and which parameters to analyse (Table 5.6).

Table 5.6 - Examples of sampling strategies for particular monitoring objectives

Objective	Sampling sites	Sampling frequency	Analytical targets
Capacity of nutrient concentrations to sustain blooms	Major inflows and central site in the water body.	Monthly, year-round; in temperate climates, one sample in spring gives preliminary indication.	Nutrients (total P, total dissolved N or total N); mean depths and thermal stratification.
Cyanobacterial or algal biomass development	Central site or multiple sites in the water body.	Monthly or twice a month; higher frequency during bloom season or in response to blooms.	Nutrients, transparency, phytoplankton, chlorophyll *a*, cyanotoxins, toxin genes.
Spatial distribution of harmful algal blooms and associated toxins	Multiple sites to capture distribution of bloom across the water body. Multiple depths especially for species that may be present throughout the water column. Note: Harmful algal blooms can be mobile and will move vertically in the water column throughout the day and horizontally due to wind movements.	Single or few sampling events during bloom season.	Phytoplankton, chlorophyll *a*, cyanotoxins, toxin genes.
Protection of health during recreational activity	Water sites used for recreation in presence of surface blooms or transparency less than 1–2 m.	As necessary, in response to visual inspection and recreational and cultural use.	Transparency, cyanobacterial biovolume, chlorophyll ***a***, cyanotoxins, toxin genes.

Source: Adapted from TCiW, Welker et al. (2021).

5.4.5.1. Developing a strategy for monitoring and planning the program

For planning a monitoring strategy, it is important to understand the patterns of bloom occurrence in time and space. Harmful blooms can be erratic in some water bodies but may follow quite predictable patterns in others. A good understanding of the water body, its growth conditions for algae or cyanobacteria growth, seasonal patterns of occurrence are useful when planning a monitoring program.

Long time series of data records on phytoplankton populations, toxic or otherwise, may:

- improve understanding of phytoplankton dynamics and ecosystem function
- allow prediction of the appearance of potentially toxic harmful algal blooms
- allow recognition of a species that is new to the area
- indicate whether recurrent blooms have become toxic.

Patterns of vertical mixing of the water body may determine formation of harmful algal and cyanobacterial blooms, and wind direction can determine where blooms accumulate. In the case of cyanobacteria, many species determine their vertical location in a water body themselves through buoyancy regulation: intensive photosynthesis in the light near the surface causes them to accumulate carbon, which acts as ballast, causing them to sink, and they rise to the surface again after consuming this carbon for growth and respiration (TCiW, Ibelings et al. 2021). Consequently, a low biomass of cyanobacteria at a bathing site on one day does not exclude a scum the next day, if potentially scum-forming cyanobacteria dominate in the phytoplankton and nutrient concentrations in the water body are high enough to support a sufficiently large biomass. However, cyanobacterial dominance will not change overnight. It usually takes at least 1–2 weeks for cyanobacterial biomass to increase from a minor fraction in the phytoplankton to dominance. Dominance may last for weeks or even months. An understanding of phytoplankton composition is a useful basis for assessing the risk of blooms at recreational water sites.

Important parameters for monitoring include temperature, salinity, chlorophyll *a* (as a measure of phytoplankton biomass) and surface current circulation (which affects transport of harmful algae). Knowledge of the distribution and sources of inorganic nutrients and other phytoplankton growth factors is also important when planning and operating a monitoring programme (Andersen 1996; Reguera et al. 2016).

When conditions favourable to algal or cyanobacterial blooms are recognised, monitoring activities should be intensified. They should include taxonomic identification of potentially toxic species and analysis of the algal toxins (Hallegraeff et al. 2004; Reguera et al. 2016).

The intensity of monitoring and sampling will depend on several factors including the intensity of recreational use of the water site (Table 5.3), bloom occurrence, time and financial considerations. In areas of high risk, weekly sampling may be appropriate; during bloom development, it may be necessary to intensify observations (e.g. through daily assessment of the development of scums and/or turbidity).

During bloom development, it may be more useful to take multiple samples (at different water sites on the same date or with greater frequency), which are analysed with less accurate methods, than to invest in a highly accurate determination of biomass or toxin concentrations from a single weekly sample.

In the context of the alert level framework, monitoring of toxin concentrations can be used to calibrate other parameters locally, showing how toxin concentrations relate to measures of biomass (e.g. in the case of cyanobacteria biovolume, chlorophyll *a* or other indicators). For an initial assessment—particularly where cyanobacteria are suspected or have been previously observed—it is useful to assess whether total phosphorus concentrations are above 20–50 µg/L and therefore capable of sustaining blooms. Where total phosphorus concentrations are higher and/or blooms have been observed, long-term information is useful on phytoplankton biomass and composition, and on conditions in the water body that may promote phytoplankton proliferation. Where total phosphorus concentrations are lower and water is clear, note the possibility of cyanobacteria growing on submerged surfaces, with lumps detaching at times. Toxins should be analysed in laboratories that use standard methods with replicable and reliable results.

Photographs of blooms or evidence of scum can be used to document visual site inspection. Additional information, such as smell and reports from water users, should also be documented. Documentation is important to underpin the reasons for any water site closure, as well as for establishing a longer-term understanding of the water body's bloom patterns.

5.4.5.2. Exploring existing data and site inspection

Data—for example, from scientific publications, authority records and surveillance records—may provide useful background information on a water body and allow an initial assessment of the likelihood of cyanobacterial blooms. The following information, where available, is useful:

- nutrient concentrations (especially total phosphorus and nitrogen concentrations) and their seasonal variation
- potential major nutrient inputs and possible input fluctuations (e.g. seasonality of surface runoff and possible long-term changes)
- activities causing nutrient loading (e.g. agricultural practices in the catchment, capacity and functioning of wastewater treatment facilities)
- water body surface area and morphology
- patterns of thermal stratification over time
- reports of timings of blooms and observations of surface scums or (for clear waters) lumps of detached material accumulating in the water or on the beach
- seasonal dynamics of phytoplankton occurrence and taxonomic composition
- satellite images showing phytoplankton (chlorophyll *a*) abundance and distribution
- location of bathing sites and seasonal use frequency
- prevailing wind direction, especially during periods when cyanobacteria (particularly surface-bloom-forming species) could be abundant
- reports of suspected or demonstrated bloom-related illness in humans and animals.

Where data for the specific water body are not available, regional information (e.g. on dominant cyanobacterial genera) may be useful. Where background data are not available, water quality analysis should be conducted.

Observations may also be available from sources such as health and environmental authorities, local businesses (e.g. campsites, boat rental companies, restaurants situated near the recreational water body) and members of the local community.

Site inspection is an important basis for planning a monitoring program, particularly where data are lacking but also to confirm whether existing data are still accurate and whether they cover key aspects. Sanitary surveys should also address the possible sources of nutrient input, significant land uses, and recent or planned changes in land use.

5.4.5.3. Water quality analysis

A range of biological, biochemical and physicochemical methods can be used to determine the likelihood of harmful algal and cyanobacterial blooms, examine their progress and detect toxins.

Algal and cyanobacterial observations range from straightforward visual examination (e.g. the presence of scum or coloured turbidity) to the use of sophisticated remote sensing. Between these extremes, microscopy can be used to identify genera (in some cases, also species), and biomass can be determined either as biovolume or as concentrations of chlorophyll *a*. Monitoring the occurrence of algae and cyanobacteria is important to understand how amounts change over time. Such an understanding enables toxin analyses to be focused on the most critical situations or—where toxin analysis is not possible—to use the occurrence of the producing organisms as an indicator of risk.

Resources with detailed information on sampling, identification and cell counts include Hallegraeff et al. (2004) and Carlson (2018) for marine phytoplankton, and Padisak et al. (TCiW 2021); the methods described there specifically for cyanobacteria may equally be applied to other phytoplankton species, including marine. A considerable amount of information is available online, including algae/cyanobacteria identification guides (e.g. Rosen and St Amand 2015).

Cheng et al. (2005) described methods to detect brevetoxins in sea breezes that has been used in epidemiological studies and in assessing how far inland brevetoxins move (Kirkpatrick et al. 2010b).

Observation of cyanobacterial occurrence

Observational methods to assess cyanobacterial occurrence include:

- straightforward visual examination onsite (e.g. the presence of scum or greenish turbidity, measuring transparency with a Secchi disc)
- use of dipsticks to assess water pH
- sampling, cell counting and determination of the biomass of key species; microscopy to identify the dominant cyanobacteria present (TCiW, Padisak et al. 2021)
- estimation of biomass using NATA approved methods
- microscopy to determine cell numbers and biovolume (TCiW, Padisak et al. 2021), and/or the concentrations of chlorophyll *a* and phycocyanin (the pigment specific to cyanobacteria), measured by chemical analysis or fluorometry in combination with a quick assessment by microscopy of the dominant phytoplankton organisms (Catherine et al. 2012; Marion et al. 2012)

- *in situ* fluorescence
- remote sensing to identify and track cyanobacterial blooms (TCiW, Welker et al. 2021).

The use of monitoring by pigment fluorescence, of either chlorophyll or phycocyanin, can potentially be useful to provide continuous and real time data of cyanobacterial hazards (Khan et al. 2019; Zamyadi et al. 2012). This is particularly the case when using on-line probes and after calibration for the local population. These methods have been incorporated as part of the cyanobacterial alert framework to trigger further investigation and action.

It must be noted that none of the observation methods will provide an indication of free dissolved toxin in water that has been released from cells. This can be substantial after a bloom has collapsed and will be unknown unless toxin is measured directly.

Molecular methods for monitoring of microorganisms in environmental samples can be used to generate information on the presence of potential toxins in short time frames. These methods detect specific genes that identify cyanobacterial species as well as the presence of the toxin-producing genes. These molecular methods have a role as a screening tool to determine the presence of cyanobacterial species and to provide an indication of toxin production, particularly as the use of the technology becomes more widespread. It is best practice to locally calibrate indicator measurements against toxin concentrations.

The sampling method for cyanobacteria in water involves collecting a single composite or pooled sample to determine measurements for each defined recreational water site (e.g. beach entry point, paddling area). Access points for sample collection can include open water by boat, shoreline and bridge or weir. Details of the sampling methods (containers, sample volumes, sampling method, and sample transport) and of the appropriate analytical methods should be sourced from the NATA-accredited analytical services provider that is providing the testing.

Establishing platforms for communication and collaboration between the authorities that manage seafood (commercially valuable fish and shellfish) and recreational water bodies would be valuable to combine monitoring to serve both purposes—recreational and food safety.

Analytical methods for toxin analysis

Toxin analyses are important to allow management measures to focus on situations in which health risks from harmful algal blooms are likely. Rapid screening for harmful algal bloom toxins can be done using immunoassays, receptor binding assays and cell toxicity assays (Diogene and Campas 2017). To assess potential toxin production, toxin genes can be monitored in the environment; however, this does not provide the quantitative information that is needed to estimate exposure risks (Diogene and Campas 2017).

In this context, high performance liquid chromatography-mass spectrometry (HPLC-MS) methods are increasingly replacing HPLC methods with optical detectors (Luckas et al. 2015; Diogene and Campas 2017).

In the case of marine toxins, most of the instrumental analyses have been developed for the control of contaminated seafood. Cheng et al. (2005) described a method to detect brevetoxins in sea breezes that has been used in epidemiological studies and in assessing how far inland brevetoxins move (Kirkpatrick et al. 2010b).

Current methods to detect and measure concentrations of many cyanotoxins in water include:

- enzyme-linked immunosorbent assay (ELISA)
- protein phosphatase inhibition assays (PPIA) for microcystins
- physiochemical analysis by high performance liquid chromatography (HPLC) methods to separate substances in the sample, combined with detection and quantification through mass spectrometry (MS), tandem mass spectrometry (MS/MS) or ultraviolet/photodiode array detector (UV/PDA).

The alert level framework incorporates the ELISA field test kit as a useful screening tool for determining the presence or absence of toxin/dissolved cyanotoxins in recreational water. It should be noted that this approach may overestimate the level of risk and it is best practice to confirm toxin content and to routinely check for false negatives using instrumental methods (HPLC, HPLC/MS; Gaget et al. 2017). Lawton et al. (TCiW 2021) gives an overview of the performance of these methods and the institutional capacity needed, including staff training.

An evolving method to assess potential toxin production is to monitor for cyanobacterial toxin genes (TCiW, Padisak et al. 2021). Relating the prevalence of these genes to that of other genes that represent the total cyanobacterial population can provide an indication of the share of toxin-producing cyanobacteria.

Genetic approaches can be useful to assess how changes in conditions (e.g. streamflow, water exchange rate, temperature extremes, water quality) affect toxin occurrence, downstream transport, and proliferation of cyanotoxin-producing cyanobacteria in large rivers (Graham et al. 2020).

5.4.6. Public health advisories and warnings

Recreational water users should have access to sufficient information to enable them to make an informed decision on using a recreational water site, particularly at a water site where harmful algal and cyanobacterial blooms may occur. This is particularly important where scum-forming cyanobacteria occur, as the location and intensity of scums may vary within hours, and responses from routine monitoring may not be valid at the time of water site use.

The alert level framework enables a proactive and transparent approach for communicating risk to the public. Raising public awareness of the potential risk to water users is triggered at the alert level. Installing information signs that provide the public with information on the appearance of harmful algal blooms and the potential risk should be considered. Options to provide information about harmful algal bloom events include signage, websites and media channels, including social media.

For freshwaters, such situations are most effectively managed in the context of an alert level framework that defines actions to take and communication channels to activate once alert levels are exceeded.

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 multiple media channels that the water body is potentially unsafe, as identified by the alert level 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 precautions necessary to minimise exposure.

Once an area has been identified as at risk from harmful algal or cyanobacterial 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.

Precautionary measures to protect health and educate water users in areas where cyanobacteria and algal blooms may occur include:

- avoiding areas with visible blooms and/or algal/cyanobacterial scums in the water, on the shore or growing on surfaces, including sediment. Direct contact and swallowing appreciable amounts are associated with the highest health risk.
- for large beaches with substantial amounts of dried bloom material accumulated onshore and blown about by wind, avoid being downwind to avoid inhaling dust
- for ocean beaches, with a *Karenia brevis* red tide and onshore sea breezes, avoid exposure to aerosolised brevetoxins by moving inland or, where available, going to an air-conditioned space
- if sailing, windsurfing, or undertaking any other activity that is likely to involve water immersion in the presence of harmful blooms, or debris/weed mats indicating the potential presence of *Moorea producens* on the sediment, wear clothing that is close fitting at the openings. Use of wetsuits may result in a greater risk of rashes because bloom material that may be trapped inside the wetsuit will be in contact with the skin for extended periods.
- after coming to shore, shower or wash yourself down to remove any debris
- wash and dry all clothing and equipment after any contact with blooms and scum
- if health effects are experienced after any type of exposure, seek medical advice.

The specific exposure scenarios leading to an increased risk for sub-populations that have been identified include infants playing in shallow waters in the presence of cyanobacterial blooms, and exposure of sub-groups such as asthmatics and workers such as lifeguards on beaches. These groups are considered more vulnerable than the general population when exposed to aerosolised marine algal or cyanobacterial toxins.

Organisations can manage the increased risk for these sub-populations in multiple ways. Firstly, within the development of regulations, risk can be accounted for by the approach of selecting body weight and water ingestion volumes relevant to children and by the use of uncertainty factors in deriving guideline values. Secondly, agencies can use a range of strategies to guide and influence the behaviour of recreational water users to avoid the hazard. Options for this range from informing users by creating awareness and enabling individual responses to bloom situations, to temporarily banning waterbody use for the duration of the bloom.

5.4.7. Public health surveillance and risk communication

Although very few cases of human illness caused by recreational exposure to harmful algal or cyanobacterial blooms are known, water body managers, lifeguards, and other stakeholders should be prepared for such incidents.

Rapid water quality testing of the recreational water body, as close as possible (in time and space) to the exposure believed to have caused illness, provides valuable information for the diagnosis and for immediate management actions (e.g. temporary water site closure). Beyond such immediate management responses, reporting suspected human/animal exposure and collating such reports, is important for improving the evidence on the relevance of harmful algal blooms to health. Awareness and networking of laboratories involved in microbiological and chemical analyses are important so that they can trigger a timely sampling campaign at the water site where patients were exposed.

Public health authorities should be informed when harmful blooms occur. This helps them to deliver a consistent message to the public and to recreational water users. It may also increase the likelihood of rapid notification of any health impacts from contact with the bloom by raising the profile of the issue and increasing medical practitioner awareness.

As people become more informed about harmful blooms, they may be more likely to suspect them to be the cause of symptoms experienced after recreational activity and to promptly seek medical advice. Medical practitioners therefore need access to information about harmful algal blooms and toxin effects, including what questions to ask their patients about exposure and what symptoms they may expect to see in exposed patients.

With the increased occurrence and persistence of harmful blooms, especially in the context of climate change, the systematic documentation of occurrence and national health data reports can provide important insights into exposure, trends and health impacts. For example, the United States Centres for Disease Control and Prevention (US CDC) have a national public health system that collects information about harmful algal and cyanobacterial blooms and the illnesses they can cause in humans and animals (refer to Box 5.5).

Box 5.5 One Health Surveillance: US CDC's One Health Harmful Algal Bloom System

The US CDC's One Health Harmful Algal Bloom System (OHHABS), established in 2016, is a reporting system that gathers information to better understand harmful algal blooms and the illnesses they can cause in humans and animals.

OHHABS is an example of One Health surveillance that aims to improve surveillance and health outcomes by recognising that the health of humans is connected to the health of animals and the environment.

The data collected helps better define patterns of harmful algal and cyanobacterial bloom occurrence, protect water and food, and to communicate with the public to prevent future illnesses.

Source: [About the One Health Harmful Algal Bloom System (OHHABS) | One Health Harmful Algal Bloom System (OHHABS) | CDC]

5.5. Research and development

5.5.1. Role of climate change in the distribution and intensification of harmful algal and cyanobacterial blooms

Climate change is transforming aquatic ecosystems, which is expected to influence the distribution and intensity of harmful algal and cyanobacterial blooms (Gobler 2020). The impacts of climate change on species distribution and occurrence have been the focus of growing research, with the IPCC's 2019 *Special Report on the Ocean and Cryosphere in a Changing Climate* the first to explicitly link harmful blooms to climate change (Gobler 2020). As this field advances, it is expected that the state of knowledge of harmful blooms in Australia will evolve.

For example, a review of the potential effects of climate change on harmful marine blooms in Aotearoa New Zealand found that certain taxa are expected to become more prevalent under warming conditions (Rhodes and Smith 2022). Species belonging to *Karenia* and *Heterocapsa*, which are associated with skin, eye, and respiratory irritation, may increase in range and bloom frequency. The review also noted that blooms of benthic dinoflagellates like *Ostreopsis* are already common in northeastern coastal areas, and the more toxic *O. cf. ovata* could become dominant with continued ocean warming. Additionally, benthic cyanobacteria, such as *Lyngbya* spp., may expand into southern waters.

Elevated sea surface temperatures resulting from a marine heatwave affecting southern Australia was considered a contributing factor to the significant *Karenia mikimotoi* algal bloom that developed along the South Australia coastline in 2025 (SARDI 2025). The bloom was accompanied by the detection of brevotoxins, the first reported occurrence in Australia, suggesting the presence of other *Karenia* species (SARDI 2025).

Burford et al. (2020) also notes that benthic cyanobacteria appear to be increasing in both marine and freshwater environments, which represent a critical area for future research under climate change scenarios. Since much of the focus on harmful algal blooms has been on pelagic species there is a need for more targeted monitoring of benthic blooms, which will also require the development of cost-effective, rapid sampling methods.

5.5.2. Characterisation of toxins in spray and aerosols and incidence of illness

Research priorities for recreational water bodies, encompassing both marine and freshwater blooms, include:

- quantitative and qualitative characterisation of toxins in spray and aerosols generated during blooms
- the identification of associated health effects in humans and animals from exposure.

To better understand exposure risk, aerosol concentrations should be measured at varying distances from the bloom sites to assess how far levels that induce health effects may travel. Sampling combined with epidemiological studies, can help clarify the health impacts of aerosol exposure, which is important for developing guidance to reduce human and animal exposures to these aerosols.

5.5.3. Toxicological studies using multiple congeners to derive cyanotoxin guideline values

For freshwater cyanobacteria blooms, it is unclear whether the current state of knowledge covers the key cyanotoxins because there is evidence of toxic effects that cannot yet be allocated to any specific substance (TCiW, Humpage and Welker 2021). Furthermore, some of the symptoms reported in connection with blooms might be due to microorganisms associated with the bloom.

In vitro effects-based assays (particularly skin irritant assays) may be helpful to isolate, characterise and quantify sum toxins and/or their congeners in recreational water samples taken from algal blooms (Hughes et al. 2025). This could potentially be useful for both exposure and hazard assessment. However, while some examples of bioassay screening methods are routinely used in other contexts for assessing neurotoxicological and skin sensitisation effects (e.g. drinking water, consumer products), further research and development is needed to increase the efficacy of this approach for assessing recreational water quality.

So far, available guideline values from other agencies for microcystins (MCs) are based on a point of departure for only one congener, MC-LR. The data from intraperitoneal injection for numerous other congeners suggest that many of them are far less toxic. However, the current intraperitoneal data cannot be used to derive a suitable point of departure, and therefore the only available option is currently a worst-case assessment based on MC-LR as one of the most toxic congeners.

Chronic or sub-chronic animal assays with the 5–10 most frequently occurring congeners would be needed to allow identification of a point of departure for these as well. This is important to enable more realistic risk assessments.

5.5.4. Monitoring techniques to detect rapid changes in biomass

A key problem for risk assessment is the rapid change of planktonic algal and cyanobacteria biomass, which is influenced by bloom buoyancy, currents and wind direction. This rapid change raises questions about the reliability of snapshot-type monitoring. Developing continuous integrative monitoring approaches would support more accurate risk assessment—for example, through permanently installed probes that measure indicators like pigment fluorescence, or via remote sensing. Although basic knowledge for these approaches exists (TCiW, Welker et al. 2021), further development is needed to make them affordable and practical for application.

The role of using emerging technologies for surveillance and assessment, such as drones and satellite data, could also be explored. The ongoing collection of data would support the development of national datasets for further analysis.

5.5.5. Standardised methods for analysis

The standardisation of analytical methods for measuring a broader range of algal and cyanobacterial toxins, along with the availability of standardised reference material for their quantification, is important for routine monitoring. Ideally, methods should be low-cost and suitable for implementation across many operational laboratories.

5.5.6. Fate of harmful algal and cyanobacterial blooms toxins in the water environment

More work is needed to understand the fate of toxins from harmful algal and cyanobacterial blooms in aquatic environments. This includes investigating the range of variation in toxin cell quotas of toxic strains and the dynamics within blooms that lead to changes in strain proportions and toxin production and release (Willis et al. 2025). This is because the timing and extent of release during blooms can be highly variable, which influences exposure risks. Additionally, research is required to better understand toxin fate under different environmental conditions, as well as the transport of toxins through water bodies, especially for benthic algae and cyanobacteria. An example of this is the need for a deeper understanding of lyngbyatoxin levels and fate, produced by lyngbyatoxin-producing marine cyanobacteria, to better understand exposure risk from mat material.

5.6. Supporting tools and information

Information sheet – Derivation of guideline values for cyanotoxins in recreational water

Information sheet – Cyanobacterial biomass triggers supporting the alert level framework

Information sheet – Exposure assumptions

Information sheet – Preparing a risk communication plan

Risk communication planning checklist

5.7. References

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6. Chemical hazards

Guideline recommendation

Water contaminated with chemicals at concentrations that may cause harm to humans is unsuitable for recreation.

Where default chemical hazard screening values (determined by multiplying the current Australian drinking water guideline value by 20) are exceeded, further risk assessment should be undertaken.

Site specific screening values for chemical hazards of concern can be developed in consultation with the relevant health authority or regulator.

Recreational water bodies should have pH in the range of 6.5-8.5 (a pH range of 5-9 is acceptable in recreational water bodies with very poor buffering capacity) and a dissolved oxygen content greater than 80%.

6.1. Overview

Chemical hazards can enter water bodies or be deposited on shore from both natural and anthropogenic sources. Chemical hazards may be from point sources of pollution, (e.g. industrial or wastewater discharges), or nonpoint diffuse sources (e.g. run-off from land). In most cases, and depending on local circumstances, such as river flows and tidal movements, there will be dilution or dispersion of chemical hazards which reduces the risk to public health. Most potential risks relate to long-term exposure to chemicals from ongoing and persistent contamination. An exception to this includes toxins produced by marine and freshwater cyanobacteria and algae, which are addressed in more detail in *Chapter 5 – Harmful algal and cyanobacterial blooms*.

Risk of human exposure to chemical hazards in recreational water bodies should be assessed on a case-by-case basis taking local factors into account. The assessment should consider potential sources of chemical hazards within the catchment and the pattern and type of recreational and cultural use of the water to determine the degree of recreational water users' exposure to those chemical hazards.

Depending on the complexity of the water site and activities that are undertaken, a simple approach using default screening values for chemicals can be used to determine if further investigation is required. For more complex scenarios, further assessment of the risks should be undertaken in consultation with the relevant health authority or regulator. For some recreational water bodies, this may involve deriving site specific chemical hazard screening values. For example, some water bodies may restrict certain activities but allow others (e.g. no swimming allowed at a local jetty but boating permitted). Site specific screening values can be derived using estimates of exposure for local water use (see *Information sheet – Deriving site specific screening values for chemicals in recreational water*).

The content of this chapter has in parts been adapted to the Australian context from the World Health Organization's *Guidelines on recreational water quality. Volume 1: coastal and fresh waters* (WHO 2021) and has also been informed by a review of the evidence base in the Australian context (O'Connor 2022).

6.2. Health effects of chemical hazards in recreational water bodies

According to O'Connor 2022 and WHO (2021), there are very few reports of human health impacts associated with recreational exposure to chemicals in fresh or marine waters. Health effects of some chemicals may be well known in human or animal studies (e.g. see individual chemical fact sheets in the *Australian Drinking Water Guidelines*, NHMRC 2011). However, these health outcomes are less likely to occur in recreational water environments where the chemicals may be very diluted, dispersed quickly or the actual exposure to humans is very low.

6.3. Assessment of risks associated with chemical hazards in recreational water bodies

Recreational water users are unlikely to come into contact with sufficiently high concentrations of most chemical hazards to suffer adverse effects from a single exposure. Depending on the activity, the exposure patterns associated with most recreational water activities means that the actual overall exposure to individual chemical hazards is generally very low. Even repeated (chronic) exposure is unlikely to result in adverse effects at the concentrations of chemicals typically found in natural water bodies.

Nevertheless, scenarios do exist that may contribute to an increased risk of a chemical water quality hazard at a particular recreational water body (e.g. spills, uncontrolled industrial discharges). Some waters may be permanently unsuitable for recreation especially where there is direct contact with contaminated water (e.g. quarries and abandoned mine pits) (WHO 2021).

It remains important to systematically identify chemical hazards and assess any potential human health risks to ensure safety on a case-by-case basis. The risk assessment should take local factors into account including any applicable local guidelines or regulations.

An evaluation of the evidence (O'Connor 2022) indicated that the available evidence was inadequate to determine if exposure to chemical hazards (e.g. per- and poly-fluoroalkyl substances (PFAS), pesticides, nanomaterials, hydrocarbons, metals, endocrine disrupting chemicals (EDCs), surfactants, or combinations) could give rise to any significant human health risks in recreational water bodies, given that such exposures are generally low. The available evidence lacked sufficient detail to determine which chemicals harmful to human health might be present at elevated concentrations in recreational water bodies and their sources. Similarly, evidence for the physicochemical properties of chemical hazards that may enhance uptake via dermal, inhalation or ingestion exposure pathways was generally limited.

First Nations' knowledge and sensory observations, informed by long-standing relationships with Country, can provide valuable complementary insights and should be considered when evaluating risks to water quality.

The chemical form and exposure assessment are important inputs into assessing the risks from chemicals in waters used for recreational or cultural purposes. These will vary depending on factors such as activity type (e.g. swimming versus kayaking), chemical form (e.g. particulate or dissolved) and climate.

Key elements for assessing the risk of chemical hazards in recreational water bodies include (Health Canada 2022):

- historical understanding of the area to identify past activities that may result in contaminated water and/or sediments
- sanitary inspection of the recreational water area to identify any obvious sources of chemical contamination, including both point (e.g. outfalls, sewage discharges) and non-point sources (overland flow from agricultural, industrial and urban catchments)
- additional actions as necessary to support a quantitative health risk assessment, including chemical analysis of representative water and sediment samples, a screening level risk assessment or review of the available toxicological information on the chemical hazard(s)
- consideration of the type and pattern of recreational activity to determine whether significant pathways of human exposure exist (e.g. through ingestion, inhalation or skin absorption)

consideration of the effects of the water body dimensions (area, depth) and other hydrodynamic and meteorological characteristics (tides, currents, prevailing winds) on the impact of the chemical water hazard in question.

6.3.1. Qualitative and quantitative assessments

6.3.1.1. Qualitative assessment

Information on the pattern and type of recreational and cultural uses of the water will indicate the degree of contact with the water, and whether there is a significant risk of ingestion or inhalation of aerosols.

Qualitative assessment is the first step of the chemical hazard identification process. This step helps identify what chemicals might be present by considering the pollution sources. This would ideally be undertaken at all water sites as part of an initial risk assessment to inform decision making including actions to eliminate the hazard, actions to reduce exposure, or whether further investigation is required.

An inspection of the water environment during an initial risk assessment (such as a sanitary inspection) should reveal obvious sources of chemical contamination. However, there may be sources of pollution that are only evident during a rainfall event, for example, sewer overflows. Therefore, rainfall event-based inspections should be conducted. Knowledge of historical industrial activities within the catchment will help inform the potential chemical hazards that should be considered in the risk assessment for a given recreational water environment. For example, sites subject to regulatory clean-up orders, such as the remediation of old industrial sites contaminated with toxic chemicals at Homebush Bay Sydney, would provide important insights into potential chemical hazards for consideration in a risk assessment.

Environmental indicators and drivers (e.g. fish deaths due to acid sulphate soils) could also be considered as part of the risk assessment as effects on aquatic organisms occur at much lower concentrations than observed for human health and could be an early warning of chemical contamination. Records of such events could assist in understanding the underlying causes and the potential relevance of chemical hazards (if any) for consideration in the risk assessment.

Site inspection of industrial facilities may be another way to monitor discharges. Issues to be noted in a site inspection are:

- types/forms of and 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
- effectiveness of wastewater treatment processes, and site containment of runoff (i.e. bunds).

Some of this information may be available through routine monitoring and reports. 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.

6.3.1.2. Quantitative assessment

Quantitative risk assessment may be required when the qualitative assessment of a water body indicates probable contamination and a significant risk of exposure (refer to section 6.3.5).

Chemical analysis is required to inform the quantitative risk assessment. A screening level risk assessment should be undertaken initially (refer to section 6.3.5.1). The outcomes of the screening level risk assessment will help determine whether further sampling and risk assessment is required.

Care should be taken in designing the sampling program to account for variations in concentrations with 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 scenario, with the results informing the frequency and intensity of a wider sampling program. In some cases, the results may indicate that a wider sampling program may not be needed, provided on-going surveillance of the catchment does not identify changes to the risk profile.

When undertaking a detailed quantitative risk assessment for a specific recreational activity, an understanding of the anticipated exposure in terms of both concentration of the chemical hazard and frequency of exposure associated with the recreational or cultural activity and water user cohort is needed (refer to section 6.3.5.2). The assessment should consider the form of the chemical hazard, particularly for inorganic chemicals, as this will determine its bioavailability and toxicity. The form of the chemical in water may also be affected by water chemistry (e.g. pH, hardness, alkalinity, dissolved organic carbon, temperature).

6.3.2. Sources and occurrence of chemical hazards in recreational water bodies

An understanding of the known and potential sources of chemical hazards will enable informed decisions regarding expected temporal and spatial occurrence variability. This understanding will support preliminary decisions regarding likely occurrence of specific chemicals at water sites and thus enable prioritisation of chemical hazards for further assessment. Consideration of known and potential sources of chemical hazards should also inform both water quality monitoring activities and risk management practices.

Chemical hazards may be present in recreational water environments from many different sources. Some potential sources of chemical hazards are listed in Table 6.1.

Common sources of chemical hazards include stormwater runoff, sewage effluent discharges, releases from sewers via leakage or wet weather overflows, industrial and commercial discharges, agricultural run-off, atmospheric deposition and erosion of contaminated land sites. Natural processes may release chemicals into water environments, such as weathering of rock or growth of algae or cyanobacteria.

Where motorboats are used extensively, exhaust fumes, fuel leaks or spills and antifouling products may be a cause for concern (Mastran et al. 1994; Mosisch and Arthington 1998; Wang et al. 2022; Carreño and Lloret 2021; Lewis 2020). Fuel spills can be visible as slicks appearing as dark or iridescent sheens. Chemical hazards may also be derived from spills from watercraft, such as ships, ferries or recreational boats. Some chemical hazards may also be introduced from bathers. A recent study in Australia (Verhagen et al. 2025) found that recreational activities, specifically boating and swimming, are a source of polycyclic aromatic hydrocarbons (PAHs). The findings of this study highlight the impact of petrol-powered boating and swimming on water quality. Chrysene, fluoranthene, and benzo(bjk)fluoranthene were the most frequently detected PAHs. Higher levels of PAHs at water sites that allow petrol-powered boating highlights the contribution of these on-water activities to the contamination of water bodies. The presence of ultraviolet filters in the lake samples reflects the direct release of these chemicals from personal care products used by recreational water users such as from ultraviolet filters used in sunscreen products. These findings are consistent with other studies (Hodge et al. 2025; Labille et al. 2020).

Many chemicals of potential concern have low water solubility and tend to accumulate in sediments such as soil, sand and mud. The accumulation of chemical hazards in water and sediments may occur in recreational water bodies receiving continuous or intermittent sources of pollution or may be the result of historical contamination. Slow-flowing lowland rivers, ephemeral streams and waterholes, and lowland lakes and coastal lagoons may be susceptible to the accumulation of chemical hazards and provide low levels of dilution or dispersal. Contaminated sediments may serve as an indirect source of contamination of waterbodies through resuspension or dissolution of contaminants into the water column.

If water quality is expected to be impacted by chemical contamination from sediments, this should be considered in the site specific risk assessment for the recreational water environment. Information on past/current industrial activities in the catchment area and geological characteristics can provide an indication of whether contaminated sediments are likely to be present and the identity of possible chemical hazards.

Where groundwater contamination is suspected within the catchment, groundwater-surface water interactions should be understood to assess potential impacts to recreational water.

There may be circumstances where discrete water bodies containing water from mineral-rich strata could contain high concentrations of some naturally occurring substances, however this is not likely to be a significant source of chemical hazards compared to industrial, agricultural and urban sources. Such water bodies may contain metals, such as iron, that may give rise to aesthetic degradation of the water (WHO 2021).

Table 6.1 - Potential chemical hazards present in water environments

Chemical or chemical class	Potential sources and drivers of contamination
Metals and other inorganics e.g. lead, mercury, tin, copper, uranium, arsenic, cadmium	Natural leaching from strata around water body, mining tailings and wastewater, industrial discharges, fertilisers, stormwater runoff and discharges, wastewater discharges
Petrochemicals/ hydrocarbons e.g. oil, petroleum	Spills, fuel leaks, exhaust emissions from motorised watercraft and marinas, run-off from land, oil terminals or service stations, wastewater discharges
Polychlorinated biphenyls (PCBs) and dioxins	Agricultural discharge and run-off, onshore and offshore industrial discharges and spills including legacy/abandoned contaminated sites
PFAS	Discharges from contaminated sites, historical firefighting and fire training activities
Pesticides **e.g.** organochlorines, herbicides, insecticides, nematicides and fungicides	From agricultural discharges and run-off from land
Microplastics	Wastewater discharges, landfill leachates, land application of biosolids, degradation of macroplastic wastes and litter
Biological toxins e.g. cyanotoxins, endotoxins	For harmful algal and cyanobacterial blooms refer to *Chapter 5*. Water environments can contain elevated levels of environmental bacteria which, whilst not overtly toxic, can trigger immunological responses that create adverse symptoms in some individuals. The general term endotoxin is used to refer to this bacterial cellular material which can trigger symptoms such as fever when ingested at elevated levels. Water activities can disturb sediments and biofilms, which in turn can increase mobilisation of living and dead gram negative bacteria and further exacerbate endotoxin-related risks.

6.3.3. Exposure assessment

Exposure is a key factor in determining the risk of toxic effects from chemicals on humans in recreational water bodies and this varies with different recreational activities. The frequency, extent and likelihood of exposure are crucial aspects of assessing risks to human health from a chemical hazard.

Understanding and making reasonable assumptions about exposure is an important step in assessing the human health risks from chemical hazards in water bodies. Several factors should be considered as part of this process:

- the source and occurrence of chemical hazard/s
- the key route/s of exposure
- the frequency and duration of exposure
- uptake assumption values.

Important exposure routes for chemical hazards relevant to recreational and cultural water use are outlined in Table 6.2.

Table 6.2 - Routes of exposure for chemical hazards in recreational water bodies

Potential route of exposure	Comments	Hazard-specific assessment
Ingestion	Ingestion is likely during immersion or partial immersion activities. 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 activities are difficult to obtain.	When undertaking a hazard-specific assessment, ingestion should be considered as the default route of exposure.
Direct surface contact (dermal, ocular, mucous membrane)	The routes of exposure through direct surface contact include absorption through skin, eyes and mucous membranes. Skin and eye irritation may result from exposure to some chemicals, including some cyanobacterial toxins such as lyngbyatoxin-a (refer to *Chapter 5 - Harmful algal and cyanobacterial blooms*), and alkaline and acidic substances with extreme pH (<4 or >11). Generally, irritation will be transient and resolved by washing in clean water. Causal agents are typically not identified except in the presence of harmful algal and cyanobacterial blooms or specific circumstances such as swimming in unsuitable water bodies (e.g. abandoned quarry or mine pits filled with water).	Exposure to chemical hazards via direct contact may need to be assessed if chemical concentrations in water exceed screening values based on ingestion for chemicals with moderate to high skin permeability. Generally, these chemicals will only be present in significant concentrations in the event of a spill.

Potential route of exposure	Comments	Hazard-specific assessment
	Skin absorption can also be a route of uptake for certain metals and for some organic chemicals (Brown et al. 1984; Moody and Chu 1995); however, this depends on the efficacy of dermal absorption for a given chemical (refer to US EPA 2004; ATSDR 2005; enHealth 2012b). Skin is an effective barrier for many chemicals; its permeability is influenced by the physical properties of the chemical. Chemicals with high permeability are typically organic chemicals of low molecular weight that are non-ionized and lipid soluble (e.g. xylene, benzene, toluene). Exposure may be exacerbated by broken or damaged skin. It is thought that wetsuits, when used for long periods in the water, trap water against the skin and create a microenvironment that may enhance the absorption of chemicals through the skin and the development of skin irritation or allergy. Skin exposure may occur if the sediments are disturbed and resuspended, or where recreational water users are in direct contact with sediments.	
Inhalation	Inhalation may be an important exposure route especially for highly volatile chemicals and where there is a significant amount of spray or aerosols generated from the recreational activity (e.g. water or jet-skiing, white water rafting)	Evidence of the significance of inhalation exposure for specific hazards should be sought. If evidence is suggestive that inhalation may be a significant exposure route, this should be considered in the risk assessment and in establishing a site specific screening value.

Consistent with WHO (2021), a conservative incidental ingestion volume of 250 mL of water by a child per swimming event and an estimated frequency of 150 swimming events per year have been adopted for calculating the default chemical hazard screening value. The basis for the exposure value is provided in the *Information sheet – Exposure assumptions*.

These default exposure values are based on the ingestion exposure route via swimming, and although the ingestion volume and frequency are sufficiently conservative for most recreational settings, it may not accurately reflect water use in all contexts. Where there is site specific data available (e.g. event frequency data), its application in the risk assessment for that recreational water environment should be undertaken in consultation with the relevant health authority or regulator.

6.3.4. Dose-response

The safe level of exposure to chemical hazards is determined in accordance with studies undertaken to assess various modes of toxicity. These studies have generally not been undertaken where recreational and cultural water use is assumed to be the principal mode of exposure.

Nonetheless, for many chemical hazards, toxicological data are used and reported in the *Australian Drinking Water Guidelines* and consistent data should generally be applied for recreational water quality guidance. Other agencies, such as Food Standards Australia and New Zealand (FSANZ) and the Australian Pesticides and Veterinary Medicines Authority (APVMA) also derive and report applicable toxicology data, such as 'tolerable daily intake' values. These values can often be directly interpreted as representing safe levels of human exposure. In other cases, toxicological data from animal-based experiments may be reported and additional safety factors will need to be applied to account for inter-species and intra-species variability.

Chemicals for which inhalation exposure is assumed to be significant during recreational activity will require the use of inhalation-based toxicological data since many chemicals exhibit different toxicity via inhalation routes compared to oral routes.

For many chemical hazards, toxicological response is assumed to exhibit a 'threshold'. That is, a level of exposure may be identified, below which, the chemical is not considered to impart significant toxicity. Safe levels of exposure can be defined as levels lower than the identified threshold, and usually lower still, by the application of safety factors.

For chemical hazards for which no threshold can be demonstrated, it can be expected that, as the level of exposure decreases, the resultant hazard similarly decreases. The risk associated with exposure to very low concentrations may be extrapolated using a risk assessment modeland is often orders of magnitude lower than the dose–response relationship observed at higher doses. Several uncertainties are involved, but the calculations used tend to overestimate rather than underestimate the risk and so provide a greater margin of safety. That is, it is possible that the actual risk from exposure to low concentrations may, in fact, be lower than the estimated values by more than an order of magnitude.

6.3.5. Risk characterisation

The derivation of recreational water quality guideline values must account for the specific nature of a chemical compound (i.e. associated toxicity) and concentration, as well as the nature of human exposure to it.

There is insufficient evidence to establish absolute guideline values for chemical hazards in recreational water bodies, therefore, each approach needs to account for the various types and frequencies of contact (e.g. passive, incidental, whole body) and types of exposure (e.g. dermal, ingestion, inhalation). NHMRC has chosen to adopt an approach consistent with WHO (2021) – the approach is to calculate a screening value that estimates a threshold level that can be used to determine if further assessment is required.

6.3.5.1. Screening values

Provided that care is taken in their application, the *Australian Drinking Water Guidelines* (NHMRC 2011) can provide a starting point for deriving values that can be used in a screening level risk assessment, together with estimates of exposure associated with recreational activities. Health-based guideline values in the *Australian Drinking Water Guidelines* are inherently conservative in their derivation and are health protective for the general population including children.

The *Australian Drinking Water Guidelines* (NHMRC 2011) provide a point of reference for exposure through ingestion, but with a few exceptions these relate to significant lifetime exposure. In most cases, with the exception of spills, unregulated industrial discharges and accidental discharges, chemical exposures will be below guideline values in the *Australian Drinking Water Guidelines.* These guideline values are based on ingestion of 2 litres of water per day – this is greater than ingestion associated with any recreational or cultural activities in and around water bodies.

Consistent with WHO (2021), a default screening value for a given chemical can be determined by multiplying the health-based guideline value in the *Australian Drinking Water Guidelines* by 20. The factor of 20 is based on conservative exposure estimates for children bathing in recreational water bodies and ingesting 37.5 litres per year. It is calculated using a conservative ingestion water volume of 250 mL per swimming event (DeFlorio-Barker et al. 2018) and event frequency of 150 events per year (enHealth 2012a). This equates to approximately 5% of the annual ingestion volume of drinking water; 730 litres assuming 2 litres per day ingested. Table 6.3 provides default screening values for some indicative chemicals based on multiplying the Australian drinking water health-based guideline value by a factor of 20.

Exceedances of the screening value do not necessarily indicate that a health risk exists. Rather, they suggest the need for a specific evaluation of the chemical, taking into consideration local circumstances and conditions of the recreational water area. These could include the types and frequencies of recreational water activities, and the effects of winds, currents and tides on chemical concentrations.

It is acknowledged that these screening values only consider the ingestion route of exposure. For some chemicals, consideration should also be given to inhalation and dermal exposure routes and patterns that cannot be extrapolated from drinking water guideline values. Refer to section 6.3.5.2 if it is determined, following a screening level risk assessment, that a specific evaluation of a chemical hazard is necessary.

Table 6.3 - Example screening values for indicative chemicals in recreational water bodies

Chemical or chemical class	Australian drinking water health-based guideline value* (mg/L)	Default screening value for assessing water bodies** (mg/L)
Arsenic	0.01	0.2
Benzene	0.001	0.02
Cadmium	0.002	0.04

Chemical or chemical class	Australian drinking water health-based guideline value* (mg/L)	Default screening value for assessing water bodies** (mg/L)
Chromium	0.05	1
Copper	2	40
Ethylbenzene	0.3	6
Lead	0.005	0.1
Manganese	0.1	2
Nickel	0.02	0.4
Toluene	0.8	16
Xylenes	0.6	12

* Source: NHMRC (2011), version 4.0. Screening values should always be calculated using the most current version of the *Australian Drinking Water Guidelines* available on the NHMRC website. ** Based on 20 times the Australian drinking water health-based guideline value.

6.3.5.2. Deriving site specific screening values for chemicals

It is intended that the default site specific chemical screening values will indicate recreational water quality concentrations that are sufficiently protective of human health across a broad population. These values should be considered and applied in the context of the data, estimations and calculations used to derive them.

In circumstances where the default chemical screening values may not be representative, site specific chemical screening values can be developed in consultation with the relevant health authority or regulator if good toxicological and local exposure data is known. The nature of exposure requires consideration of potential exposure routes, and estimation of exposure durations and frequencies.

The general considerations and approach that should be applied to developing health-based site specific screening values for chemical hazards in recreational water are described in *Information sheet – Deriving site specific screening values for chemicals in recreational water*.

Dermal exposure may need to be considered if concentrations exceed screening values based on ingestion for chemicals with moderate to high skin permeability. Generally, these chemicals will only be present in significant concentrations in the event of a spill.

The *Environmental Health Risk Assessment – Guidelines for assessing human health risks from environmental hazards* (enHealth 2012b) should be referred to where dermal and inhalation exposure are relevant for a specific hazard, for example, chemicals with moderate to high skin permeability or volatile compounds. The *Australian Exposure Factor Guide* (enHealth 2012a) provides exposure factors including for ingestion, dermal and inhalation pathways.

6.4. Management and communication

A risk management approach is the most effective way of protecting recreational water users from the risk of exposure to chemical contamination at recreational water areas. This encompasses identifying sources of chemical hazards that can be eliminated, or restricting recreational activities including type and occurrence during periods or in areas perceived to be of increased risk. Public communication to raise awareness and timely advisories are essential to reducing human health risk from exposure to chemical hazards in recreational water.

A sanitary inspection (refer to *Information sheet – Sanitary inspections)* can help identify potential sources of chemical hazards and inform both mitigation strategies and monitoring requirements. When potential sources of chemical contamination are known to exist upstream of a recreational water area, additional risk management planning and assessment is required.

Management strategies should focus on catchment protection to eliminate sources of chemical hazards and improved regulation to abate pollution. Catchment protection measures may include improved land use practices to prevent runoff from industrial and agricultural areas (including prevention of fertiliser and pesticide contamination) and reduce soil erosion; improved stormwater management including containment of emissions and run-off from industrial premises; reduction and treatment of wastewater and effluent discharges; and preventing discharges and emissions from watercraft.

In the event of a chemical spill, or uncontrolled discharge, measures should be implemented to prevent or minimise exposure. In some cases, water bodies may be assessed as being permanently unsuitable for human contact (refer to Box 6.1 for examples). Where this is the case (e.g. some quarry lakes), it is essential that the public is informed and regularly reminded of the risks associated with recreational water contact. There needs to be an ongoing inspection and maintenance program to ensure the integrity of fences and signs installed to prevent access to such water bodies.

Box 6.1 Chemical spills and discharges (adapted from WHO 2021)

Uncontrolled discharges often cause visible and distinct discolouration of receiving waters (see *Chapter 7 - Aesthetics aspects of recreational water*).

Oil spills can release complex mixtures of chemicals, primarily hydrocarbons. Most are not soluble, and spills produce large, visible floating slicks that discourage use of the water body. A common feature of the soluble hydrocarbons (e.g. toluene, ethylbenzene, xylenes) is the production of distinctive tastes and odours at concentrations that are well below those that represent health concerns (WHO 2008, 2017). These tastes and odours will typically render water unsuitable for primary contact recreational or cultural use, although secondary contact uses may occur. Studies of human health impacts of oil spills have largely focused on impacts on clean-up volunteers and communities living near the site of spills, rather than exposure through recreational and cultural use of water bodies (Aguilera et al. 2010).

Uncontrolled discharges from industrial and mine sites can release high concentrations of chemicals such as metals and metalloids into receiving waters (Nancucheo et al. 2017; Petrounias et al. 2019). Mine wastewaters can have a pH <3 or >11. Quarries and abandoned mine pits that have filled with water will typically contain high concentrations of the minerals associated with the ore being extracted, may contain high concentrations of chemicals used in extraction processes, and can have very high or low pH. Quarry and mine-pit lakes can contain metals (e.g. iron, aluminium, manganese, lead, copper, cadmium, nickel, zinc) and metalloids (e.g. arsenic, antimony). They can contain water with pH <3 (Nancucheo et al. 2017; Petrounias et al. 2019), and limestone quarry lakes can contain water with pH >11. Swimming in waters with pH <4 or >11 can cause irritation of the eyes, skin and mucous membranes.

(Source: WHO 2021)

6.4.1. Monitoring and environmental surveillance

General information on sampling and monitoring is available in *Information sheet- Monitoring programs.*

Considerations in designing a monitoring program for a given recreational water environment include:

- selection of water quality parameters of concern, including hazards and physicochemical parameters, as determined by the historical review and sanitary inspection.
- environmental events that may indicate changes in chemical water quality (e.g. fish deaths or extreme events including floods and droughts)
- the efficacy of upstream control measures for mining and industrial activities, including treatment (if used) and compliance with discharge permits (including flow rates or chemical loads)
- implementation of good management practices associated with use of agricultural and pesticide chemicals in a water catchment
- sampling soil, sediments and underlying groundwater downstream of historical contaminated sites.

Monitoring for chemicals should be risk-based and focused on chemicals of concern in the water body based on an assessment of local pollution sources (refer to *Information sheet – Monitoring programs* or *Information sheet – Sanitary inspections*). While regular monitoring for a large suite of chemicals may not be justified or feasible depending on available resources, there may be instances where local knowledge of contamination events, for example, accidental spills, justifies increased surveillance.

Monitoring of priority chemicals or indicators of chemical contamination (refer to Table 6.4) should be more frequent for recreational water bodies where there are potential sources of chemical hazards as informed by historical reviews and sanitary inspections. Monitoring for the indicators in Table 6.4 is inexpensive and rapid, and therefore can be monitored more frequently.

NHMRC

Table 6.4 - Other measures of chemical or physical quality of recreational water bodies

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, e.g. acid mine drainage.	Waters used for recreational and cultural activities involving direct contact 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. Low pH increases the probability that inorganic substances will occur naturally in water. Whenever the pH is less than 5.5 (e.g. 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.
Oxygen (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 excessive nutrients which may increase cyanobacterial growth. Low oxygen concentrations may be associated with the growth of nuisance organisms, causing taste and odour problems, including the formation of undesirable amounts of hydrogen sulphide. Oxygen saturation greater than 80% should prevent such problems.
Redox potential	Can be used to predict how a chemical will react in water.	Low oxygen concentration and low redox potential can indicate an oxygen poor anaerobic environment which may give rise to the presence of hydrogen sulphide, causing odour problems, or mobilisation of iron and manganese. High oxygen concentration and high redox potential can indicate healthy aerobic environments.
Turbidity	A physical property of water that indicates the presence of fine suspended matter (e.g. sediments)	Turbidity describes the cloudiness of water caused by suspended particles. While this might be due to solids such as clay/silts, it might also include the presence of chemical precipitates such as manganese or iron that might need to be considered in a risk assessment.

For persistent chemical hazards, 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(s) within the recreational water area.

Using a fixed sampling point (or points) will enable statistically 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 the concentration of the chemicals being monitored.

If persistent water quality complaints are received from stakeholders, 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 frequency.

6.4.2. Advisories

It is good practice, as a precautionary measure, for recreational water users to shower with soap and water following recreational activities involving direct contact with water and to always avoid ingestion of the water to ensure that any risk is minimised.

In the case of a pollution event, management of the event will be influenced by its duration, volume and the type and form of contamination. For example, spills can require shorter-term responses, with a focus on clean-up and remediation. Management may be driven by the need to mitigate environmental impacts rather than public health impacts and may be directed by environmental protection agencies. Detection of potentially persistent events, such as pollutants being carried from sites upstream from water bodies, will require much longer remediation strategies, even after the polluting activity ceases. These are also likely to be directed by environmental protection agencies.

The management response to pollution events involving chemical hazards in recreational water environments should include timely and effective risk communication. If changes are detected in water quality as a result of pollution events, multifaceted approaches will generally be needed to provide public health advisories, including:

- issuing of media advice, including social media
- communication with community or residents' groups
- installation of signage and its maintenance (e.g. in the event of vandalism).

Information should be provided on:

- the cause and nature of contamination
- the basis for assessing risks, including the source of guideline or screening values applied

- activities to be avoided
- potential health risks
- remedial action.

6.5. Research and development

More data are needed on volumes of water ingested and inhaled during various recreational activities (e.g. swimming, waterskiing), and on frequencies of exposure in temperate, subtropical and tropical settings.

Research is also needed into dermal exposure to chemicals in recreational water with the potential to cause skin rashes and eye irritation; many reports on these reactions are anecdotal. Research could specifically examine whether wearing of wetsuits increases the risk of skin irritation and the absorption of chemicals through the skin.

6.6. Supporting tools and information

Information sheet – Exposure assumptions

Information sheet – Deriving site specific screening values for chemicals in recreational water

Information sheet – Sanitary inspections

Information sheet – Monitoring programs

6.7. References

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7. Aesthetic aspects of recreational water

Guideline recommendation

Recreational water bodies should be aesthetically acceptable to recreational water 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.

7.1. Overview

Aesthetic issues are important in the public's perception of a recreational water area. Primary aesthetic concerns are obvious pollution of the water body, turbidity, scums and odour. When addressing these issues, measures to protect natural ecosystems should also be considered.

Importantly, poor aesthetic qualities at a recreational water site may indicate the presence of microbial, algal or chemical hazards in the water that require investigation.

This chapter describes aesthetic aspects that may affect the acceptability of recreational water. The content of this chapter has in parts been updated and adapted to the Australian context from the World Health Organization's *Guidelines on recreational water quality. Volume 1: coastal and fresh waters* (WHO 2021).

7.2. Aesthetic parameters

The aesthetic value of recreational water areas including their shoreline beach areas is associated with the absence or presence of objectionable visible materials (e.g. cotton-buds washed up on beaches from ocean wastewater outfalls), colour, oil, grease, scum, litter, odour and other matter. It is also associated with the absence or presence of substances and conditions that produce undesirable aquatic life (e.g. large accumulations of seaweed (macroalgae), nutrient enrichment by nitrogen and phosphorus promoting harmful algal and cyanobacterial blooms).

7.2.1. Transparency and colour

For aesthetic acceptability of recreational water, the transparency and colour of the water should not be significantly worse than natural background.

Ideally, water at swimming areas should be clear enough for water users to estimate depth, to observe subsurface hazards easily and to detect swimmers or divers in the vicinity. Beyond safety considerations, clear water fosters enjoyment of the aquatic environment.

The main factors affecting the depth of light penetration in natural waters include suspended microscopic algae and animals, suspended sediment and mineral particles, dissolved substances, detergent foams, and dense mats of floating and suspended debris.

There are two measures of colour in water: true and apparent.

The true colour of water is the colour after particulate matter has been removed (usually by filtration through a 0.45 µm pore size filter). Added dissolved materials can impart differing true colours. For example, dissolved calcium carbonate in limestone regions gives a greenish colour; ferric hydroxide gives a red colour. Dissolved organic substances such as tannin, lignin and humic acids from decaying vegetation also give true colour to water, usually brown to almost black. Black discoloration of water may particularly become evident following flood events where organic matter may be washed into waterways. Once in the waterway, organic matter can be consumed by bacteria leading to the release of dissolved carbon compounds, a change in pH, and a sudden depletion of dissolved oxygen which in turn can result in the death of aquatic organisms (DSEWPC 2012).

Apparent colour results from both particulate and dissolved materials. Particulates scatter light in water, causing it to look turbid. For example, particulates such as cyanobacteria may impart a dark-green hue to water. Diatoms or dinoflagellates can give a yellowish or yellow-brown colour. Some algae may tint the water red.

The causes of colour in marine waters are not thoroughly understood, but dissolved substances, suspended detritus and living organisms are contributors. Estuarine waters have a different colour from the open sea; darker colours result from higher turbidity and greater amounts of dissolved organic substances. This characteristic colour can also affect coastal recreational water bodies receiving estuarine input, and in some cases the public may mistake this colour difference as pollution.

Some regulatory authorities have recommended absolute values for transparency, colour and turbidity in recreational water bodies. This approach can be difficult to apply at a local level because many waters have naturally high levels of turbidity and colour that vary seasonally. Changes from the normal situation can be used to indicate potential water pollution.

Maintenance or larger-scale dredging operations to support boating and shipping access and navigational channels can result in temporary increase in water turbidity, debris, and/or discolouration to surrounding waters that may include deleterious health impacts including skin, and eye irritation, potential injury through small rocks/debris washing up onto ocean foreshore areas.

7.2.2. Oils, grease and detergents

Oils, grease and detergents include many different substances of mineral, animal, vegetable or synthetic origin, all of which can have vastly different physical, chemical and toxicological properties (Health Canada 2022). A chemical analysis should be undertaken of the substance to determine the potential constituents and their health significance (refer to Box 7.1 and *Chapter 6 - Chemical hazards*).

Even very small quantities of oily substances make water aesthetically unattractive. Oils and tars can form films on the water's surface and can accumulate along shorelines. Some oil-derived substances, such as xylenes and ethylbenzene, which are volatile components commonly found in recently spilled oil, may also give rise to odours or tastes. In recreational water bodies where motor sport activities take place, polycyclic aromatic hydrocarbons can be an important source of contamination (Verhagen et al. 2025).

Debris balls (also referred to as 'fatbergs') and cotton buds are increasingly being found in coastal waters and at beaches (refer to Box 7.2). Debris balls may originate from the sewerage system where various oils and fats combine with other chemicals and materials that have been tipped down the drain or from palm oil dumped from shipping. Given these debris balls and cotton buds may be indicative of a sewage discharge, the presence of other hazards including microbial and chemical should be investigated. Debris balls can be harmful to dogs, and pets should be prevented from eating them.

Detergents can give rise to aesthetic problems if foaming occurs, particularly since this can be confused with foam caused by dissolved organic substances such as the by-products of algal proliferation.

Box 7.1. Oil spill disrupts summer holiday activities at Melbourne beaches

The Victorian Environment Protection Authority (EPA Victoria) forecasts water quality at 36 beaches in Port Phillip Bay and issues water quality alerts for water bodies in Victoria.

In early January 2023, swimmers and other recreational beach users were urged to avoid contact with oily material found along the beach and in the water at many popular bayside beaches around Port Phillip Bay in Victoria. EPA Victoria issued water quality alerts for the affected beaches as it investigated the source and nature of a large oil spill and undertook a clean-up. EPA Victoria and other local authorities erected large electronic signs and warning notices on the foreshore of these beaches advising beachgoers not to swim, eat locally caught fish or allow pets to enter or drink the water. EPA Victoria's Beach Reports noted improving water quality after several days.

Locals reported seeing dead fish and large quantities of oil on the surface of the local canal, Elster Creek, which runs into the bay. The Little Penguin colony at the nearby St Kilda Breakwater was monitored by wildlife experts from Zoos Victoria during this pollution event.

The spill was ultimately determined to be due to vegetable oil (mainly palm oil) which presented no hazard to human health but is nonetheless unpleasant for beachgoers and can harm wildlife. The volume of oil that made its way into the bay was substantial, suggesting it was likely to have come from a commercial source.

Source: EPA Victoria (2023)

Box 7.2. Debris balls washed up on multiple Sydney beaches

In late 2024 and early 2025, confirmed reports of debris balls at several beaches in Sydney resulted in closure of beaches by local government and an investigation by the NSW Environment Protection Authority (EPA NSW).

Analytical testing found the debris balls along Sydney's beaches to be comprised of fatty acids, petroleum hydrocarbons, and other organic and inorganic material. While testing was unable to confirm the exact origin, authorities considered several possible causes, such as a shipping spill or wastewater outflow, which had coagulated into a spherical shape over time. All beaches that were impacted were cleaned up and reopened by local government.

Source: EPA NSW (2025)

7.2.3. Litter and debris

Litter or debris affecting freshwater and coastal areas can be defined as any persistent, manufactured, processed or solid material discarded, disposed of, or abandoned in the environment (definition based on UNEP 2009). Litter or debris can be roughly categorised according to its source: either water-based (e.g. from fisheries, recreational boats and shipping, wastewater ocean outfalls) or land-based (domestic, agricultural, industrial and recreational user sources). It may also arise from wastewater and stormwater overflows.

Visitors to recreational water sites are a predominant or major source of litter, at both freshwater and coastal sites (Hoellein et al. 2015; Asensio-Montesinos et al. 2019; Kiessling et al. 2019).

The variety of litter found in recreational water or washed up on the shoreline is considerable (e.g. Munari et al. 2016; Nelms et al. 2017; Asensio-Montesinos et al. 2019). Although proportions vary, litter is typically dominated by plastic (e.g. Khairunnisa et al. 2012; Kuo and Huang 2014; Munari et al. 2016). Cigarette butts or filters, made from cellulose acetate, frequently dominate the plastics category (e.g. Laglbauer et al. 2014; Lopes da Silva et al. 2015) and are among the most abundant litter items (Araújo and Costa 2019; Ocean Conservancy 2019; Clean Up Australia 2024; CSIRO 2021).

A report by CSIRO found that within Australia, approximately three-quarters of the rubbish along the coast is plastic. Most is from Australian sources, with debris concentrated near urban centres (CSIRO 2021). The most problematic categories of consumer single-use plastic are plastic bottles, soft plastics, disposal foodware, disposable packaging and containers, cigarettes and microplastics (WWF 2020; Clean Up Australia 2024). Recreational fishing activities can be a prevalent source of marine debris in marine and coastal areas (Smith et al. 2014).

Levels of litter at recreational water sites may be particularly elevated after sporting events, festivals, holiday periods and after significant weather events (e.g. heavy rainfall). In addition to being aesthetically undesirable and an environmental issue, litter may present a health hazard, such as injury from discarded hypodermic syringes or broken. Litter may also attract animals and birds which subsequently introduce faecal contamination into the water (Campbell et al. 2016; JRC/EC 2016, 2020).

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 sites (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 products.

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). To be worthwhile in research, litter counts as measures of aesthetic quality and as potential indicators of the likelihood of illness associated with the recreational and cultural use of the recreational water body, must be able to:

- classify different levels of 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 quality
- differentiate between the density of different pollutants deposited by the public on shorelines 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
- show a correlation with variations in the human population density at recreational water sites (Philipp 1992; IEHO 1993; Philipp et al. 1997).

7.2.4. Odour

Odour thresholds and their association with the concentrations of different pollutants of the recreational water environment have not been determined; however, they can deter recreational water users.

Objectionable smells may arise from a variety of sources. These include sewage and septic tank effluent, decaying organic matter (e.g. vegetation, dead animals, dead fish) and discharged diesel oil or petrol. Odours can be natural, such as when anoxic sediments (without oxygen) in vegetated coastal areas (e.g. mangroves, salt marshes) are exposed during low tide. The presence of dissolved oxygen in the water body will be important in preventing the formation of undesirable amounts of odorous hydrogen sulphide.

In Australia, salt marshes, mangroves, tropical wetlands, hot springs (e.g. Bitter Springs in Elsey National Park, and Katherine Hot Springs in Katherine, Northern Territory; Witjira-Dalhousie Springs, South Australia) and hot spring-fed public pools and spa pools (Murphy 2023) may be the source of unpleasant sulphurous odours. Some of these thermal pools draw their water supply from bores accessing the Great Artesian Basin (e.g. Charlotte Plains Hot Artesian Springs near Cunnamulla, Queensland).

Hydrogen sulphide gas has a characteristic odour of rotten eggs. It occurs naturally in geothermal areas and is also emitted from swamps and stagnant bodies of water under anaerobic conditions where organic material and sulphate are present. Hydrogen sulphide gas can be produced by microorganisms living in the water and sediments of wetlands/mangroves or through the decomposition of organic matter. In addition, volatile organic sulphur compounds and sulphur dioxide can also be produced through the decomposition of organic matter or by algae and microorganisms living in marine, estuarine and salt marsh environments. The human nose can detect some of these compounds at very low concentrations (Hicks and Lamontagne 2006).

7.2.5. Aquatic weeds

Exotic plant species can flourish in our waterways and significantly reduce water flow, quality and release unpleasant odours and colours when decomposing. Serious waterweeds such as salvinia (*Salvinia molesta*), cabomba (*Cabomba caroliniana*), water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes,* native to northern Australia but regarded as a weed in other parts of Australia) are commonly grown in aquariums and have been introduced into our waterways. These floating aquatic weeds can cover the entire surface of a water body, reducing its aesthetic value and limiting recreational activities. They can grow quickly to form dense mats over the water surface resulting in light, temperature and oxygen levels that are unfavourable to local flora and fauna. Infestations can also reduce water quality as rotting vegetation reduces the oxygen content, fouls the water, producing foul odours and contributing to water stagnation in natural watercourses. Salvinia, Cabomba and water hyacinth have been declared weeds of national significance in Australia due to their invasiveness, potential for spread, and economic and environmental impacts (Weeds Australia 2023; van Oosterhout 2009).

7.2.6. Seaweed (macroalgae)

Large accumulations of seaweed (macroalgae) are likely to be an aesthetic problem (in terms of visual impact and odour), may attract nuisance insects and birds, and can be a source of bacterial contamination (Williams et al. 2016; Zielinski et al. 2019). When onshore, seaweed can decompose releasing dissolved organic materials that can discolour the water. The decomposition process can lead to anoxic conditions, releasing hydrogen sulphide and causing noxious odours. The source of seaweed is influenced by global processes that cannot be controlled at the local scale (WHO 2021).

7.3. Assessment of risks

The aesthetic aspects of a water body may deter recreational and cultural use and indicate potential pollution and the need for further investigation to determine the presence of chemical and microbial hazards. Table 7.1 provides a summary of aesthetic aspects and potential hazards that should be investigated following their occurrence.

In addition to conventional assessments, Aboriginal and Torres Strait Islander communities have highlighted the use of sensory indicators—such as changes in water colour and odour—as culturally grounded methods for evaluating water quality. These traditional practices, informed by long-standing relationships with Country, offer valuable insights in the holistic evaluation of recreational water environments (see Administrative Report).

Table 7.1 - Aesthetic aspects, potential hazards and implications

Aesthetic aspect	Potential hazards and implications
Transparency and colour (refer to 7.2.1)	Low transparency may be the result of pollution sources including wastewater discharges and chemical spills. Polluted waters may also have high apparent colour, including industrial and wastewater discharges. An investigation should be conducted to determine the potential presence of microbial or chemical hazards in the water (see *Chapter 3 – Microbial pathogens from faecal pollution* and *Chapter 6 – Chemical hazards*). Poor transparency may impede the effects of environmental stresses on microorganisms such as impeding the actions of UV radiation. Microorganisms attached to particulate matter may interfere with the quantification of faecal indicator organisms resulting in an underestimation of risk. Cyanobacteria and algae can impart colour to water. The potential presence of a harmful algae bloom should be investigated (see *Chapter 5 – Harmful algal and cyanobacterial blooms*).
Oil, grease and detergents (refer to 7.2.2)	Organic chemical pollution can result from road runoff, residual hydrocarbon deposits from motorboat engine exhaust emissions, the discharge of fuel tank contents of ships (either accidentally or deliberately), oil drilling activities, and shipwrecks. Marinas and boat ramps can also be important sources of oil and grease contamination for recreational water bodies. Oils can form films, and some volatile components (such as xylene and ethylbenzene) can create odours or impart a taste to water (WHO 2021). Spills of oily substances or detergents may result in the need to issue an advisory or recreational water site closure. Refer to *Chapter 6 - Chemical hazards* to assess the potential impacts of oil and grease contamination on recreational water users.
Litter and debris (refer to 7.2.3)	Litter or debris may be associated with stormwater discharges or sewage outfalls, overflow or spill, and therefore there is a potential risk from microbial pathogens and chemical hazards in the water. Litter also has the potential to attract wildlife, which can contribute to faecal contamination of recreational water bodies.
Odour (refer to 7.2.4)	Depending on the characteristics of the odour, it may indicate a possible chemical (e.g. petrochemical) or wastewater spill. Decaying organic matter or harmful algal/cyanobacterial blooms can also release odours.

Aesthetic aspect	Potential hazards and implications
Seaweed (macroalgae) (refer to 7.2.5)	Accumulations of macroalgae may attract flying or biting insects and birds that can carry pathogens. Allergic reactions and bacterial skin infections may occur from bites and scratching the bites.

7.4. Management and communication

No guideline values have been established for aesthetic aspects of recreational water quality. However, aesthetic aspects should be considered in assessing risks given their potential inference to the presence of other hazards (i.e. microbial pathogens and chemicals).

7.4.1. Preventive and control measures

Preventive measures to manage aesthetic aspects of a recreational water body can be taken at a regional and local scale.

The UN Environment Programme's global assessment of marine litter and plastic pollution reports that emissions of plastic waste into aquatic ecosystems are projected to nearly triple by 2040 (from 2016 quantities) without meaningful action (UNEP 2021). The National Plastic Plan 2021 includes several actions to avoid unnecessary and problematic plastics, improve product design to reduce plastic waste, increase recycling rates, find alternatives, and reduce the amount of plastics impacting the environment (DAWE 2021).

At a local level, strategies to improve the aesthetic aspects of a recreational water body may include:

- regulating potentially polluting activities within the catchment and at marinas
- establishing riparian buffers to improve water quality
- undertaking beach grooming and litter clean-ups at recreational water sites receiving litter or excessive macroalgae from offshore
- stormwater management and treatment such as installing coarse screens to remove large debris and gross pollutants like litter and coarse sediment
- inhibiting litter creation at its source (e.g. prohibiting smoking on beaches to prevent cigarette butts)
- providing secured waste bins and emptying them frequently to prevent overflow, pest animals and insects
- enforcing local laws on littering and providing information to water users on proper solid waste disposal
- implementing policies and management for non-native animals at recreational water sites (e.g. discourage pets and feeding of birds, keep solid waste inaccessible). If dogs are permitted, put in place policies and procedures to minimise their impacts on the aesthetic quality
- engaging the community in clean-up activities.

7.4.2. Operational monitoring and community engagement

Local authorities and/or citizen science can undertake periodic (e.g. daily, weekly) operational monitoring via visual inspection and data collection on priority aesthetic aspects of concern.

Where aesthetic aspects indicate the potential presence of microbial/chemical hazards or harmful algal blooms in water (see Table 7.1, *Chapters 3 – Microbial pathogens from faecal sources*, *Chapter 5 – Harmful algal and cyanobacterial blooms* and *Chapter 6 – Chemical hazards*), investigations should be conducted to identify and abate the source, and measures implemented to prevent exposure.

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

Methods for debris surveys are discussed in Bartram and Rees (2000). The purposes of debris monitoring may include:

- providing information on the types, quantities and distribution of debris
- providing insight into problems and threats associated with an area
- assessing the effectiveness of legislation and coastal management policies
- identifying sources of debris
- exploring public health issues relating to debris
- increasing public awareness of the condition of the coastline.

Large-scale monitoring programs for recreational water sites may rely on volunteers to survey sites and collect data. Refer to examples in Boxes 7.3 and 7.4 about initiatives that engage the community to collect data and improve water quality.

Box 7.3. Queensland Environmental Report Cards

Reef 2050 Long-Term Sustainability Plan

In Queensland, five regional collaborative groups are working to improve water quality in catchments that may affect the Great Barrier Reef.[1] Funded by the Australian and Queensland governments, these partnerships support government, local communities, Traditional Owners, industry, farmers, fishers, scientists, tourism operators and conservation groups to work together to achieve healthy waterways in each region. Each partnership produces an annual report card that outlines the condition of waterways in their region. The data collected guides local management decisions to improve water quality in local waterways/ecosystems that flow to the Reef and contribute to the Reef 2050 Long-Term Sustainability Plan.

Health Land & Water's Ecosystem Health Monitoring Program

Healthy Land & Water, South-East Queensland's natural resource management organisation, has conducted data collections over the past two decades. Their Ecosystem Health

Monitoring Program, established in 2000, is a waterway monitoring program that provides a regional assessment of the health of each of South-East Queensland's major catchments, river estuaries, and Moreton Bay zones. The monitoring results are summarised and communicated through Water Report Cards published for each catchment annually.[2,3] In addition, Healthy Land & Water undertakes a wide range of habitat re-establishment, weed eradication, litter clean-ups and educational activities. In the 2022/2023 year, a litter clean-up program removed over 60 tonnes of litter from targeted waterways, largely consisting of lightweight plastic pollution. This included specifically: over 50 tonnes of floating and bank-bound litter was removed from flood-impacted and litter hot spot sites across the Brisbane, Bremer, Logan, and Caboolture Rivers; and over 10 tonnes of post-flood marine debris was removed from coastal waters and banks of Quandamooka Country in partnership with the Quandamooka Yoolooburrabee Aboriginal Corporation.

References: 1. https://www.reefplan.qld.gov.au/tracking-progress/regional-report-cards; https://reportcard.hlw.org.au/results; 2. https://www.hlw.org.au/portfolio/clean-up-program; 3. https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0024/207708/gbr-report-card-explainer.pdf

Box 7.4. Citizen scientists help monitor marine debris across Queensland.

Tangaroa Blue Foundation (an Australian registered charity) helps communities look after their coastal environment by providing resources and support programs. They collaborate with industry and government to create change on a large scale. The foundation's Australian Marine Debris Initiative (AMDI) Database is a national platform that tracks and records marine data across Australia and supports evidence-based strategies for protecting marine environments and wildlife. It enables the identification of pollution sources and trends, guiding targeted actions to reduce marine debris at its origin. Since the ADMI started in 2004, more than 2,000 tonnes of marine debris have been removed from the Australian coastline and recorded on the AMDI Database.

Tangaroa Blue Foundation also coordinated the ReefClean monitoring network to gather high-resolution litter data, covering 17 beaches across Queensland over a stretch of 18 degrees of latitude and spanning approximately 1,800 kilometres. Partnerships with 12 organisations supported training of citizen scientists to use standardised protocols and highlighted the power and effectiveness of engaging local communities to collect data for scientific research, contributing to a deeper understanding of plastic pollution and marine debris.

Their beach monitoring program focused on the monitoring macro-debris (> 5 mm) on ocean-facing, sandy beach sites that were surveyed quarterly between March 2019 and December 2021. Plastics were the dominant litter material identified (87% of total debris, with hard, soft and foam plastics aggregated). Potential drivers of specific debris types (i.e. plastics, commercial fishing items, items dumped at-sea, and single-use items) were assessed and significant relationships between debris accumulation with distance from the nearest population centre and site characteristics were identified (modal beach state, beach orientation and across-beach section).

Sites oriented towards the prevailing wave energy throughout the year (i.e. exposed to East-South-Easterly swells) were linked to higher debris count, relative to those orientated away from wind and wave energy. Cape York had the highest rates of debris accumulation, which could be linked to the East and South-East orientation of sampled beaches, exposing them to offshore debris (e.g. at-sea dumping, release from neighboring countries).

These initiatives illustrate how the community can be involved in developing targeted marine debris management strategies and monitoring.

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7.5. References

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8. Radiological hazards

Guideline recommendation

Regular monitoring for radiological hazards is not recommended for all recreational water bodies, however there may be instances where local knowledge, concerns, past practices or routine discharges indicate a potential for increased risk and possibly a need for increased surveillance.

Monitoring for radiological hazards should be considered on a case-by-case basis if a recreational water body may be of concern (i.e. based on legacy or planned exposures, past activities).

For protection of people against radiation exposure from recreational and cultural water use, the recommended guideline is 10 millisievert per year (10 mSv/year).

Where default radiological screening values are exceeded, further risk assessment should be undertaken.

8.1. Overview

In Australia, naturally occurring radioactive materials (e.g. uranium, thorium and potassium) are present in the environment, including in most water bodies, at very low concentrations. In some water bodies anthropogenic (human-made) radionuclides may also be present, such as strontium-90 and caesium-137. In Australia, these radionuclides typically originate from controlled discharges by medical and industrial facilities, which are regulated by the respective state or territory; this guideline does not replace the regulatory requirements for planned exposure situations. [2] Human-made radionuclides may also be present in the environment due to fallout from nuclear weapons testing or accidents, however, fallout in the Southern Hemisphere from such events is significantly lower than has been observed in the Northern Hemisphere.

A review of the small number of published research studies examining the presence of radioactive materials in Australian recreational water bodies suggests that there are very few recreational water bodies that are likely to be contaminated by radionuclides at levels greater than those found naturally in the environment (ARPANSA Evidence Evaluation Report). These water bodies are typically in the vicinity (or catchment area) of current or former mine sites, or former nuclear weapons test sites. They are typically known to regulatory bodies and management of these sites is captured under the existing regulatory framework for radiation protection (ARPANSA 2017). In addition, mineral and thermal springs or pools may contain higher concentrations of naturally occurring radionuclides from the underground rocks and minerals they pass through.

[2] A Commonwealth facility with routine discharges will still need to adhere to the requirement under RPS C-1 Code for Radiation Protection in Planned Exposure Situations (ARPANSA 2020). This process is similar across all Australian radiation jurisdictions.

This chapter describes the sources of radiation in the environment and in recreational water, the health effects of radiation, how people are exposed to radiation during recreational and cultural activities and how exposure can be measured. It also explains the reference level (guideline value) for radiation protection when accessing recreational water bodies, and provides guidance on monitoring and risk assessment for radiation protection.

8.2. Health effects of radiation

There have been many large-scale studies worldwide of cancer risk in people arising from ionising radiation exposure (UNSCEAR 2018). The risk from exposure to high radiation doses is well quantified. For low radiation exposures the scientific evidence for increased health risk is limited.

The average Australian is exposed to approximately 1.7 millisieverts (mSv) of background radiation annually, primarily from natural sources such as soil, rocks, cosmic rays and air travel (ARPANSA 2025). At this level of exposure, there is no evidence of adverse human health effects.

ARPANSA's Radiation Protection Series G-2 *Guide for Radiation Protection in Existing Exposure Situation* (2017) provides guidance on setting reference levels for radiation exposure that are designed to protect public health and guide decision making regarding any potential risk management or mitigation activities (e.g. warning signs, restricting access to a site or remediation activities).

Regulation of radiation protection is based on the precautionary assumption that any exposure to radiation involves some level of risk (WHO 2017). The International Commission of Radiation Protection (ICRP) endorses and recommends the linear no-threshold (LNT) model for radiation dose-response relationships (ICRP 2007). This theorizes that any exposure to ionising radiation, regardless of how minimal, carries a level of risk of cancer or genetic mutations. This model assumes a direct, linear relationship between dose and risk with no safe threshold. This signifies theoretically possible increased risk of cancer and hereditary effects at very low radiation doses or for radiation delivered over a long period of time. However, these effects have not been detected through scientific studies (Guseva Canu et al. 2011).

8.3. Assessment of risks associated with radionuclides in recreational water environments

In general, the potential risks from radiological contamination of recreational water bodies are likely to be lower than the potential risks from many other chemical and biological hazards, e.g. exposure to chemicals and toxins produced by cyanobacteria and algae. This is because recreational water users are very unlikely to come into contact with sufficiently high concentrations of radiological material to suffer adverse effects from a single exposure. Even repeated (chronic) exposure is unlikely to result in adverse effects at the concentrations of radiological material typically found in water and with the exposure patterns of most recreational water users. However, it remains crucial to ensure that radiological hazards and any potential public health risks associated with them are recognised and controlled. This helps reassure water users about their personal safety and maintains public confidence in the safety of recreational water bodies.

8.3.1. Sources and occurrence of radiation in recreational water bodies

Radioactive materials occur naturally in the environment (e.g. uranium, thorium and potassium). Some radioactive compounds arise from human activities (e.g. from medical or industrial uses of radioactivity) and some natural sources of radiation are concentrated by mining and other industrial activities. By far the largest proportion of human exposure to radiation comes from natural sources of radiation, including cosmic radiation, external gamma radiation from rocks and soil, and from ingestion or inhalation of radioactive materials.

Elevated levels of radioactivity in recreational water bodies can result from:

- naturally occurring concentrations of radioactive material (e.g. radionuclides of the thorium and uranium series in water sources). This includes groundwater resources and mineral and thermal springs (see Box 8.1).
- technological processes involving naturally occurring radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertilizer production), where there is contact with water bodies
- manufactured radionuclides (produced and used in medicine or industry) that might enter recreational water bodies as a result of routine or incidental discharges or emergency situations
- radionuclides released in the past into the environment from historic mining processes or former nuclear weapons testing.

The need to monitor a recreational water body should be considered based on legacy or planned exposures, past activities near the body (such as mineral sands mining), and/or the need for public assurance. The identification of the source of the radiation is a crucial step throughout the radiation risk assessment and guides the implementation of appropriate risk management measures. A source is anything that may cause radiation exposure in recreational water bodies, such as by emitting ionising radiation or by the release of radioactive substances or materials. The source of radiation (single or multiple radionuclides) can be treated as a single entity for the purposes of protection and safety.

Box 8.1 Mineral and thermal springs

Mineral and thermal springs may contain increased concentrations of naturally occurring radionuclides. Recreational or cultural activities at these water sites may also result in elevated exposures through the inhalation of radon or by drinking mineral waters. Radioactivity due to the naturally occurring radioactive gas radon can be a health concern.

Radon gas emissions at the Paralana hot springs in the Northern Flinders Ranges in South Australia measured 10,952 becquerels per cubic metre (Bq/m^3) in one study (Brugger et al. 2005). This level significantly exceeds the Australian reference level for radon exposure (ARPANSA 2017). These hydrothermal springs offer a permanent water source in an arid environment and are culturally important to local Aboriginal communities. Exposure to natural sources of background radiation should be reviewed using a specific risk assessment for the water site by the relevant authority (refer to section 8.4). Although the activity concentrations exceed the reference levels for indoor settings, this does not necessarily indicate a high risk to recreational water users.

Guidance on how to do a radiological dose assessment and case studies using the tiered approach for determining the radiological monitoring and management of recreational water bodies are provided in the draft ARPANSA Technical Report.

8.3.2. Qualitative assessment

A qualitative assessment represents the initial phase of the radiological hazard identification process. This helps determine the presence of radionuclides by evaluating the contamination or pollution sources. This process would ideally be undertaken at all water sites as part of an initial risk assessment to support informed decision-making, including whether to eliminate the hazard, reduce exposure, or initiate further investigation.

If after a risk characterisation has been completed and it is determined that there is no significant potential for radiological exposure, no further assessment is required.

8.3.3. Routes of radiological exposure (exposure pathways)

Exposure pathways describe the ways in which radioactive materials enter or impact the body. The potential health impact from a radiation exposure can vary depending on the exposure pathway, chemical and physical characteristics of the radioactive material and the age of the exposed person. The exposure routes for radiological hazards relevant to recreational and cultural water use are described in Table 8.1.

Table 8.1 - Routes of exposure for radiological hazards in recreational water

Potential route of exposure	Description	Expected significance for radionuclides
Ingestion – inadvertent ingestion of water	This occurs when individuals accidently swallow water that may contain contaminants. Very young children are particularly vulnerable to inadvertent ingestion of contaminated water and sediment. However, data on the quantities of water incidentally ingested during recreational and cultural water activities are difficult to obtain. Default ingestion assumption values have been estimated in Table 8.2 and elsewhere in the Guidelines (see Information sheet – Exposure assumptions).	Exposure to radionuclides via ingestion routes during swimming, bathing, diving or playing in water is expected to occur. Indirect exposure can also occur through water-based sports including sailing, kayaking and surfing. Inadvertent ingestion of water during recreational and cultural activities in or on a water body is expected to occur.

NHMRC

Ingestion – Inadvertent ingestion of sediment	Accidental ingestion of sediment, especially by children through hand-to-mouth contact or exposure to suspended beach sand can lead to the intake of radionuclides that have settled on the shoreline from nearby water bodies.	Exposure to radionuclides via accidental ingestion of sediment is dependent on the recreational and cultural water activity. Recreational and cultural activities such as swimming, wading, beach play, fishing, and boating can involve direct contact with shoreline sand or sediment. During these activities—especially for children—there is a chance of accidentally swallowing small amounts of sediment through hand-to-mouth contact or exposure to stirred-up sand.

Direct surface contact (dermal) – Immersion in water	The most frequent routes of exposure are absorption through the skin, eyes and mucous membranes. Wetsuits, when used for long periods in the water, trap water against the skin and create a microenvironment that enhances the absorption of radionuclides through the skin.	Direct dermal contact with water can lead to radionuclide exposure, through full or partial immersion in water, depending on the scenario. Full immersion can be assumed for swimming and diving, while partial immersion can be considered for surfing and fishing.
Direct surface contact (dermal) – External contact with sediment or sand	Contaminants in sediment or sand can adhere to the skin, especially if the sediment is fine-grained or if the skin is wet.	Contact with contaminated sediment or sand can also result in dermal exposure to radionuclides. This can occur in individuals engaged in activities such as swimming, wading, playing in water and fishing.

Inhalation of sea spray	Inhalation of volatile contaminants may occur. Inhalation of non-volatile contaminants may be important in circumstances where is a significant amount of spray, such as in surfing or water skiing.	Inhalation of sea spray in areas where there is significant wind or surf, inhalation of suspended water particles in the air (sea-spray) may be a significant exposure pathway for activities in close proximity to the water body, such as surfing and kayaking.
Inhalation of radon	Inhalation of volatile contaminants may occur. Inhalation of non-volatile contaminants may be important in circumstances where is a significant amount of spray, such as in surfing or water skiing.	Areas with high naturally occurring radionuclides, such as mineral and thermal springs, commonly have high levels of radon gas. Radon gas and its progeny is released from these water body bodies and can be a significant source of exposure for those consistently in proximity.

8.3.4. Exposure assessment/Quantitative assessment

Quantitative risk assessment is only required when there is a level of evidence to suggest a potential radiological exposure that may warrant regulatory attention. According to ARPANSA RPS G-2, the decision to proceed with a quantitative assessment should follow the preliminary evaluation that includes a qualitative assessment of the exposure scenario, source characteristics, and potential pathways of exposure.

Development of exposure scenarios is necessary to comprehensively assess the potential risks and health impacts from exposure to radionuclides in recreational water bodies. This is achieved by identifying and evaluating various scenarios that accurately reflect the environmental conditions of the water body and the recreational and cultural activities that may occur there. This includes thinking about how a recreational water user might come into contact with radiation. The representative scenario should consider common activities including swimming, boating, and fishing, and the frequency and duration of these activities.

The exposure scenario should be conservative but still realistic and is chosen on the basis that the recreational activity is representative of the majority of the general water user population of the water body being assessed. A range of factors need to be considered including the characteristics of those exposed (e.g. age, lifestyle habits) and whether members of the public will be spending an extended period of time undertaking an activity in the body of water.

For the purposes of deriving scenario-specific screening levels, exposure scenarios have been developed to represent the broad range of popular recreational and cultural activities in and around water in Australia. These scenarios are described in Table 8.2. Multiple scenarios are required to reflect the different pathways by which people can be exposed to radiation when undertaking recreational and cultural activities in and around water. Details on these scenarios including references and justifications are provided in the draft ARPANSA Technical Report. These activities are not designed to capture every activity around recreational water which may result in a dose from contaminated water, but instead to offer sufficient variety in activities that most exposure situations will be covered by a similar activity. Each scenario is based on a member of the public spending an extended period undertaking an activity in the same body of water. The scenarios are designed to be conservative but not excessive. Guidance on how to design a representative exposure scenario is provided in the draft ARPANSA Technical Report.

Table 8.2 - Exposure scenarios used to derive the scenario-specific screening levels for radiological hazards representing a broad range of recreational and cultural water activities and descriptions

Scenario	Exposure pathways	Duration of recreational activity	Description of exposure
Reference scenario- water ingestion from swimming only (enHealth)	Ingestion (water)	150 events per year (enHealth 2012). 250 mL of water swallowed per swimming event (DeFlorio-Barker et al. 2018)	This refers to the incidental ingestion of water during recreational activities such as swimming, surfing, or kayaking. See *Information sheet – Exposure assumptions*.

Scenario	Exposure pathways	Duration of recreational activity	Description of exposure
Reference scenario-water ingestion from swimming and external exposure (enHealth)	External exposure Ingestion (water)	150 events per year (enHealth 2012). 250 mL of water swallowed per swimming event (DeFlorio-Barker et al. 2018) 1 hour of water immersion per event (AusPlay 2023a)	This refers to the incidental ingestion of water and external exposure due to immersion during recreational and cultural activities such as swimming, surfing, or kayaking. See *Information sheet – Exposure assumptions*.
Fishing (recreational inshore)	External exposure Inhalation (sea spray)	720 hours per year (i.e. 60 hours per month) (Pita et al. 2022)	Close proximity to a water body during fishing can result in external exposure from water shine and internal exposure from inhalation of sea-spray
Surfing	External exposure Ingestion (water) Inhalation (sea spray)	260 events per year (i.e. 5 days per week); 2 hours per event (AusPlay 2023b) 170 mL water swallowed per event (Stone et al. 2008)	Inadvertent ingestion of water could occur during wipeouts or paddling. Inhalation of sea spray could occur with frequent motion and external contact with the water.
Diving	External exposure Ingestion (water)	160 events per year; 2 hours per event 200 mL water swallowed per event (Schijven & de Roda Husman 2006)	Inadvertent ingestion may occur when diving; water may enter the mouth during mask cleaning or breathing. Full immersion in the water could result in external exposure to the skin.
Sailing	Inadvertent ingestion (water) External exposure Inhalation (sea spray)	100 hours per year (Taverner Research Group 2023) 20 mL water ingestion per event (Dorevitch et al. 2011)	Sailing can result in inadvertent ingestion of water through splashing or spray leading to swallowing small amounts of water. Direct skin contact with water and wet surfaces can result in external exposure

Scenario	Exposure pathways	Duration of recreational activity	Description of exposure
Kayaking	External exposure Inadvertent ingestion (water) Inhalation (sea spray)	100 events per year; 4 hours per event (AusPlay 2023c) 20 mL water ingestion per hour (Dorevitch et al. 2011))	Kayaking may result in inadvertent ingestion of water that may be swallowed during paddling or capsizing. Sea spray may be inhaled during paddling in rough conditions. External exposure through skin contact with water and wet gear.
Wading	External exposure (water and sediment) Inadvertent ingestion (water) Inhalation (sea spray) Inadvertent ingestion (sediment)	150 events per year (enHealth, 2012); 1 hour per event (AusPlay 2023a) 30 mins of immersion in water 30 mins of external exposure from sediment 125 mL water ingestion per event (DeFlorio-Barker et al. 2018) 25 mg of inadvertent sediment ingestion per event (IAEA 2015)	Spending time close to the water's edge, wading in shallow water. Sediment may be inadvertently ingested via hand-to-mouth contact or splashing. Skin contact with water especially in muddy or silty environments.
Thermal spring	Inhalation (radon)	150 events per year; 2 hours per event (enHealth 2012)	Bathing in mineral-rich thermal springs could result in the inhalation of radon gas released from the water.

8.3.5. Risk characterisation

Risk characterisation involves compiling all available information (both qualitative and quantitative) to form a comprehensive assessment of the radiation risk. In most cases, radiation exposures from the pathways within the scope of these Guidelines (i.e. immersion in water, accidental ingestion) are not as high as the exposures from pathways that are out of scope of the updated Guidelines (e.g. external exposure from soil, rock and sediment, deliberate ingestion of seafoods, mineral waters and bush foods, inhalation of dust or radon). In line with the preventive risk management approach outlined in these Guidelines, a scenario-based, graded approach for radiation risk assessments is recommended as outlined in ARPANSA's RPS G-2 and the draft

ARPANSA Technical Report. This recommended approach to assessing radiation risks from ionising radiation closely aligns with international best practice as laid out by the Recommendations of the ICRP (ICRP, 2007), the International Atomic Energy Agency's (IAEA) Safety and Security Series and Codes of Conduct (2014) and the World Health Organization (WHO). Risk assessments for radiation are undertaken in line with the Commonwealth Guidelines for assessing human health risks from the environment (enHealth 2012).

8.4. Reference level

The Australian generic reference level selected for protection of people against radiation exposure from recreational and cultural water use is 10 mSv/year.

Under the system of radiation protection, reference levels serve as a benchmark to determine if protective measures are necessary and are not mandatory limits. If the potential dose to a person exceeds the assigned reference level, further decisions on protective measures should be taken based on advice from the relevant health authority. The benefit of reducing radiation exposure to humans should be balanced with any benefits to the individual to engaging in recreation and the overall cost of achieving a reduction of dose to ensure any protective measures result in more good than harm.

The reference level is a measure of annual effective radiation dose to a representative person as a result of radiation exposure from all exposure pathways during leisure in or around recreational water. Reference levels for existing exposure situations, such as recreational and cultural water use, can be defined between 1 and 20 mSv/year, as per ARPANSA RPS G-2 (ARPANSA 2017) and IAEA GSR Part 3 (IAEA 2013). The selected reference level of 10 mSv/year is equivalent to the reference level recommended as a starting point for remediation of contamination from past activities (ARPANSA 2017).

When an existing exposure situation has been identified, actual exposures could be above or below the reference level. The reference level is used as a benchmark for judging whether further protective actions are necessary and, if so, in prioritising their application. Once an existing exposure is identified a different value might be selected for the site specific reference level following stakeholder engagement and based on the prevailing circumstances (ARPANSA 2017).

8.5. Screening values

The reference level is a measure of annual effective radiation dose, which accounts for the potential health impacts for a person from radiation exposure. However, effective dose cannot be directly measured from a water or sediment sample. Therefore, screening values have been determined to allow for practical, timely and affordable measurement and risk assessment.

Generic screening values in Table 8.3 have been set such that if a measurement is below the screening value a decision maker can have a very high level of confidence that the 10 mSv/year reference level will not be exceeded. If screening values are not exceeded, no further analysis of the water body is required.

These generic screening values are conservative and are derived such that they correspond to a radiation dose of approximately one tenth of the reference level (operational dose value).[3] Exceeding a screening value does not indicate that a water body is unsafe for recreational or cultural use.

If the screening value is exceeded, further assessment of the water body is recommended to better understand the radionuclide content of the water body and to allow for a more detailed risk assessment.

Scenario-specific screening values are measurable concentrations of gross alpha and beta activity in the recreational water body (as becquerels per litre or Bq/L). It is based on a realistic worst-case exposure for a representative recreational activity (e.g. swimming, surfing) that results in a dose greater than the operational level.

In circumstances where the default radiological screening values may not be representative, site specific radiological screening values[4] can be developed in consultation with the relevant health authority or regulator if exposure data is known. The nature of exposure requires consideration of potential exposure routes, and estimation of exposure durations and frequencies.

It is intended that the default scenario-specific screening values will indicate recreational water quality considerations that are sufficiently protective of human health across a broad population. These values should be considered and applied in the context of the data, estimations and calculations used to derive them.

Table 8.3 - Generic screening values (for unfiltered water) for radionuclides in recreational water bodies

	Gross Alpha	Gross Beta
Generic screening value	1 Bq/L	1 Bq/L

Guidance on how to do a site specific radiological dose assessment and case studies using the tiered approach for determining the radiological monitoring and management of recreational water bodies are provided in the draft ARPANSA Technical Report.

8.6. Risk management

The IAEA and ARPANSA classify recreational water as an existing exposure situation for radiation safety and protection purposes. Existing exposure situations include elevated exposure due to radiation of natural origin; exposure due to residual radioactive material from past activities that were not subject to regulatory control; or exposure remaining after an emergency response.

[3] The operational dose value is the level at which the screening value is exceeded. It is an indicator that further assessment of the recreational water body may be required. The operational level for recreational water is defined as 1/10 of the reference level (1 mSv/year).

[4] A radionuclide specific screening value is a measurable concentration of activity from a particular radionuclide in a recreational water body (Bq/L). It is based on a realistic worst-case scenario from exposure to a specified radionuclide in the water body that would result in a dose greater than the operational level.

ARPANSA is the Australian Government's primary authority on radiation protection and nuclear safety, regulating Commonwealth entities that use or produce radiation and work collaboratively with State and Territory Government regulators and health authorities to protect people and the environment from harm.

Radiation exposure risks related to recreational and cultural water use in Australia are currently managed under the framework described in the ARPANSA RPS G-2. This guide applies a risk-based approach for the application, justification and optimisation of existing exposure strategies and remedial actions, and includes guidance on identifying, evaluating, and managing radiological risks in all existing exposure situations.

The *Framework for the management of recreational water quality* (Chapter 2) provides a structured approach for assessing and managing hazards, including radiological hazards, at recreational water sites. This approach is broadly consistent with that outlined in ARPANSA RPS G-2.

8.7. Monitoring and environmental surveillance

Current evidence indicates that there are very few recreational water bodies that are likely to be contaminated by radionuclides at levels greater than those found naturally in the environment. Regular monitoring for radiological contaminants is not recommended for all recreational water bodies, however, there may be instances where local knowledge, concerns, past practices or routine discharges indicate a potential for increased risk and possibly a need for increased surveillance (ANZG 2018).

Radiological contamination of surface waters above background levels is possible in the vicinity of current and former mine sites. These water bodies are known to local, state, territory and Australian Government agencies, and risk mitigation strategies and environmental monitoring have been established for these sites under relevant Commonwealth or state legislation. Regulators of mining activities in Australia require routine environmental monitoring for metals, including uranium, and other toxic substances. Results of such monitoring may indicate the potential for radiological contamination of the environment and nearby water bodies.

In areas where there is known historical radiological contamination, monitoring should take into consideration those radionuclides to ensure that management practices address all potential radiological contaminants in recreational water. Sediments often concentrate radiological contaminants over time; water samples should be inclusive of suspended sediment as exposure from external dose and inadvertent ingestion of sediment is likely.

The methods for sampling, radiological monitoring and assessment of recreational water including requirements for further investigations if screening levels are exceeded are provided in the draft ARPANSA Technical Report. An effective radiological water quality monitoring program integrates water and sediment assessments, if relevant to the recreational water body. Sampling methods include:

- Water sampling: Collecting and analysing whole water (i.e. unfiltered) samples to include both dissolved and particulate-bound radionuclides. This approach captures contributions from suspended sediments and sand, providing a more accurate representation of the total radionuclide load in the water body. Considering particulate-bound radionuclides is crucial as they can settle and accumulate in sediments.

- **Sediment sampling**: Collecting sediment samples for radionuclide concentrations, particularly if the radiation risk assessment of a recreational water body involves exposure scenarios where recreational water users come into contact with sediment or sand. Sediments can act as sinks for radionuclides, and their disturbance during recreational and cultural activities can lead to resuspension and increased exposure. Testing sediments helps in understanding the extent of contamination and the potential for exposure through direct contact or resuspension.

For practical purposes, a simplified approach for freshwater sites or water bodies that are known to be potentially impacted by radiological contamination is to collect and analyse unfiltered water samples and apply the screening value for both gross alpha and gross beta shown in Table 8.3. This method focuses on the ingestion of water, inhalation of sea-spray, and external exposure, considering both dissolved and suspended sediments, which is an appropriate assumption for recreational and cultural water use. This provides a conservative public safety margin while simplifying the risk assessment process. When assessing the suitability of gross alpha and gross beta analysis, it is essential to consider the impact of sample characteristics i.e. presence of suspended sediments or particulates in unfiltered samples. Appropriate quality parameters should be applied to ensure results remain fit for purpose specific analysis (refer to the draft ARPANSA Technical Report for more details).

8.8. Protective measures

If the reference level has been exceeded, intervention is expected, and protective measures must be taken to reduce doses to below the reference level of 10 mSv/year.

As a precautionary measure, it is best practice for recreational water users to shower with soap and water after activities involving direct contact with water and always avoid swallowing the water to ensure that any risk is minimised.

The response by the relevant regulatory authority should include timely and effective risk communication. If changes are detected in water quality, multifaceted approaches will generally be needed to provide public health advisories, including:

- issuing of media advice, including social media
- communication with community or residents' groups
- installation of signage and its maintenance (e.g. in the event of vandalism).

Information should be provided on:

- the cause and nature of contamination
- the basis for assessing risks, including the source of guideline or screening values applied
- activities to be avoided
- potential health risks

- remedial action.

8.9. Operational guidance

A flow chart outlining the approach to demonstrating whether or not the radiological content of a recreational water body complies with these Guidelines is shown in Figure 8.1. The first step is always to make a decision about whether or not monitoring is required (refer to discussion in section 8.7).

The screening process varies depending on the water source (freshwater or seawater). A summary of recommended operational responses to screening results is provided in Table 8.4.

Figure 8.1 - Flowchart showing how to determine whether the radiological quality of recreational water bodies complies with the Guidelines

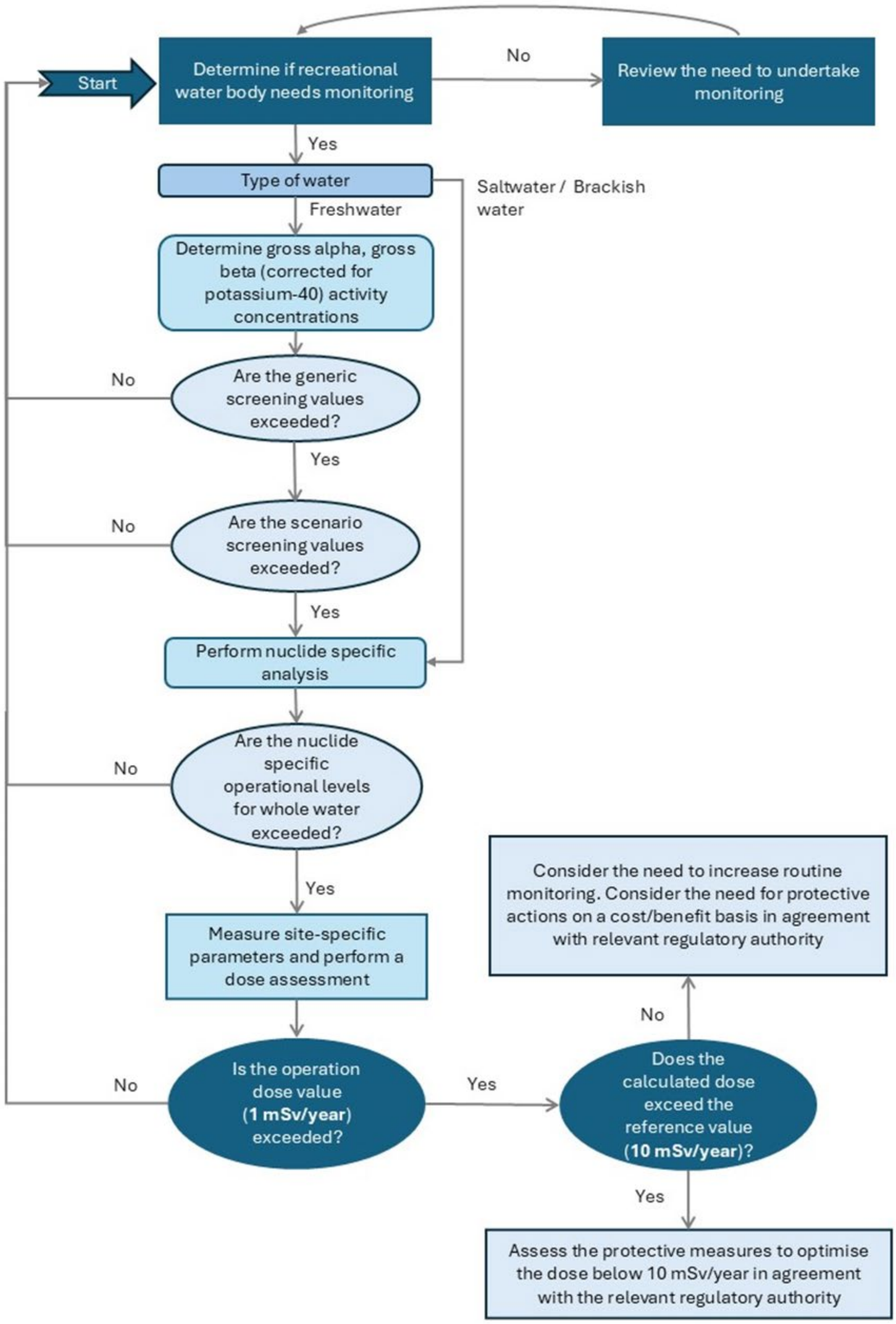

Table 8.4 - Summary of operational responses

Dose level (mSv per year)	Response
<1	Gross alpha, gross beta (corrected for potassium-40) and gamma screening values and/or the operational dose value are not exceeded. Review the need to continue routine monitoring.
1-10	Evaluate dose and if required, perform assessments based on local conditions. Consider the need to increase the frequency of monitoring in agreement with the relevant health authorities or state regulators based on if the operational dose value is exceeded. Assess in detail possible protective measures e.g. remedial/protective actions, considering potential cost-effectiveness of actions.
>10	Consult with relevant health authorities or state regulators. Assess in detail possible protective measures e.g. remedial/protective actions. Implement appropriate remedial/protective measures. Intervention is expected and protective measures must be taken to reduce doses to below the reference level of 10 mSv/year.

8.10. Research and development

Conducting baseline surveys of recreational water bodies in Australia, including mineral and thermal springs, provide a reference point against which future changes in water quality can be measured and help to identify trends and potential sources of contamination. Baseline surveys provide a comprehensive understanding of the current radiological conditions of recreational water bodies before any significant changes or developments occur. These surveys should include the collection and analysis of water, sediment, and biota samples to establish background levels of radionuclides. Monitoring programs should be established to regularly assess the levels of these contaminants in recreational water bodies.

Further research is also needed to understand the risks associated with sand, soil, and erosion in arid environments, particularly near mine sites or former nuclear test sites. These environments can contribute to the mobilisation of radionuclides into water bodies, posing significant health risks to recreational water users. Studies should focus on the transport mechanisms of radionuclides from contaminated soils and sediments into water bodies, and the subsequent exposure pathways for humans.

The long-term social and health impacts from recreational water bodies on local communities near former nuclear weapon testing sites should also be better understood, including the impacts on the traditional Aboriginal custodians of the land.

8.11. Supporting tools and information

Draft ARPANSA Technical Report

8.12. References

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Information sheets and tools

NHMRC

Information sheet – Water quality risk management planning checklist

Table 1 - Water quality risk management planning checklist

Framework element	Key actions	Checkbox	Notes
Identify responsible authorities	• Identify the leadership entities that will lead and manage water quality and public health • Identify a coordinating entity to lead and oversee risk management actions • Nominate a site manager for the water site/s	☐ ☐ ☐	
Regulatory and formal requirements	• Identify and document all relevant regulatory and formal requirements • Establish a plan to regularly update the list of relevant regulatory and formal requirements • Relevant obligations should be communicated to the appropriate stakeholders	☐ ☐ ☐	

Framework element	Key actions	Checkbox	Notes
Engage stakeholders	• Identify and document key stakeholders • Involve stakeholders with responsibilities and expertise in public health in relation to water environments • Engage stakeholder groups to obtain early feedback such as public values and preferences, any local factors that will impact risk management • Consult and plan with First Nations communities and Traditional Owners regarding water sites on Country • Engage water users on forms of recreational and cultural activities, responsibilities and strategies for risk communication	☐ ☐ ☐ ☐ ☐	
Recreational water quality policy	• Develop a water safety policy for the recreational or cultural use of water sites, endorsed by senior managers • Establish partnerships with agencies or organisations • Regularly update the list of relevant agencies and their details	☐ ☐ ☐	
Ensure capability	Identify and document the expertise required Ensure that work is undertaken by agencies and operators with appropriate expertise	☐ ☐	

Framework element	Key actions	Checkbox	Notes
Consider the water environment and its context	• Assemble a risk assessment team with appropriate knowledge and expertise • Identify and document key characteristics of the water environment and its context (e.g. sanitary inspection) • Identify intended and other potential uses of water environments • Identify and consider use of the water site by vulnerable or sensitive populations	☐ ☐ ☐ ☐	
Collect relevant data	• Assemble relevant data to assess the risks for water environments used for recreational or cultural activities • Collate and present information for use in the subsequent risk assessment • Start the process of filling important data gaps for future assessments	☐ ☐ ☐	
Assess hazards, hazardous events and risks	• Plan and undertake a risk assessment of the water site using suitable methods and approaches (e.g. sanitary inspection) • Identify relevant hazards and hazardous events • Identify and assess relevant human exposure pathways and events against each relevant hazard • Estimate the level of risk to water users • Prioritise the most significant risks requiring risk management	☐ ☐ ☐ ☐ ☐	

Framework element	Key actions	Checkbox	Notes
Determine preventive measures and performance targets	• Identify and assess existing and additional preventive measures for each significant hazard or hazardous event and estimate residual risk • Document the preventive measures and strategies into a plan addressing each significant risk • Prioritise preventive measures and identify any critical control points • Establish appropriate performance targets • Identify appropriate response actions and corrective actions	☐ ☐ ☐ ☐ ☐	
Implement operational procedures and maintenance programs	• Establish mechanisms for evaluating and managing performance of preventive measures • Formalise operational procedures and maintenance programs	☐ ☐	
Set up processes to monitor and verify water quality	• Determine the characteristics to be monitored and design an appropriate sampling program • Implement systems to assess and respond to feedback from water users • Establish mechanisms to report on performance and respond to exceedances	☐ ☐ ☐	
Planning for incidents and emergencies	• Establish protocols to assess and respond to incidents and emergencies • Establish mechanisms to investigate and report on incidents and emergencies	☐ ☐	

Framework element	Key actions	Checkbox	Notes
Communications planning	• Develop a communications plan that supports the responsible management of water sites, including incident and emergency response • Communicate the risks in terms and ways that the community can understand and access	☐ ☐	
Training	• Increase awareness and participation of personnel including water users • Ensure personnel with important roles are appropriately skilled and trained	☐ ☐	
Community involvement and awareness	• Develop an active two-way communication program to promote community involvement and risk awareness in water quality protection and risk minimisation	☐	
Validation, research and development	• Confirm that preventive measures and response actions mitigate risks effectively • Conduct research to validate new processes and procedures • Collaborate to increase understanding of water environments	☐ ☐ ☐	
Documentation and reporting	• Develop a document-control and record-keeping system for managing and updating relevant information • Establish processes for conducting internal and external reporting	☐ ☐	

Framework element	Key actions	Checkbox	Notes
Evaluate and audit	• Collect and evaluate long-term data to assess performance and identify problems • Establish processes and requirements for internal and external audits	☐ ☐	
Review and improve processes	• Review risk assessment and risk management system and evaluate the need for change • Develop and implement a water quality improvement plan	☐ ☐	

Information sheet – Monitoring programs

Monitoring is essential to evaluating existing hazards, controlling hazards and detecting changes that may occur. Monitoring enables authorities to implement a responsive strategy to protect public health.

The monitoring program should be embedded within the Water Quality Risk Management Plan for the recreational water site and encompass:

- monitoring requirements to identify and assess of water quality hazards (or indicators)
- routine sampling to measure water quality hazards (or indicators)
- operational, verification and validation monitoring to demonstrate the efficacy of preventive measures and provide a real-time indication of water quality
- investigative monitoring into the causes of elevated concentrations of water quality hazards, and increase sampling to enable a more accurate assessment of the risks to recreational water users
- triggers to warn the public that the water body is considered unsuitable for recreational and cultural use
- research and development requirements to address knowledge gaps or emerging threats.

Guidance on monitoring for managing specific water quality hazards is provided in the relevant technical chapters (Chapters 3-7).

The *Framework for managing recreational water quality* (Chapter 2) (the Framework) describes four key forms of monitoring that are captured within different sections. The types of monitoring discussed are:

- **Operational monitoring** — used to assess whether preventive measures are working in an operationally informative timeframe to answer the question "*is it working?*".
- **Verification monitoring** — used to determine whether management systems have worked and have successfully achieved safe water quality that is fit-for-purpose to answer the question "*did it work?*".
- **Validation monitoring** — used to test preventive measures to determine whether they will work in theory to answer the question "*will it work?*".
- **Investigative or research monitoring** — used to provide additional data or information to fill identified knowledge gaps and uncertainties to answer the question *"what else do we need to know to help us manage water quality at the water site?"*

While some general guidance is given on these types of monitoring, the approaches taken will be site- and event-specific and highly dependent on the available resources. Further advice should be sought from the relevant health authority or regulator.

The responsible entity should determine the characteristics to be monitored. This should include determining the points at which monitoring will be undertaken as well as the timing of monitoring (including any routine baseline sampling frequency as well as event-based sampling triggers).

The responsible entity should establish and document a monitoring plan for each characteristic. This includes the location and timing of sampling and monitoring to ensure that monitoring data is representative and reliable. The Water Quality Risk Management Plan or some other document should set out the basis for the characteristics monitored, the points at which monitoring will be undertaken and the timing of that monitoring.

The Water Quality Risk Management Plan should outline the process for ensuring results obtained from the monitoring program are credible. Quality assurance principles are set out in documents such as ISO 9001 and supported by programs such as the NATA schemes. Wherever possible, analyses should be undertaken at NATA accredited laboratories.

In remote areas, there may be a greater reliance on field measurement kits rather than NATA accredited laboratories, especially where timely information is necessary. The responsible entity should consult with the relevant health authority or regulator on their appropriateness and seek training and technical support for operators deploying such monitoring equipment.

When reviewing historical data, it is important to understand that future water quality might differ from previous results. Effects such as climate change and changes in development in the catchment might change water quality over time. This may make historical data less reliable for anticipating water quality in the future.

Consideration should be given to incorporating parameters that will improve the collective understanding of potential hazards in the environment and address knowledge gaps. Ideally, a process for sharing the information generated from sampling programs will help advance the collective understanding of risks and potential emerging contaminants or pathogens of concern.

Operational monitoring

Operational monitoring is used to confirm that preventive measures and the mechanisms in place for operational control are functioning properly and effectively to keep the water site safe for its intended recreational and cultural use. Operational monitoring is different from verification monitoring.

Data from operational monitoring can be used as triggers for timely corrective actions to protect water quality or to allow for early action to protect water users from poor water quality. This requires the selection of operational parameters against which to assess performance for comparison against the target criteria and alert and critical limits. The purpose of this operational monitoring is to assess and confirm the performance of the preventive measures through a planned sequence of observations and measurements. Key elements of operational monitoring include:

- development of operational monitoring plans from catchment to exposure site/s, detailing precisely what is monitored, where, how and which entity is responsible; and
- setting up systems for ongoing review and interpretation of results to confirm operational performance and to undertake timely actions to protect water quality at water site(s) and/or issue alerts if poor performance arises.

Selection of parameters

Operational parameters should reflect the effectiveness of each process or activity, and provide as immediate an indication of performance as practicable. Ideally, monitoring parameters should be readily measured and able to be responded to appropriately. For example, where detention is used to reduce the concentration of infectious pathogens, flow measurement can be used to determine that minimum requirements are being met. Similarly, where disinfection processes are used, online measurement of residuals can be used to determine that requirements are being met.

Surrogates are often used as operational parameters in place of direct measurement of hazards. For example, turbidity is used as an indicator of the performance of filtration and detention system performance and can be a surrogate for removal of pathogens from upstream pollution sources and designated treatment processes.

Program design

Operational parameters should be monitored with sufficient frequency to reveal, in a timely fashion, any violation of operating targets, alert levels, or critical limits. Online and continuous monitoring should be used wherever practicable, particularly for treatment processes deemed to be critical control points. However, in practice many of the preventive measures relevant to water environments are natural systems or are not actively managed systems and are somewhat passive controls that are not amenable to reliable, active, engineered controls linked to online operational monitoring. For example, for water environments much of the monitoring may be observational in nature and could include:

- regular inspections of catchment conditions and situations upstream of the water environment, such as pollution control facilities, containment and treatment infrastructure, wastewater and stormwater infrastructure integrity and equipment
- sanitary inspections to check for pollution events such as livestock breaching fencing
- monitoring of recreational or cultural activity, such as levels of activity, bather density, access controls and signage.

Because recreational or cultural activity at a water site is often subject to limitations on the range of permitted activities, operational monitoring needs to include observational monitoring or auditing to ensure that these controls and limitations are being maintained. Observational monitoring programs are often part of a broader environmental or catchment management plan, or water environment site management plan.

In other cases, operational monitoring may involve some form of automated testing of the performance of more engineered or active controls, or provide earlier warning. This may include for instance:

- rainfall within the catchment
- turbidity in the waterway
- salinity
- temperature

- pH
- river height
- water flow rate
- upstream wastewater treatment processes such as UV or chlorine doses (if these types of critical control points are present).

Some preventive measures can be monitored using surrogates and linked to warnings based on historical correlations, for example, relating flow rates to historical water quality results.

As part of the application of the Framework, or referenced from within that document, operational monitoring protocols should be formalised and documented. Results should be reviewed frequently to confirm that records are complete and accurate, and to identify any deviations from critical limits or target criteria. Those responsible for interpreting and recording operational results should understand how the results should be assessed.

A system should be established for regular reporting of operational monitoring results to relevant staff, sections and organisations, using methods such as graphs or trend charts to facilitate interpretation.

Verification monitoring

This relates to developing verification programs at water sites where recreational or cultural activities take place.

This includes:

- selecting the appropriate water quality parameters to be monitored for the water site
- designing an appropriate sampling and monitoring program
- verifying the quality of the results.

Further advice should be sought from the relevant health authority and/or water site regulator for local procedures and requirements.

Selection of parameters

In managing risks to public health associated with water activity, verification monitoring is often used as part of classifying the safety of those environments. The focus is on microbial indicators of faecal contamination using faecal indicator organisms (FIO), along with indicators of harmful algal and cyanobacterial blooms and their toxins. In addition, in some contexts, *Naegleria fowleri* are quantified.

The coordinating entity and site manager should determine the characteristics to be monitored. This should include determining the points at which monitoring will be undertaken as well as the timing of monitoring (including any routine baseline sampling frequency as well as event-based sampling triggers).

As a minimum, monitoring of water environments is required for FIO, specifically faecal indicator bacteria (FIB) as indicators of faecal contamination. Specifically:

- enterococci are preferred for both marine and freshwaters and a dose-response relationship has been described that forms the basis of the WHO guideline values.
- *E. coli* are sometimes selected for freshwaters and a no-observed-adverse-effects-level has been described that forms the basis of the EU guideline values.

These two FIB are the most commonly used indicators since relationships have been historically established between their concentrations and highly credible gastroenteritis (HCGI) (for enterococci and *E. coli*) and acute febrile respiratory illness (AFRI) (for enterococci) symptoms. However, while these FIB have the greatest evidence base to assist with interpreting results, the relationships between FIB, HCGI and AFRI are relatively poor. The within-day and within-site variation in FIB concentrations is very high, making their use limited even if it represents a best available evidence approach. In addition, FIB can grow naturally and bloom in water under certain conditions leading to potentially elevated FIB concentrations that imply a falsely elevated level of faecal contamination and risk.

In addition to FIB, verification monitoring may involve a variety of parameters informed by the risk assessment. This may include one or more of the following parameters depending on the circumstances:

- harmful algal and cyanobacterial blooms
- *Naegleria fowleri*
- *Acanthamoeba*
- *Burkholderia pseudomallei*
- *Pseudomonas aeruginosa*
- temperature
- pH
- salinity
- nutrients including total phosphorus and total nitrogen
- turbidity.

The parameters selected for verification monitoring should be set based on consideration of risks and exposures as well as local conditions. For instance, if salinity is high enough, and/or temperature low enough, there may not be a need to test for *Naegleria fowleri.* Similarly, if euphotic (light penetrating) depth, water turnover rates and nutrient concentrations are within low-risk ranges, testing for harmful algal blooms might not be required.

Sampling program design

The coordinating entity should establish and document a sampling and monitoring plan for each characteristic, including the location and timing of sampling and monitoring, ensuring that monitoring data is representative and reliable. The Water Quality Risk Management Plan or some other document should set out the basis for the characteristics monitored, the points at which monitoring will be undertaken and the timing of that monitoring.

The timing of sampling is based on consideration of risks and periods of exposure:

- Baseline sampling frequencies are likely to vary over the year, with higher frequencies up to daily during seasons where there is increased recreational or cultural use, and dropping to weekly or even not at all during periods of low or no significant use. The actual frequency of baseline monitoring can be informed by historical data and an understanding of what might drive variability in water quality and exposure.
- Event-based sampling triggers are likely to include upstream wet weather or high flow events, response to spills or polluting events upstream, bushfires (related both to direct impacts and contaminated runoff thereafter) or floods, periods of peak bather density, or reports of issues at the water site, such as algal blooms, scums or dirty water.
- The time of day of sampling should ideally be matched to periods of peak exposure or risk which often means late in the day, at periods of maximum water site use. This may be moderated by sampling first thing in the morning to help separate contributions from the broader environment and from bather shedding.

The location of sampling needs to be informed by consideration of within-site variability and should ideally be targeted to locations most relevant to exposure. Mixing can be very poor in some water environments and it may be worth drawing samples from multiple locations as a result, including reaches of lakes and reservoirs, low flow areas of high use and in some cases at multiple depths.

Flow-weighted, time-averaged or space-averaged and integrated sampling techniques that draw multiple samples and then combine them can provide representative estimates of average concentrations. Such methods are particularly helpful if there is limited funding for analytical work or where the average statistical concentration is what is important. However, such methods fail to fully reveal peak concentrations and so if spatial or temporal variability over smaller scales or shorter timeframes and upper bound statistics need to be understood, multiple samples may still be required to be individually analysed.

Quality and reliability of results

Procedures for sampling and testing should be documented. It is important to have credible, quality procedures for sampling and testing, such as making use of accredited sampling and analytical techniques. A summary of considerations for ensuring reliability of verification monitoring is given in Box 1.

Australia Standard AS/NZS 5667.1:1998 *Water Quality – Sampling Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples* should be referred to when planning sampling programs. To ensure that samples are collected and transported in an appropriate manner, advice of an analyst should be sought before taking a sample.

When reviewing historical data, it's important to understand that future water quality might differ from previous results. Effects such as climate change and changes in development in the catchment might change water quality over time, making historical data less reliable for anticipating water quality in the future.

Box 1 - Ensuring reliability of verification monitoring

Monitoring is only as good as the data collected. Every effort should be made to ensure that the data are representative, reliable and fully validated. Important considerations are listed below.

For a sampling plan, consider:

- parameters measured, sampling locations, sampling frequency
- qualifications and training of personnel
- approved sampling methods and techniques
- quality assurance and validation procedures for sampling
- assessment of data (such as requirements associated with assessing compliance with means, medians or 95^{th} percentiles).

For analytical testing, consider:

- qualifications and training of personnel
- suitability of equipment
- approved test methods and laboratories
- sensitivity of testing and properties measured (such as whether microbial methods measure viability or infectivity)
- quality assurance and validation procedures (such as positive and negative control samples, interlaboratory comparisons)
- accreditation with an external agency such as the National Association of Testing Authorities (NATA).

For monitoring equipment, consider:

- calibration and inspection procedures to ensure control of monitoring equipment.

Investigative and research monitoring

The responsible entity should collaborate with stakeholders to establish programs to increase understanding of the water environments and use this information to improve their management processes.

Investigative studies and research monitoring include strategic programs designed to increase understanding of the water environment in its broader context, to identify and characterise potential hazards and to fill gaps in knowledge. Hazard specific knowledge and development needs are identified in the respective chapters.

For example, the quality of water reaching recreational water environments can vary over a wide range, so improved understanding of factors that affect water quality can lead to a better understanding of preventive measures required to improve management of the quality of water environments used for recreational or cultural purposes. Other examples include:

- baseline monitoring of parameters or contaminants, or testing of potential new water environments that might be used for recreational and cultural purposes to identify water quality problems
- monitoring to understand the temporal and spatial variability of water quality parameters
- modelling (e.g. hydrodynamic modelling) to predict and better understand water movement and the fate and transport of water quality hazards and monitoring parameters
- developing early-warning systems to improve the management of poor water quality
- event-based monitoring to determine the magnitude of impacts (duration and maximum concentrations)
- examining chemical or microbial quality of water environments using tracers and trackers to identify potential point sources of industrial discharges
- assessing upstream discharge licences to identify chemical contaminants that may be discharged into source waters that feed water environments used for recreational or cultural purposes
- studying the movement of water within storages, including lagoons and wetlands in the catchment, to determine real detention times and to identify short-circuiting effects
- examining seasonal or outbreak impacts on microbiological quality of water feeding into, or present within, the water environment.

Note that the above examples can be related. For instance, increasingly monitoring is being used to provide input into predictive modelling of source water quality to assist in the selection of management and treatment approaches. Careful consideration should be given to selection of water quality characteristics to be analysed, use of statistical techniques, collection of samples (frequency and location), use of appropriate sampling and testing procedures and evaluation and management of results.

At the site scale, local research increases site specific understanding of water quality and could include:

- detailed analysis of temporal and spatial variations in water quality parameters, and their relationship to drivers such as weather events or usage patterns
- mechanisms to improve and optimise use and protection of the water environment, including the validation of target criteria, alert and critical limits.

These activities should be carried out under controlled conditions by qualified staff and all protocols and results should be documented.

Partnerships and sector-wide cooperation in research and development can be a cost-effective way to address broader issues associated with water quality, including the development and evaluation of new technologies. Opportunities for such collaboration should be identified with partnership organisations, including health, environment and natural resource management agencies, industry associations, other water users, university departments, cooperative research centres and community groups.

Information sheet – Faecal indicator organisms

Different methods used to assess faecal indicator organism levels may target a slightly different subset of faecal indicator organisms. Hence, it is critical to use a standard method or methods for analysis performed by a NATA-accredited laboratory within each specific jurisdiction. Recently, non-culture-based molecular methods (qPCR) have been developed for both enterococci and *E. coli* (Haugland et al. 2016; Shrestha et al. 2019; Sivaganesan et al. 2019). However, at the time of writing these Guidelines, only qPCR for enterococci had been used in epidemiological studies of recreational water users (Wade et al. 2010).

Enterococci

The intestinal enterococci species found most predominant in faecally contaminated aquatic environments are *Enterococcus faecalis*, *E. faecium* and *E. durans*. In freshwater, *E. faecium* may prevail over *E. faecalis*, whereas in seawater the opposite is observed (Figueras et al. 1998; Tiwari et al. 2018).

Intestinal enterococci have some potential drawbacks for assessment of recreational water quality. For example, their environmental habitats can serve as both sources and sinks. In addition, some intestinal enterococci (and *E. coli*) may be endogenous in sediments, in soils and within submerged aquatic vegetation (particularly in warm and tropical climates, or in warm periods in temperature climates), and therefore may not indicate recent faecal contamination (Byappanahalli et al. 2012; Tiwari et al. 2019).

Intestinal enterococci have been isolated from beach sand (Figueras et al. 1992; Signorile et al. 1992; Ghinsberg et al. 1994), and correlations have been found between contamination of beaches and contamination of adjacent seawaters (Oshiro and Fujioka 1995; Aulicino et al. 1985; Roses Codinachs et al. 1988; Badilla-Aguilar and Mora-Alvarado 2019).

Escherichia coli (E.coli)

E. coli is abundant in human and animal faeces, comprising approximately 1% of the total bacterial biomass (Tallon et al. 2005). It is generally present in greater numbers than intestinal enterococci in fresh excreta. *E. coli* is usually an innocuous resident of the gastrointestinal tract; however, some strains are pathogenic, and can cause significant diarrhoeal and other illness (Croxen et al. 2013). These pathogenic strains generally represent less than 1% of the total *E. coli* in raw sewage (García-Aljaro et al. 2019).

E. coli has been isolated from tropical water systems that have no known sources of faecal contamination (Tallon et al. 2005). *E. coli* populations that have adapted and evolved to survive and replicate in water environments also exist (Luo et al. 2011; Sinclair et al. 2019), as do treatment resistant biotypes very similar to urinary-pathogenic *E. coli* (Zhi et al. 2020). Thermotolerant coliforms including *E. coli* have also been isolated from beach sand (Figueras et al. 1992; Signorile et al. 1992; Ghinsberg et al. 1994). Numbers of faecal indicator organisms in recreational water bodies correlate with the numbers of faecal indicator organisms in adjacent beach sand (Phillip et al. 2011).

Coliphages and culturable human viruses

Culturable viruses (human enteric viruses and bacteriophages) are useful faecal indicators of wastewater disinfection efficacy, such as when chlorination or ultraviolet irradiation is used, or in environments with significant solar irradiation. These culturable human viruses include adenoviruses (Rodríguez et al. 2013), enteroviruses (Costán-Longares et al. 2008) and retroviruses (Betancourt et al. 2018). However, methods are complex and expensive, and total enteric virus presence (infectious and non-infectious) by qPCR will still provide value in identifying the risk from human excreta (Vergara et al. 2016).

Several bacteriophages have been suggested as candidate indicators (McMinn et al. 2017), but most attention has been on coliphages (bacteriophages that infect *E. coli*). Coliphages are not specific to human excreta; they occur in many animal faecal sources, and have been isolated from both fresh and marine recreational water bodies, although generally in low numbers (Contreras-Coll et al. 2002; US EPA 2017). However, certain genotypes of coliphages are more likely to indicate contamination by human excreta (García-Aljaro et al. 2019).

Other organisms

Some jurisdictions have considered alternative faecal indicator organisms in response to specific local conditions. For example, the bacterium *Clostridium perfringens* has been used as an additional faecal indicator organism in Hawaii. In tropical climates, enterococci are naturally present in soils, whereas the presence of *C. perfringens* indicates faecal matter (Vierheilg et al. 2013).

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Information sheet – Sanitary inspections

Introduction

A sanitary inspection is a tool that enables the systematic qualitative assessment of a recreational water catchment's susceptibility to microbial, chemical and radiological hazards. The purpose of a sanitary inspection is to formally identify and investigate possible sources of pollution, and assess the extent of the pollution. Sanitary inspections also help inform water quality monitoring and development of models to predict recreational water quality.

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 water quality monitoring results, where available), be collected before the inspection. 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. The rationale for this is that under certain conditions (e.g. during rainfall and for up to three days after heavy rainfall) bathing water quality may deteriorate significantly. In wet event conditions the sanitary inspection would record additional sources of pollution (e.g. sewage overflows into stormwater) and this would be expected to result in increases in microbial numbers.

Given that the most significant hazards in recreational water bodies are microbial pathogens introduced by faecal contamination, and that most recreational water bodies are susceptible to faecal contamination, this information sheet provides an emphasis on identifying potential sources of faecal pollution. Sanitary inspections can help determine the influence of human versus bird and other animal faecal contamination. The sanitary inspection underpins the 'sanitary inspection category' which is combined with 'microbial assessment category', as determined by the microbial (enterococci) indicator measure of faecal contamination, to provide a primary classification of the water body (refer to *Chapter 3 – Microbial pathogens from faecal sources*).

It is likely that risks associated with harmful algal blooms (from associated nutrients) and chemicals will also arise in some inland waters associated with discharges (i.e. sewage) that are a source of microbial pathogens.

1. 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, or is it the entire recreational water body. 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
- water quality data 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 (e.g. occurrence of microorganisms or other factors such as algal blooms)
- the significance of the recreational water body, its importance to the community, and community reaction to the water being unsuitable for recreational or cultural use.

2. 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 (e.g. state natural resources agencies, environmental regulators, catchment management authorities and other water and land management agencies). First Nations' knowledge and sensory observations, informed by long-standing relationships with Country, can provide valuable complementary insights and should be considered in planning and undertaking the sanitary inspection.

Initially information should be gathered to:

- determine, in the relevant catchment:
    - where pollution discharges may arise from
    - the contaminants that may travel to the water body (note: 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.

Comprehensive sanitary inspections should identify all sources of microbial, radiological and chemical hazards, including sources of nutrients that may promote proliferation of harmful algal blooms.

In relation to microbial pathogens, recreational water can be contaminated with faecal microorganisms from animals, human sewage and faecal sludge-related effluents and leachates; the recreational population using the water (from defecation, vomiting or accidental shedding); and—in decreasing order of human health risk—livestock, farming activities, domestic animals and wildlife. Sewage and faecal sludge are normally the most likely source of human-infectious pathogens. Table 1 provides a list of possible sources of microbial pathogens. In some instances, sources identified as being less significant for microbial pathogens may be significant sources of chemical hazards (e.g. agricultural chemicals, spills of hazardous materials, landfills, mining and groundwater contamination).

Table 1 - Possible sources of microbial pathogens

Likely to be most significant for microbial pathogens	Likely to be less significant for microbial pathogens
• bathers • wastewater discharges • local sewage discharges (e.g. 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 • wildlife near waterways • algal blooms (including nutrients).	• 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 (e.g. run-off, erosion) • landfills • spills of hazardous materials (e.g. fuel, fertilisers, septage) • industrial (wastes, aerial deposition) • mining • contaminated groundwater sources.

The information listed in Table 2 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.

Table 2 - Information to support assessment of potential contamination sources

Information source	Description
Maps	• A map of the catchment on which to identify potential contamination sources.
Discharges 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.

Information source	Description
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 (e.g. 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 (e.g. waterfowl) which contribute mainly faecal indicator organisms, although seagulls may also transport bacterial and other pathogens if the birds feed on nearby sewage ponds.

3. 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.

4. Carry out field inspection, interviews and workshop

Table 3 – Information to support field inspections, interviews and workshop

Information source	Description
Field inspection	In undertaking the sanitary 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 • 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 Hazard Analysis and Critical Control Points (HACCP) and risk assessment to keep the responses focused within the *Framework for the management of recreational water quality* (see Chapter 2). 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.

Information identified during the sanitary inspection should provide a comprehensive description of the recreational water environment. Table 4 provides a summary of the types of information produced from a sanitary inspection.

Table 4 - Types of information identified by sanitary inspections (adopted from WHO 2021)

Characteristic	Detail
Physical characteristics of the immediate water site	• Type of water body (e.g. sea, ocean, estuary, natural or constructed lake, dam, river, springs) • Type of beach (e.g. sand, gravel, rocks) • Nature of foreshore or bank area (e.g. natural sand dunes, riparian zones, river or lake banks that are heavily modified with paved or concreted areas) • Dimensions of the recreational area • Water catchment • Depth of water • Water flows (for rivers), tidal movement and wave action • Susceptibility to storms and heavy rainfall
Amenities and populations	• Presence of toilets and showers • Presence of camping sites and facilities • Populations that frequent the water body, including any vulnerable populations • Presence of homeless populations • Markets, festivals, temporary events
Recreational water activities	• Types of activity and extent of exposure (e.g. swimming, fishing, surfing, windsurfing, rowing, triathlons, kayaking, sailing, waterskiing, paddle boarding) • Local use of motorised vessels (e.g. boats, jet skis) • Numbers of people, including densities of water users, with seasonal and weekday/weekend variations and population variation of water users (e.g. local versus incoming tourists and event water users) • Distribution of activities (e.g. greater activity from rock ledges/outcrops) • Duration of the recreational or cultural water use season
Local sources of animal waste	• Access of dogs, horses, wild animals, and grazing animals such as sheep and cattle to recreational water bodies, beaches and foreshores • Presence of significant bird populations or breeding colonies • Aquaculture activities

Characteristic	Detail
Agricultural impacts	• Run-off from agricultural land with animal grazing or use of manures • Run-off containing fertilisers and pesticides • Erosion or animal access to shorelines creating flow paths for run-off
Wastewater outfalls, combined sewer overflows and municipal stormwater discharges	• Type of sewage treatment, and nutrient concentrations in discharge • Volumes, periods of flow and turbidity (e.g. for stormwater discharges) • Existence of combined sewer/stormwater systems • Location of outfall (e.g. onto beach, or through short or long pipes into the water body) • History of sewerage system failures (e.g. substantial mains breaks, sewer pump station overflows)
Septic tanks/ latrines and faecal sludge management	• Areas serviced, density of septic tanks and type of liquid effluent disposal (e.g. to groundwater, to open drains, direct to water bodies) • Buffer zones between tanks and recreational water bodies • Frequency of faecal sludge emptying and location of disposal site in relation to water bodies
Marinas, ports and mooring sites	• Wastewater receiving stations • Petroleum product receiving stations • Local use of motorised vessels (e.g. boats, jet skis)
Sources of industrial chemical contamination	• Shore-based industries, including discharges • Contaminated sites from historical disposal of chemicals • Offshore industries (e.g. oil wells) • Effluent discharges from hospitals, factories and landfill if not connected to central wastewater treatment systems
Riverine discharges	• Potential impacts on river water quality (e.g. human excreta [open defecation, septic tank effluent and sewage], livestock, municipal stormwater) • Weirs and dams controlling flow/discharges • River flows in the recreational or cultural water use season
Dilution, detention and mixing	• Depending on the type of recreational water body: - river flows - occurrence of thermal stratification and water residence time of lakes - tidal movements, wave action and currents of marine waters

Characteristic	Detail
Fish cleaning and gutting	• Discharge of blood water into recreational lagoon leading to algal blooms or heavy increase of seaweed population
Climatic conditions	• Seasonal temperatures • Wind speeds and directions • Rainfall • Frequency and nature of extreme events
Water conditions	• Whether conditions such as presence of subsurface aquatic vegetation support the growth or survival of significant free-living microorganisms (e.g. *Naegleria fowleri*, pathogenic noncholeragenic vibrio) or vectors (e.g. snails carrying schistosomes)
Coastal development	• Planning for increasing residential and industrial developments
Beach conditions	• Presence of beach wrack and seaweed, including seasonal variations • Programs for litter or solid waste disposal
Legislative requirements	• Nature of the legislation (e.g. public health regulations, specific recreational water regulations) • Recreational water quality standards and health advisory levels • Responsible agencies

5. Report and review

The sanitary inspection methodology and outcomes should be documented in a report and inform the risk assessment as part of the *Framework for the management of recreational water quality* (Chapter 2). The sanitary inspection should be periodically reviewed within a specified timeframe documented in the Water Quality Risk Management Plan. It is good practice to conduct sanitary inspections regularly (3 – 5 years) to capture gradual changes within the catchment area. It should also be revisited when significant changes occur.

Changes in catchment characteristics, including land use, should also trigger a review of the sanitary inspection.

Useful resources

Resource	Reference
The Water Research Australia sanitary survey guidance was developed for drinking water sources. However, it contains useful generic guidance on conducting sanitary surveys, both upfront, and on an ongoing basis as part of site management. This guidance can be adapted to recreational water environment sanitary surveys.	Deere D and Billington K (2021). Good Practice Guide to Sanitary Surveys and Operational Monitoring to Support the Assessment and Management of Drinking Water Catchments, 126 pp. Water Research Australia, October 2021. ISBN 978-1-921732-63-8.
Sanitary Surveys for Recreational Waters | US EPA	User Manual: Sanitary Surveys for Maine Water with Recreational Uses (EPA 820-B-21-001) User Manual: Sanitary Surveys for Fresh Water with Recreational Uses (EPA 820-B-21-002) EPA Sanitary Survey App for Marine and Fresh Waters
Beachwatch Programs protocol for assessment and management of microbial risks in recreational waters. Guide for implementing sanitary inspections and monitoring programs for microbial water quality	NSW Department of Planning Industry and Environment (2020). Protocol for assessment and management of microbial risks in recreational waters. ISBN 978-1-922493-42-2

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WHO (World Health Organization) (2021). Guidelines on recreational water quality. Volume 1: coastal and fresh waters. Geneva: WHO.

Information sheet – Calculating the 95th percentile

Introduction

95th percentiles of distributions of enterococci in recreational water are used by water managers for several purposes:

- to classify a body of water according to its microbial water quality assessment category, a key step (along with its sanitary inspection category) in determining its ultimate recreational water categorisation
- to conduct ongoing verification monitoring of a recreational water, and particularly to check that its microbial assessment category continues to be suitable
- to identify exceptional circumstances warranting a reactive response from management
- to assist in the setting of trigger levels for a reactive response from management.

Types of 95th percentiles

95th percentiles classically fall into two categories:

- *parametric 95th percentiles*, in which a statistical distribution of the enterococcal results is fitted to the data or assumed to apply, for the purpose of determining statistical parameters used to calculate the 95th percentile
- *nonparametric 95th percentiles*, in which a variety of formulas are available for use in calculating the level below which 95 per cent of the samples of enterococcal concentration in the recreational water body are estimated to lie, without making any *a priori* assumption about their distribution.

More recently, a third type of 95th percentile for a distribution of enterococci in recreational water has emerged, based on its associated risk of gastrointestinal illness (GI) as calculated by the method in Kay et al. (2004) (Lugg et al. 2012). This type of 95th percentile, which may be regarded as a *standardised 95th percentile*, corresponds to the parametric 95th percentile of a distribution of enterococci with the same characteristics as those described in Note 4 of Table 3.7 of *Chapter 3 – Microbial pathogens from faecal sources*, but with a risk of GI illness equivalent to that of the distribution being studied.

Choice of 95th percentile

All types of 95th percentile have strengths and weaknesses, and recreational water managers and regulatory authorities need to consider which type to choose in analysing distributions of enterococci in recreational water bodies. Perhaps the biggest weakness of parametric and nonparametric 95th percentiles is that they will not align with the underlying GI illness rate of their respective distributions of enterococci unless those distributions have very similar characteristics to those described in Note 4 of Table 3.7, *Chapter 3 – Microbial pathogens from faecal sources*, i.e.

they are essentially lognormal distributions with $\log_{10}$ standard deviations not far from 0.8103. This leads to the very real prospect of misclassifying the recreational water body, that is, placing it in the wrong microbial assessment category. This can get the task of categorising the water body off to a bad start.

Concerns about results below laboratory detection limits (so-called “left censoring”) have been resolved for parametric 95th percentiles (Greene 2018), provided the data set contains at least 20 enumerated results and they constitute at least 20% of the entire set (Verrill and Johnson 1988). Such concerns have never been an issue for nonparametric 95th percentiles, nor are they for standardised 95th percentiles.

A strength of parametric 95th percentiles is that there is less scatter, and hence less uncertainty, about their calculated concentrations, than for nonparametric 95th percentiles (Hunter 2002). However, there is even less scatter and uncertainty about standardised 95th percentiles, meaning that fewer samples need be taken to achieve the same level of confidence in the results (Lugg et al. 2012).

A strength of nonparametric 95th percentiles is the opportunity they offer for developing trigger levels. But standardised 95th percentiles also offer this opportunity, as evidenced by the trigger levels provided by the automated calculator known as the Enterotester (*ibid*) (available online at https://www.health.wa.gov.au/Articles/A_E/Bacterial-water-quality).

The main strength of standardised 95th percentiles is that they reliably place recreational water bodies in their correct microbial assessment category, as calculated by the method of Kay et al. (2004). They accommodate left censoring, and there is more confidence in their results, even where it is unsafe to assume that the data set is lognormally distributed. The Enterotester is easy to use, permits automated calculations, and provides suggested trigger levels for use by management.

Parametric 95th percentiles

The parametric approach relies on a particular statistical distribution being fitted, or alternatively being reasonably assumed to apply, to all the samples in the data set. The standard default assumption for microbial data is the lognormal distribution. Where the lognormal distribution is used, its 95th percentile is calculated from the estimated population parameters, which are derived from the mean and standard deviation of the logarithms of the data.

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 (although not necessarily of infection risk), with less variance than any nonparametric method.

Should there be left-censored data, resulting from incomplete enumeration by the microbiology laboratory (reported, for example, as < 10 per 100 mL, or as zero counts) testing for lognormality by the method of Greene (2018) for dealing with censored data should be followed. Censorship of up to 80% of the results may be accommodated, provided the sample size is sufficient and the number of enumerated samples is at least 20 (Verrill and Johnson 1988).

Adjustments previously used for dealing with left-censored data tend to produce 95th percentile estimates that are too low and should be avoided. Also, note that Excel™ spreadsheet percentile formula gives estimates that are too low to be satisfactory.

For datasets with sufficient entries, the 95th percentile point of the lognormal probability density function is defined as:

Log_{10} 95%ile = Arithmetic mean log_{10} bacterial concentration + (1.6449 standard deviation of log_{10} 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.

For left-censored data, where lognormality can be reasonably assumed, estimates of the log-transformed mean, standard deviation and 95th percentile can made using the statistical toolkit supplied by Royston (1993).

Nonparametric 95th percentiles

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:

$$Log_{10} X_{0.95} = \log_{10} X_r + r_{frac} (\log_{10} X_{(r+1)} - \log_{10} X_r)$$

$$= (1 - r_{frac}) \log_{10} X_r + r_{frac} \log_{10} X_{(r+1)}$$

Where:

- $X_{0.95}$ is the required 95th percentile
- $X_1, X_2, \ldots X_n$ are the n data arranged in ascending order
- r is the ranking formula being used for the 95th percentile (see below)
- X_r is the rth ordered datum (i.e. the integer part of r)
- r_{int} and r_{frac} are the integer and fractional parts of r respectively.

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 (Hunter 2002). For the most part, the average of these two yields an estimate more accurate than either on its own. For the 95th percentile their formulae are:

$r_{Hazen} = 0.5 + 0.95n$

$r_{Blom} = 0.375 + 0.95(n + 0.25)$

$r_{Average} = 0.4375 + 0.95(n + 0.125)$

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). 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 statistics (e.g. Biometrika Tables for Statisticians, Vol II (1976), Table 9), 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 parametric and standardised approaches described above and below, respectively (Lugg et al. 2012). Also, the absence of any quantitative measure of the dispersion of the data makes interpretation problematic.

An example of a calculation of a 95th percentile is shown in Box 1.

Box 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_{Hazen} = 95.5, r_{Blom} = 95.6125 and $r_{Average}$ = 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_{frac} = 0.55887). Note that averaging produces a more accurate result than either the Hazen or Blom method used alone.

Standardised 95th percentiles

The standardised approach begins by evaluating the GI illness risk of a distribution of enterococci for which the standardised 95th percentile is desired. That illness risk is calculated according to the method of Kay et al. (2004). The *reference distribution* having the same illness risk is then selected. A reference distribution is a lognormal distribution having a $\log_{10}$ standard deviation of 0.8103 (see Note 4 of Table 3.7 of *Chapter 3 - Microbial pathogens from faecal sources*). The parametric 95th percentile of the reference distribution becomes the standardised 95th percentile of the original distribution.

Distributions that have been assessed in this manner can be directly compared with each other in terms of their illness risk, by comparing their standardised 95th percentiles. Importantly, they can be compared with the reference distributions that mark the boundaries between the four microbial assessment categories, allowing them to be placed directly into their correct category.

The Enterotester automates the above procedures (Lugg et al. 2012). To calculate the illness risk of the total distribution, it takes the lognormal distribution by default, unless the probability of its being true is less than 0.05. In that case it uses the empirical distribution, summing the illness risk of all individual sampling results, and dividing by the total number of samples in the distribution

Some features of the Enterotester method are:

- the operator may over-ride the spreadsheet's choice of the lognormal assumption or the empirical distribution, or may sequentially choose both to compare outcomes
- where the empirical distribution is used, $\log_{10}$ standard deviations are, on average, about 10% higher than when the lognormal assumption is applied
- calculations accommodate left-censored data, but right-censored data are entered at the highest enumerated value
- if more than 80% of results are left-censored, a warning appears that the test of lognormality is suspect
- overall, the variance is lower than any other known method of calculating a 95th percentile (almost 30% lower, on average, than for the parametric method)
- in consequence, a standardised 95th percentile based on a data set of 65 results will have confidence limits comparable to a parametric 95th percentile based on 100 results
- the method automatically generates two suggested triggers.

In practice, right-censored results should be rare; if they become troublesome, the laboratory can be requested to avoid them by choosing more suitable dilutions.

Box 2 presents an example on the application of the Enterotester tool to assess the microbial water quality of a recreational water body.

Box 2: Application of the Enterotester tool to assess microbial water quality of a recreational water body

Situation:

A lake commonly used for swimming with a short beach immediately in front of residential housing is flanked by a wetland that contributes faecal contamination to the shallow water fringing the beach. This water has a microbial assessment category (MAC) of C. The local environmental health department takes samples for microbiological analysis from a sampling point in the water, approximately fortnightly during the year, averaging 24 samples per year. The microbiological laboratory reports numbers of enterococci that are 10 organisms per 100 mL or above (numbers less than 10 organisms per 100 mL are reported as "not detected").

At the end of 2023 the principal environmental health officer undertakes a review of the last five years' results to determine whether the beach's classification could be revised.

Method:

The review encompasses 118 results collected from November 2018 to November 2023. These results are entered into an Enterotester spreadsheet to check the beach's MAC. The light version of this macro-enabled Excel® spreadsheet, which will accommodate a dataset with up to 200 results, is chosen (the full version will accommodate up to 677 results, but is not needed in most circumstances).

The dataset consists of 57 enumerated results ranging from 1300 to 10 enterococci per 100 mL, and 61 results below the limit of detection. They are manually entered in column B of the spreadsheet, with their corresponding dates of collection entered in column A.

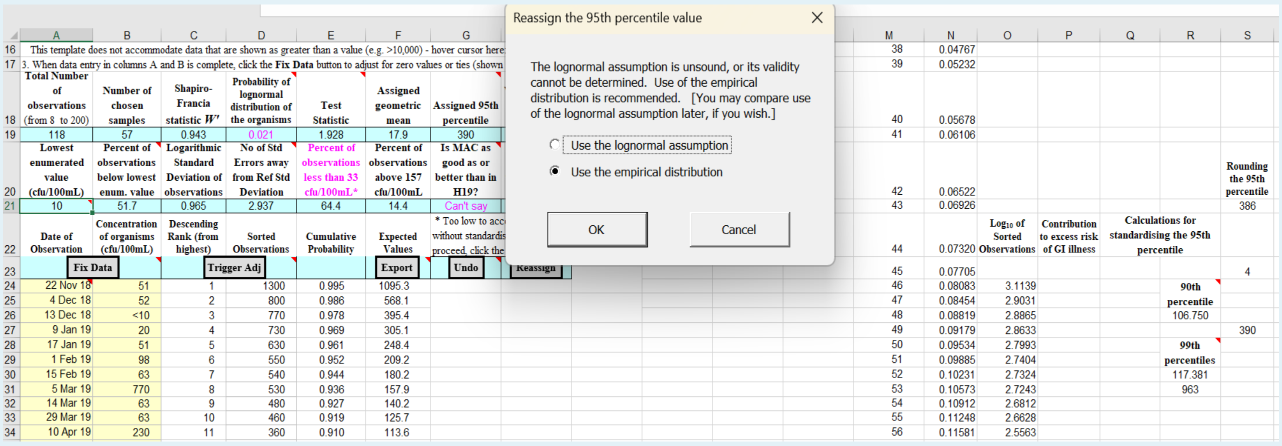
The spreadsheet displays the data from highest to lowest, puts tied results in sequential rank order, and censors all results below the limit of detection. It also displays various statistics, including the probability of the default assumption that the distribution of enterococci is lognormal, which for this dataset is 0.018.

12	**INSTRUCTIONS**								
13	1. Paste data to be assessed in the yellow cells. The microbiological concentrations should start at B24. For the time being,								**Suggested**
14	these concentrations should be in the form of a *continuous*, single-column array, not exceeding 200 observations.								**Water Quality**
15	2. Data that are shown as less than a value (e.g. <10) should be entered *with* a "<" sign. Complete cell A21 if desired.								**one-off**
16	This template does not accommodate data that are shown as greater than a value (e.g. >10,000) - hover cursor here: X.								**Trigger Level**
17	3. When data entry in columns A and B is complete, click the **Fix Data** button to adjust for zero values or ties (shown as pink).								
18	**Total Number of observations** (from 8 to 200)	**Number of chosen samples**	**Shapiro-Francia statistic W'**	**Probability of lognormal distribution of the organisms**	**Test Statistic**	**Assigned geometric mean**	**Assigned 95th percentile**	**Microbial Water Quality Assessment Category**	**Suggested Water Quality two-in-a-row Trigger Level**
19	118	57	0.940	0.018					
20	**Lowest enumerated value (cfu/100mL)**	**Percent of observations below lowest enum. value**	**Logarithmic Standard Deviation of observations**	**No of Std Errors away from Ref Std Deviation**	**Percent of observations less than 33 cfu/100mL**	**Percent of observations above 157 cfu/100mL**			
21	10	51.7			64.4	14.4			
22	**Date of Observation**	**Concentration of organisms (cfu/100mL)**	**Descending Rank (from highest)**	**Sorted Observations**	**Cumulative Probability**	**Expected Values**			
23	**Fix Data**		**Trigger Adj**			**Export**	**Undo**	**Reassign**	
24	22 Nov 18	51	1	1300	0.995	1095.3			
25	4 Dec 18	52	2	800	0.986	568.1			
26	13 Dec 18	<10	3	770	0.978	395.4			
27	9 Jan 19	20	4	730	0.969	305.1			
28	17 Jan 19	51	5	630	0.961	248.4			
29	1 Feb 19	98	6	550	0.952	209.2			
30	15 Feb 19	63	7	540	0.944	180.2			
31	5 Mar 19	770	8	530	0.936	157.9			

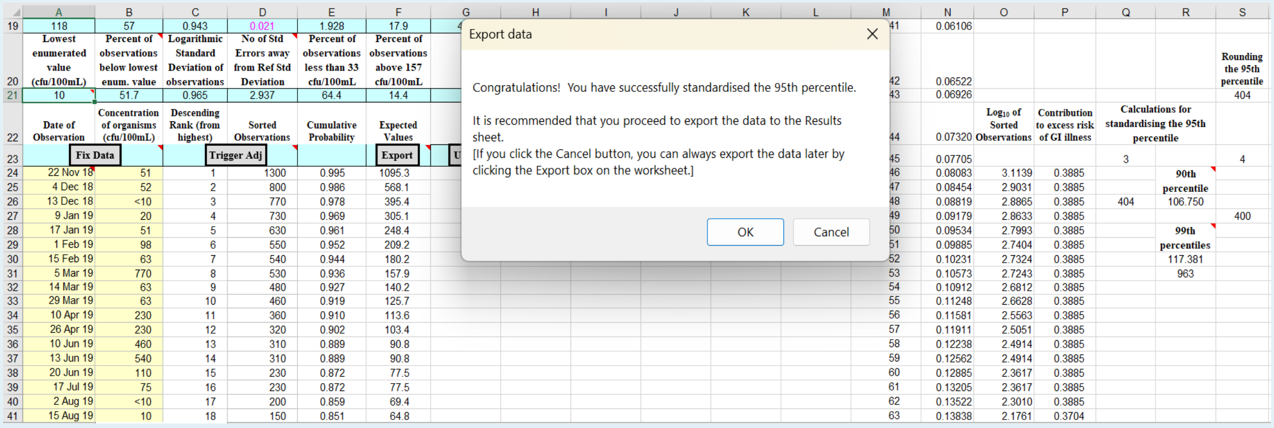
34	0.02527	C	10.49	**Intercept μ_Z**	**Slope σ_Z**		
35	0.03177			1.1182	1.2089		
36	0.03751						
37	0.04276						
38	0.04767						
39	0.05232						
40	0.05678						
41	0.06106						
42	0.06522					**Rounding the 95th percentile**	
43	0.06926						
44	0.07320	**Log10 of Sorted Observations**	**Contribution to excess risk of GI illness**	**Calculations for standardising the 95th percentile**			
45	0.07705						
46	0.08083	3.1139			**90th**		
47	0.08454	2.9031			**percentile**		
48	0.08819	2.8865			106.750		
49	0.09179	2.8633					
50	0.09534	2.7993			**99th**		
51	0.09885	2.7404			**percentiles**		
52	0.10231	2.7324			117.381		
53	0.10573	2.7243			963		

Results:

A macro is then run to fix the data for further analysis. Among other things, this calculates water quality one-off and two-in-a-row trigger levels. Because of the low probability that the distribution of these results is lognormal, the macro recommends use of the distribution's empirical data for standardising the 95th percentile (if that probability had been more than 0.05, standardisation of the 95th percentile using a lognormal model would have been recommended).



The next step standardises the 95th percentile, which turns out to be 400 enterococci per 100 mL, corresponding to an MAC of C. It also adjusts the one-off and two-in-a-row trigger levels to 963 and 317 enterococci per 100 mL, respectively. The manager is aware that the level of confidence in a 95th percentile standardised by the Enterotester from 65 results is higher than that of a 95th percentile calculated by the usual parametric method from 100 results (Lugg et al. 2012).



In the final step, the analysed data is exported to a results sheet, where results from a number of water sites can be listed.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Site Code	Site Name	Seasons Covered	Number of Observ-ations	Percent of observations below lowest enum. Value	Percent of observations less than 33 cfu/100mL	Percent of observations above 157 cfu/100mL	Assigned or Standard-ised 95th Percentile	Microbial Water Quality Assessment Category	Website Traffic Light Colour	Suggested Water Quality one-off Trigger Level	Suggested Water Quality two-in-a-row Trigger
3	AR3/020	Residential Beach A	2018-23	118	52	64	14	400	Category C	Amber	963	317

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It is also worth noting that the trigger level false alarm rate (the probability that either trigger level will be exceeded if there has been no change in the underlying distribution of enterococci) is 0.5 for a series of 58-59 samples, meaning that there is a roughly even chance of at least one false alarm every two to three years at a sampling rate of 24 per year.

Conclusion:

The principal environmental health officer concludes that the standardised microbiological results over the previous five years do not suggest any opportunity to re-classify the beach from a MAC of C.

Source: EnteroTester-V200-v2. Available from the Western Australia Department of Health website at https://www.health.wa.gov.au/Articles/A_E/Bacterial-water-quality

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Information sheet – Derivation of guideline values for cyanotoxins

This information sheet summaries the derivation of the guideline values for cyanotoxins in recreational water, specifically anatoxins, cylindrospermopsin, microcystin-LR, and saxitoxins as described in *Chapter 5 – Harmful algal and cyanobacterial blooms* in freshwater and marine waters. Information on the critical studies that underpin the point of departure adopted for these specific cyanotoxins and assumptions are further described in the Administrative Report (see *Evidence-to-Decision tables - Harmful algal and cyanobacterial blooms water quality in recreational water – cyanotoxins*.

The guideline values are based on a scenario of a young child playing in a bloom-infested water body and taking into account the higher total exposure of children due to their likely longer playtime in recreational water environments and greater accidental ingestion. Children are particularly vulnerable because of their smaller body weight, which increases their relative dose of toxin. Toddlers are at even greater risk, as they are prone to ingesting water and putting materials, such as dislodged mats, into their mouths. Consuming even a small amount can cause serious harm. Consistent with WHO (2021), the default bodyweight of a young child and the volume of water unintentionally swallowed are 15 kilograms (kg) and 250 millilitres (mL), respectively (WHO 2003; WHO 2021) (refer to *Information sheet – Exposure assumptions*).

Guideline values have been rounded to one significant figure to reflect the level of precision resulting from the use of uncertainty factors. Consistent with standard rounding convention, mid-way values are rounded up.

$$Cyanotoxin\ guideline\ value = \frac{point\ of\ departure\ \times\ body\ weight\ \times\ allocation\ factor}{volume\ of\ water\ ingested\ \times\ uncertainty\ factor}$$

Where:

Point of departure	is a reference point on a dose-response curve, often derived from the no observed adverse effect level (NOAEL) or benchmark dose (BMD) for the selected critical health effect observed in an epidemiological (human) or animal toxicity study. It represents the lowest dose that can be extrapolated to estimate the risk of a chemical.
Uncertainty factor	is a number to account for uncertainties in data when extrapolating from experimental or epidemiological studies to a broader population or setting. Factors considered include adequacy of the toxicity study, interspecies extrapolation, inter-individual variability in humans, adequacy of the overall database, nature and extent of toxicity and scientific uncertainty. This is likely to vary for each cyanotoxin and key toxicity study under consideration, and will require expert judgement to determine the most appropriate uncertainty factors to apply in the guideline calculation.

Body Weight	is the average body weight (kg) of the population group selected as the most sensitive for the selected critical health effect. The default bodyweight adopted for of a young child (approximately 2-years) is 15 kg.
Volume of water ingested	the estimated amount of water unintentionally swallowed is 250 mL (refer to *Information sheet – Exposure assumptions* for default ingestion values).
Allocation factor	is also referred to as the 'relative source contribution'. An allocation factor of 1 is assumed for an acute exposure event assuming that the majority of exposure to cyanotoxins is expected to be through water ingestion during recreational activities.

Guideline value for anatoxins in recreational water

The guideline value for anatoxins is adapted from the 2020 WHO provisional recreational water health-based reference value for anatoxin-a (section 8.1 of the WHO background document for anatoxin-a and analogues; p 15) (WHO 2020a).

The guideline value for anatoxins of 20 µg/L (rounded up) ATX equivalence is calculated as follows:

$$19.6\ \mu g/L = \frac{\frac{98\frac{\mu g}{kg}}{day} \times 15\ kg \times 1}{0.25\ L/day \times 300}$$

Where:

- 98 µg/kg bw/day is the point of departure (no-observed-adverse-effect-level) based on neurotoxicity of anatoxin-a in the experimental mice study of Fawell et al. (1999a).
- 300 is the associated uncertainty factor applied to the point of departure derived from animal studies. The uncertainty factor incorporates a factor of 10 for interspecies extrapolation and 10 for intraspecies variation and an uncertainty factor of 3 for database deficiencies.

According to the WHO background document for anatoxin-a and analogues (WHO 2020a), although ATX is the best studied analogue, limited evidence suggests that homoanatoxin-a (HTX) and the dihydro derivatives of ATX and HTX bind to the same receptor and may have similar potency to ATX when administered orally. Given the evidence that the analogues mentioned above are of similar toxicity to ATX, it is recommended that they be included in calculations of total ATXs as gravimetric or molar equivalents.

Guideline value for cylindrospermopsins in recreational water

The guideline value for cylindrospermopsin is adapted from the 2020 WHO provisional recreational water guideline value for cylindrospermopsin (section 8.1 of the WHO background document for cylindrospermopsins; p 21–22) (WHO 2020b).

The guideline value for cylindrospermopsin of 6 µg/L CYN equivalence is calculated as follows:

$$6\ \mu g/L = \frac{\frac{30\frac{\mu g}{kg}}{day} \times 15\ kg \times 1}{0.25\ L/day \times 300}$$

Where:

- 30 µg/kg bw/day is the point of departure (no-observed-adverse-effect-level) based on renal toxicity in the experimental mice study of Humpage and Falconer (2003).
- 300 is the associated uncertainty factor applied to the point of departure derived from animal studies. The uncertainty factor incorporates a factor of 10 for interspecies extrapolation and 10 for intraspecies variation and an uncertainty factor of 3 for database deficiencies.

The calculation is based on toxicology data for cylindrospermopsin. Due to similar toxicity observed in cylindrospermopsin congeners (based on limited evidence), WHO recommends that total cylindrospermopsins are assessed as molar equivalents (WHO 2020b).

Guideline value for microcystins in recreational water

The guideline value for microcystins is adapted from the 2020 WHO provisional recreational water guideline value for microcystin-LR (section 8.1 of the WHO background document for microcystins; p 40) (WHO 2020c).

The guideline value for microcystins of 8 µg/L (MC-LR equivalence) is calculated as follows:

$$8\ \mu g/L = \frac{\frac{40\frac{\mu g}{kg}}{day} \times 15\ kg \times 1}{0.25\ L/day \times 300}$$

Where:

- 40 µg/kg bw/day is the point of departure (no-observed-adverse-effect-level) based on liver toxicity in the experimental mice study of Fawell et al. (1999b).
- 300 is the associated uncertainty factor applied to the point of departure derived from animal studies. The uncertainty factor incorporates a factor of 10 for interspecies extrapolation and 10 for intraspecies variation. Unlike WHO (2020c) and consistent with NHMRC approaches to derive guideline values, an uncertainty factor of 3 for database deficiencies has been applied to acknowledge the limitations of currently available chronic studies for microcystins.

The calculation is based on toxicology data for microcystin-LR. However, microcystins usually occur as mixtures. In the absence of oral toxicity data for other microcystin congeners, WHO recommends that total microcystins are assessed as gravimetric or molar equivalents on the assumption that all microcystins have similar toxicity to microcystin-LR (WHO 2020c). Although not explicitly stated in the WHO guidance, nodularins should also be assessed in the same manner. A toxicity equivalence factor of one should be used for all microcystin and nodularin congeners unless new oral toxicity information becomes available.

Guideline value for saxitoxins in recreational water

The guideline value for saxitoxins is adapted from the 2020 WHO recreational water guideline value for saxitoxins (section 8.1 of the WHO background document for saxitoxins; p 18) (WHO 2020d).

The guideline value for saxitoxins of 30 µg/L STX equivalence (STX-eq) is calculated as follows:

$$30\ \mu g/L = \frac{\frac{1.5\frac{\mu g}{kg}}{day} \times 15\,kg \times 1}{0.25\,L/day \times 3}$$

Where:

- 1.5 µg STX-eq/kg bw/day is the point of departure (lowest-observed-adverse-effect-level) based on neurotoxicity summarised in the 2009 EFSA study on case reports of human poisoning (EFSA 2009).
- 3 is the associated uncertainty factor for use of a lowest-observed-adverse-effect-level rather than a no-observed-adverse-effect-level.

The calculation is based on human poisoning data for a mixture of saxitoxins reported as STX-equivalents. Saxitoxin measurements in recreational freshwaters should also be assessed as STX-equivalents. STX-eq can indicate concentration equivalents, calculated by simple addition of the concentrations of all analogues present (WHO 2020d).

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Information sheet – Cyanobacterial biomass triggers supporting the alert level framework

This information sheet provides the context for the biomass triggers as part of the alert level framework in *Chapter 5 – Harmful algal and cyanobacterial blooms*. The content of this information sheet is informed by a review of the evidence base in the Australian context (Burch 2021) and the World Health Organization (WHO) guidebook *Toxic cyanobacteria in Water (TCiW)* (Chorus and Welker 2021). It also incorporates biomass triggers and guideline values that have been developed for the Australian context.

The alert level framework for managing cyanobacteria in recreational water bodies is adapted from WHO (2021), while retaining some key features and nomenclature from NHMRC (2008). While the structure and nomenclature of the current NHMRC (2008) guidelines alert level framework remain suitable to retain given that it is already widely used across Australia, these Guidelines adopt an alert level framework based on biomass triggers for biovolume and chlorophyll *a*. This change reflects experience that the use of cell number thresholds may lead to undue restrictions of recreational use if the dominant cyanobacteria are species with very small cells. This is because toxin concentrations relate more directly to cellular biomass rather than cell numbers.

Biomass indicators provide a practical means of assessing risk in a timely manner. In practical terms, waiting to act on cyanotoxin results may result in delays in taking the necessary action to minimise risks to public health. However, biomass indicators have limitations. Cyanotoxin concentrations may be high during and immediately following the dissipation of a bloom when biomass measurements are low. Thresholds should be conservatively set so that investigation and action is taken before guideline values for cyanotoxins are reached. A combination of their use is important as guideline values have only been established for a few cyanotoxins.

Microcystis has been identified as possessing the smallest average cell size and the highest per-cell cyanotoxin production capacity of the toxigenic species. Therefore, microcystin-LR has been adopted as the reference cyanotoxin to derive the biomass triggers for biovolume and chlorophyll *a* in Table 1.

Consistent with WHO (2021), the biovolume triggers are calculated using a ratio of 3 µg microcystins per mm^3 biovolume and a ratio of 1 µg microcystins per µg chlorophyll *a* based on the work of Ibelings et al. (2021). These ratios serve as conservative estimates that are not likely to be exceeded in field samples.

The exception is when cylindrospermopsin-producers are present. Biomass triggers will not provide an indication of free dissolved toxin in water that has been released or liberated from cells. This can be substantial after a bloom has collapsed and will be unknown unless toxin is measured directly. Specifically, cylindrospermopsins are excreted by cyanobacterial cells more extensively and extracellular concentrations can exceed intracellular content (Bormans et al. 2014; Lu et al. 2019). The potentially high dissolved and cell-free fraction of cylindrospermopsins in the water cannot be accounted by cell biovolume measurements or chlorophyll *a*. In such circumstances, toxin testing is warranted.

Table 1 - Biomass triggers supporting the alert level framework

Biomass indicator	Action level	Trigger value
Biovolume	Surveillance level	Biovolume equivalent of < 0.4 mm^3/L for the total of all cyanobacteria
Biovolume	Alert level	Alert level biovolume equivalent of ≥ 0.4 to < 3 mm^3/L for the total of all cyanobacteria
Biovolume	Action level	biovolume equivalent of ≥ 3 mm^3/L for the total of all cyanobacteria
Chlorophyll *a*	Surveillance level	< 1 µg/L chlorophyll *a* with dominance of cyanobacteria
Chlorophyll *a*	Alert level	≥ 1 - < 8 µg/L chlorophyll *a* with dominance of cyanobacteria.
Chlorophyll *a*	Action level	≥8 µg/L chlorophyll *a* with dominance of cyanobacteria.

Note: The biovolume value of 0.4 mm^3/L and chlorophyll *a* value of 1 µg/L are derived from the Australian drinking water guideline value for microcystin-LR of 1.3 µg/L (NHMRC 2011).
The biovolume value of 3 mm^3/L and chlorophyll *a* value of 8 µg/L are based on the recreational water guideline value for microcystin-LR of 8 µg/L in (refer to *Chapter 5 – Harmful algal and cyanobacterial blooms*).

The relationship between microcystin-LR and biomass indicators is based on Ibelings et al. (2021). The biovolume triggers are based on a ratio of 3 µg microcystins per mm^3 biovolume and a ratio of 1 µg microcystins per µg chlorophyll *a*.

It is acknowledged that cell count measurement is widely used despite its drawbacks. Cell counts can be used, as can any other locally convenient indicator of the presence and amount of potentially toxic cyanobacteria (e.g. *in situ* fluorescence, turbidity, satellite data), provided that such a parameter is calibrated with occasional toxin analyses. The construction of a cyanobacterial cell size library for use in recreational water quality management needs to be undertaken in consultation with internal or external phycological laboratory services providers. It is important to maintain cell size assessments throughout the year through spot checking to ensure that cell sizes are not systematically changing and where necessary cell size to biovolume library values need to be adjusted to stay representative. A hierarchy of source material to inform the generation and updating of the library is as follows:

- Lowest level of site specific accuracy is the use of literature published cell sizes from a global scan. Due to water site and genetic variability and expression this should be considered to start the building of a cell library but should be updated with more national or site specific information where available.
- National cell size values built from Australian or New Zealand literature.

- National cell size values built from Australian or New Zealand measured values for species and cell sizes, possibly from a large laboratory or where samples are sent long distances to the laboratory.
- Site or region specific values built from measured cell sizes from water site or regional phycological assessments.

A summary of the various indicators used to estimate cyanobacteria and cyanotoxins, and their respective advantages and disadvantages is provided in Table 2.

Irrespective of which biomass indicator is used, measurements need to be locally calibrated against toxin concentration (Chorus and Testai 2021). To capture the conclusions to this question regarding the advantages and disadvantages of using surrogates versus monitoring specific toxins the statement by Ibelings et al. (2021) is a useful summary: "estimates of maximum cyanotoxin concentrations based on surrogate measurements will not be accurate; they merely serve as indicators to support decisions on where to focus efforts for monitoring and for further analyses e.g. of cyanotoxins. Due to their variability over time and between waterbodies, using any of them as an estimate for cyanotoxin concentration implies that follow-up by toxin analysis is most likely to result in considerably lower rather than a higher human health risk" (Burch 2021).

Table 2 - Summary of the advantages and disadvantages of indicators to estimate cyanobacteria and cyanotoxins (source: Burch 2021)

Indicator	Advantages	Disadvantages
Cell Counts	Used widely in many countries over a long period of time. Allows direct assessment of types and potentially of strains.[3]	High cell numbers of very small cells have negligible toxin concentrations.[1] Need to be locally calibrated against toxin concentrations.[1] Microcystin content is widely variable between isolates.[2] Laborious and time consuming.[3] Skilled expert needed.[3] Cells may be incompletely dispersed in suspension, leading to errors in counting.[3] Dispersal methods may damage cells resulting in an underestimation of cell numbers.[3] Time delays in the provision of results due to practical requirements for sample collection, transportation, laboratory analysis and reporting.[4] Potentially high dissolved cell-fraction of cylindrospermopsin in the water cannot be accounted for by cell counts.[5] Reliable values for taxon and toxin specific cell quotas are not extensive.[5]
Biovolume	Toxin per cell is more closely related to biovolume than number of cells.	Needs to be locally calibrated against toxin concentrations.[1] Time delays in the provision of results due to practical requirements for sample collection, transportation, laboratory analysis and reporting.[4] The potentially high dissolved and cell-free fraction of cylindrospermopsin in the water cannot be accounted by cell biovolume measurements.[5]

Indicator	Advantages	Disadvantages
Chlorophyll	Widely used.[3] Submersible probes are suitable for monitoring variable population compositions.[3]	Needs to be locally calibrated against toxin concentrations.[1] Interference by other accessory pigments or suspended particles.[3] Conventional laboratory methods are time consuming.[3] Probes are potentially expensive. Chlorophyll content may vary with species and metabolic state of cells.[3] Probes may be prone to fouling during long-term deployment.[4] Chlorophyll containing organisms other than cyanobacteria are included in the measurement so microscopic examination is needed to determine the relative dominance of cyanobacteria in the water body.[5]
Phycocyanin (PC)	PC is specific to cyanobacteria. Rapid assessment tool.[3] Probes are easily applicable in the field, can monitor blooms daily, and provide instantaneous information.[3] Probes can be suitable for long-term continuous monitoring.[4]	Needs to be locally calibrated against toxin concentrations.[1] PC content may vary with species and metabolic state of cells.[3] Interference by other accessory pigments or suspended particles.[3] Probes may be prone to fouling during long-term deployment.[4] Probes cannot distinguish between cyanobacterial species.[4] Probes are potentially expensive.
Molecular approaches	Rapid and sensitive.[3] Differentiation of toxic/nontoxic strains.[3] Potential for high throughput analysis.[3] Quantitative analysis of cyanobacterial strains and potential for information on variations in community dynamics.[3] Amplification of genes via sensitivity of the techniques allows for early detection of potentially toxic organisms.[3]	Potentially expensive.[3] Not widely available and generally skilled expertise is required. Needs to be locally calibrated against toxin concentrations.[1] Mutations in the gene cluster may overestimate potential toxin producers within the bloom.[3] Time delays in the provision of results due to practical requirements for sample collection, transportation, laboratory analysis and reporting.[4]

1. Chorus and Testai (2021); 2. Fastner and Humpage (2021); 3. Srivastava et al. (2013); 4. Zamyadi et al. (2016); 5. Lu et al. (2019).

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Information sheet – Deriving site specific screening values for chemicals in recreational water

This document describes the general considerations and approach that should be applied to developing health-based site specific screening values for chemical hazards in recreational water.

Derivation of tolerable ambient concentrations of chemical hazards in recreational water must account for the specific toxic nature of a chemical, as well as the nature of human exposure to it. The nature of the exposure requires consideration of potential exposure routes, as well as estimation of exposure durations and frequencies. Since exposure durations and frequencies may vary significantly among people, representative estimations must be made. The selection of representative estimations must account for people who have greater than 'typical' exposure to ensure broad protection across a population.

It is intended that screening values will indicate concentrations for chemical hazards in recreational water bodies that are sufficiently protective of human health across a broad population. Nonetheless, screening values should always be considered and applied in the context of the data, estimations and calculations used to derive them. In circumstances where the applied screening values may not be representative, this should be accounted for when interpreting and applying guidance.

These Guidelines advocate a preventive approach to the management of recreational water that focuses on assessing and managing hazards and hazardous events within a risk-management framework. Chemical screening values are a tool to help inform decisions on prioritising chemical hazards requiring further investigation and managing risks, rather than a 'pass'/'fail' measure.

Default chemical screening values

There is no 'typical' exposure to chemical hazards in recreational water. Default chemical screening values can provide a generic starting point for assessing potential risk associated with chemical hazards in recreational water.

The default chemical screening value approach, described in *Chapter 6 – Chemical hazards*, is based on multiplying the relevant Australian drinking water guideline value by a factor of 20. It assumes that ingestion is the primary pathway of exposure to chemicals in recreational water.

Noting that recreational water use may be highly seasonal, exposure assumptions are based on annual total exposure scenarios using an Annual Accidental Ingestion (AAI) volume of 37.5 litres per year. This figure is taken to be approximately 5% of the of the annual ingestion volume of drinking water of 730 litres assuming 2 litres per day (NHMRC 2011). Equating to approximately 20 times the Australian drinking water guideline value.

The AAI has been estimated using the following calculation.

Annual accidental ingestion volume (litres/year)	=	*ingestion volume per event (litres/event)*	×	*event frequency (events/year)*

It has been derived using the following conservative default assumptions:

- ingestion volume of 250 mL per swimming event for children (DeFlorio-Barker et al. 2017)
- event frequency of 150 events per year (enHealth 2012a)

Applying the above assumptions provides an annual accidental ingestion (AAI) volume of 37.5 litres/year: 37.5 litres/year = 0.25 litres/event × 150 events/year.

Refer to *Information sheet – Exposure assumptions* for background information on the assumptions adopted.

The approach taken in these guidelines is different from the approach taken in NHMRC (2008), which multiplied the Australian drinking water guideline value by 10. This screening value was based on the suggestion from Mance et al. (1984) that recreational water makes a minor contribution to intake, equivalent to 10% of drinking water consumption. Given most authorities (including WHO) assume consumption of 2 litres of drinking water per day, ingestion of 200 mL (i.e. 10% of 2L) per day from recreational contact with water is assumed. This value assumes a daily lifetime exposure from swimming and hence is overly conservative.

Deriving site specific screening values

Across Australia, people's use of recreational water is not the same, given Australia's climate and geography. Some recreational water resources may be used less frequently than assumed in these guidelines, and some may be used more frequently. In such cases, relevant bodies such as a local council may want to consult with health regulators or experts to derive a screening value based on a more locally appropriate event frequency or activity-related ingestion volume. This should be done in consultation with the relevant health authority or regulator.

When doing so, the relevant body needs to provide a clear evidence base to the relevant health authority or regulator for the alternative event frequency or ingestion volume before deriving a site specific screening value. This justification may be based on observational data or other considerations, including seasonal patterns of recreational water use. These scenario-specific screening values may then be used to assess recreational water quality risks associated with chemical exposure in such specific scenarios.

The *Environmental Health Risk Assessment – Guidelines for assessing human health risks from environmental hazards* (enHealth 2012b) provide a framework for assessing human health risks from exposure to chemical hazards and should be referred to in circumstances where the default chemical screening values may not be representative, or where dermal and inhalation exposure routes are relevant for a specific hazard. The *Australian Exposure Factor Guide* (enHealth 2012a) provides exposure factors including for ingestion, dermal and inhalation pathways.

Site specific chemical screening values for recreational activities involving ingestion as the primary route of exposure may be calculated using the equation below:

$$Site - specific\ screening\ value = \frac{point\ of\ departure\ \times\ body\ weight\ \times\ 365\ \times\ allocation\ factor}{volume\ of\ water\ ingested\ \times\ uncertainty\ factor}$$

Where:

Point of departure	is a reference point on a dose-response curve, often derived from the no observed adverse effect level (NOAEL) or benchmark dose (BMD) for the selected critical health effect observed in an epidemiological (human) or animal toxicity study. It represents the lowest dose that can be extrapolated to estimate the risk of a chemical. The point of departure in the *Australian Drinking Water Guidelines* (NHRMC 2011) for the specific chemical hazard should be adopted. The tolerable daily intake, an estimate of daily oral exposure that is likely to be without appreciable risk of deleterious effects, is calculated based on the point of departure and application of an uncertainty factor. Where an estimate for the chemical hazard of interest is not available in the *Australian Drinking Water Guidelines*, seek advice from the relevant health authority or regulator.
Uncertainty factor	is a number to account for uncertainties in data when extrapolating from experimental or epidemiological studies to a broader population or setting. Factors considered include adequacy of the toxicity study, interspecies extrapolation, inter-individual variability in humans, adequacy of the overall database, nature and extent of toxicity and scientific uncertainty. This is likely to vary for each chemical hazard and key toxicity study under consideration, and will require expert judgement to determine the most appropriate uncertainty factors to apply in the guideline calculation.
Body Weight	is the average body weight (kg) of the population group selected as the most sensitive for the selected critical health effect. These guidelines assume default body weight values of 15 kg for a young child (2 years) and 70 kg for an adult (see *Information sheet – Exposure assumptions*).
365	days per year
Volume of water ingested	the estimated amount of water incidentally ingested during the activity within a year (litres per year or L/year) (see *Information sheet – Exposure assumptions* for default ingestion values used in these guidelines).
Allocation factor	is also referred to as the 'relative source contribution'. It is the proportion of total exposure to a chemical attributable to recreational water, relative to other sources like drinking water, food, or air. This is likely to vary for each chemical hazard and will require expert judgement to determine the most appropriate allocation factor to apply in the guideline calculation.

The following scenarios are intended to provide an illustration on how to apply this equation to derive a site specific screening value under a range of hypothetical recreational water activities.

Scenario 1: A freshwater river popular with kayakers but not used for swimming

A local assessment of a river confirmed the presence of pesticides, namely simazine. Simazine is a herbicide used in agriculture and urban environments to control weeds. Kayakers are the primary recreational users of the river and tend to accidentally ingest less water than swimmers.

A site specific simazine screening value of 2.6 mg/L was calculated to account for this difference in accidental ingestion volume as follows:

$$2.6\, mg/L = \frac{\frac{0.5\frac{mg}{kg}}{day} \times 70\, kg \times 365\, days/year \times 0.1}{4.9\frac{L}{year} \times 100}$$

Where:

- 0.5 mg/kg/day is the point of departure (no-observed-effect-level) derived on the basis of decreased survival, decreased bodyweight gain, and evidence of anaemia from a long-term (2-year) dietary study in rates (NHMRC 2011).
- 100 is the associated uncertainty factor applied to the point of departure derived from animal studies. The uncertainty factor incorporates a factor of 10 for interspecies extrapolation and 10 for intraspecies variation (NHMRC 2011).
- 70 kg is the assumed body weight for an adult.
- 4.9 litres per year is the estimated amount of water incidentally ingested. The upper confidence limit of 16.5 mL/hr is assumed for water ingestion whilst kayaking based on a study by Dorevitch et al (2011). A local assessment confirmed that the upper estimate for the duration of kayakers in the water is 2 hours, and frequency is 150 events per year.
- is the allocation factor, or relative source contribution, based on the assumption that 10% of the tolerable daily intake of simazine will arise from exposure to recreational water, assuming the main sources of public exposure to simazine are residues in food and use in swimming pools (NHMRC 2011).

The calculated site specific simazine screening value is orders of magnitude above the typical concentrations of simazine (nanograms/L) in surface water, suggesting very low risk for kayakers in this scenario. This screening value would only be useful during a major simazine spill.

Scenario 2: Young children regularly swimming in an inter-tidal beach lagoon in a tropical area

A creek receives stormwater from an airport with historic use of aqueous film forming foam containing per-and polyfluoroalkyl substances (PFAS). The creek discharges into the ocean at a popular beach, where it forms a lagoon. The lagoon is still and shallow, making it an attractive recreational area for young children. A site specific chemical screening value that considers exposure for young children was considered more appropriate for this scenario as they will accidentally ingest more water than adults.

A site specific PFOS screening value of 35 ng/L (0.035 µg/L) was calculated as follows:

$$35.4\, ng/L = \frac{\frac{728\frac{ng}{kg}}{day} \times 15\, kg \times 365\frac{days}{year} \times 0.1}{37.5\frac{L}{year} \times 300}$$

Where:

- 728 ng/kg/day is the point of departure (benchmark dose level (BMDL10)) derived on the basis of bone marrow effects (extramedullary haematopoiesis and bone marrow hypocellularity) from a sub-chronic (28-day) toxicity study in female rats (NHMRC 2011).
- 300 is the uncertainty factor applied to the human equivalent dose derived from an animal study. The uncertainty factor incorporates a factor of 3 to account for the uncertainty of extrapolating from animals to humans, a factor of 10 to account for human variability and a factor of 10 for use of a short-term study (NHMRC 2011).
- 15 kg is the assumed body weight for young children recreating in the lagoon.
- 37.5 litres per year is the estimated volume of water incidentally ingested (assuming 250 mL is the volume of water ingested per exposure event, and 150 is the number of days the exposure event occurs in a year).
- A default 0.1 is a relative source contribution factor based on the conservative assumption that recreation exposure accounts for 10% of the tolerable daily intake of PFOS.

Water from the lagoon was sampled at low tide and high tide and subject to PFAS analysis. The high tide result was below the site specific PFOS screening value, while the low tide sample exceeded the site specific PFOS screening value.

It was concluded that children recreating in the lagoon were not at risk of significant health effects from PFOS, because:

- the level of PFOS in the lagoon may not exceed the site specific PFOS screening value at all times
- an existing 'do not swim' sign was present at the lagoon, advising people that playing near or around a stormwater drain is a danger at any time.

Scenario 3: Young children swimming in a water body in a remote tropical area

A recreational water body that receives groundwater inflow is in an area historically used for uranium mining. A local assessment confirmed that the water body is regularly used by the local community and especially children for swimming. Therefore, a site specific chemical screening value for uranium was considered more appropriate to assess the risk of health effects from chemical toxicity.

A site specific uranium screening value, for chemical toxicity, of 0.0036 mg/L was calculated as follows:

$$0.0036\,mg/L = \frac{\frac{0.0006\frac{mg}{kg}}{day} \times 15\,kg \times 365\,days/year \times 0.1}{92\,L/year}$$

Where:

- 0.0006 mg/kg/day is the tolerable daily intake for uranium underlying the Australian drinking water guideline value for uranium, and is derived on the basis of degenerative kidney lesions from a 91-day rat drinking water study and application of an uncertainty factor of 100 (NHMRC 2011).
- 15 kg is the assumed body weight for children swimming.
- 92 litres per year (rounded) is the estimated volume of water incidentally ingested (250 mL is the volume of water ingested per exposure event, and 365 is the number of days the exposure event occurs in a year; i.e. every day of the year).
- a default 0.1 is a relative source contribution factor based on the conservative assumption that recreation exposure accounts for 10% of the tolerable daily intake of uranium.

Water from the river was sampled and subject to chemical analysis for uranium. The results were above the site specific uranium screening value.

It was concluded that the water body was not suitable for swimming by children in the absence of risk minimisation measures and additional investigations including a radiological assessment.

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Information sheet – Exposure assumptions

Exposures associated with different types of recreational activities should be characterised when assessing the risk of illness, including whether the recreational activities involve:

- direct contact with the water, involving full immersion and potential to swallow water
- direct contact with the water with low potential to swallow water
- no contact with the water
- potential for exposure to water droplets in air.

The risk of illness increases with the extent of contact with water and time spent in the water (Russo et al. 2020). Recreational activities associated with less water contact may result in a lower risk of illness compared to recreational activities associated with greater water contact; however, even relatively limited contact with the water can lead to ingestion volumes of health relevance (Dorevitch et al. 2012).

The available evidence suggests that children have higher exposures to recreational water compared with other age groups, because of their activities and type of play, and that when estimating risk, it is important to integrate the amount of time spent in the water with the amount of water swallowed (DeFlorio-Barker et al. 2018; Arnold et al. 2016).

The infectious risks from pathogens and the risk of toxic effects from chemicals depend upon the route of exposure to the human body (refer to Table 1). Without exposure, there is no risk. Ingestion is considered the primary pathway of exposure for most water quality hazards.

Table 1 - Routes of exposure for water quality hazards in recreational water

Potential Route of exposure	Comments	Relevance
Ingestion	Ingestion is likely during immersion or partial immersion activities. This ingestion is usually unintentional and occurs either through gasping for air, or by water entering the nose and then swallowed. Smaller volumes of water are ingested by hand to mouth contact and aerosolised droplets that enter the mouth or nose and are subsequently swallowed.	Ingestion should be considered as the default route of exposure for all hazards unless otherwise indicated.

Potential Route of exposure	Comments	Relevance
Direct surface contact (dermal, ocular, mucous membrane)	The routes of exposure through direct surface contact include absorption through skin, eyes and mucous membranes. Exposure may be exacerbated by broken or damaged skin. Skin and eye irritation may result from exposure to some chemicals, including some algal and cyanobacterial toxins, and alkaline and acidic substances with extreme pH. Skin is an effective barrier for many chemicals and microorganisms.	Direct dermal exposure with water or sediment may need to be considered for some algal and cyanobacterial toxins or chemicals in the risk assessment. *Vibrio parahaemolyticus:* infection via cuts in the skin. *Pseudomonas aeruginosa*: infection of skin and eyes. *Naegleria fowleri*: infection via the nasal membrane.
Inhalation	Inhalation refers to entry of the hazard into the lungs while breathing in air. Consideration should be given to highly volatile chemicals and microbial hazards entrained in aerosols.	Where inhalation is considered an exposure route, this should be accounted for in the risk assessment.

Quantifying exposure

Quantitative risk assessments are widely used in defining health-based targets as they translate the concentration of hazards (or their indicators) in water to an estimated health risk. The 'acceptable' or 'tolerable' concentration of the hazard in water can then be inferred from the estimated health outcomes.

Such risk assessments rely on a dose-response function to quantify risk. For application in these functions, dose is typically quantified as the concentration of the hazard in water multiplied by the exposure. An exception to this approach is the dose-response function for microbial hazards used in these guidelines. In that case, the dose-response function is fitted to epidemiological data and directly relates recreational water indicator bacteria concentration to estimated health outcomes. Volume of exposure is not explicitly quantified.

Quantifying exposure for any activity involves estimating:

- **Volume**: How much water is intentionally or inadvertently ingested during the activity?
- **Duration**: How long are participants exposed to water while undertaking the activity?
- **Frequency**: How often do participants engage in the activity?

If the hazard presents an acute risk, then the risk may only be quantified for a single event. For chronic risks, the exposure is typically quantified over a year.

Previous studies indicate that there is wide variation in the volume of water assigned to unintentional ingestion, and so it is important to consider the context, methods and relevance of the study settings before applying their results/recommendations/values to other settings.

The *Australian Exposure Factor Guide* (enHealth 2012a) provides a useful resource for defining quantitative estimates of exposure for some activities. In that guide, Australian conditions are explicitly considered and recommendations for selection of ingestion estimates for risk assessment (where relevant) are provided. However, there is no Australian data for incidental ingestion of water while swimming and there is only very limited information available relating to the time that various Australian age groups spend swimming in swimming pools or natural water bodies (enHealth 2012a). Swimming activity will likely be dependent on the location in Australia; e.g. higher duration and frequency in tropical and sub-tropical regions compared with temperate or colder areas.

In the absence of Australian data on the likely number of maximum recreational events per year, enHealth (2012a) suggests using the United States Environmental Protection Agency (US EPA 1997, Table 15-18) upper estimate of 150 events per year for a person who swims regularly for exercise or competition.

Key findings from available experimental studies conducted in the United States and Netherlands include:

- Exposure increases with the amount of contact with the water, and with head submersion. Recreational activities that involve limited contact with water (such as kayaking, canoeing) would typically lead to a lower exposure (Dorevitch et al. 2011). Surfing results in relatively high ingestion of water (Stone et al. 2008).
- The amount of water ingested by an individual increases with the duration of their activity. By implication, exposure may be expected to be lower in a cold climate or during winter where swimming events are typically of shorter duration, in comparison to tropical climates or during summer.
- Children are likely to ingest proportionally greater amounts of water than adults when bathing, swimming or playing in the water due to their increased likelihood of longer playtime in recreational water environments and propensity to swallow water (Arnold et al. 2016; Dufour et al. 2006; Dufour et al. 2017; DeFlorio-Barker et al. 2018; Schets et al. 2011). There is no data available for children less than 6 years of age.

Most guidelines recognise that children are a sensitive sub-population with regard to recreational exposure, are likely to spend more time in direct contact with waters and ingest more water than adults. It is therefore appropriate that the default exposure assumptions are based on water ingestion in children. In particular, older toddlers (e.g. 2-3 years old) who may have less supervision in shallow waters than an infant will potentially be accidentally ingesting the largest amount of water while playing or paddling. A bodyweight of 15 kg has been selected as a default value for an older toddler by adopting the default bodyweight in WHO (2021). This is considered a reasonable assumption for this particular population group and consistent with the average bodyweight of 2-4 year olds outlined in the *Australian Exposure Factor Guide* (2012a).

Consistent with WHO (2021), for these guidelines, the study by DeFlorio-Barker et al. (2018) which examined exposure to water in marine and freshwater, among children, has been used as the basis for calculating a default exposure volume. The calculation was based on averaging the upper 95th percentiles of the volumes swallowed by the groups of children 6-12 yrs (220 mL for marine water and 184 mL for freshwater per event) and ages 13-18 yrs (280 mL for marine waters and 174.7 mL for freshwater per event). This produced upper 'average' figures of 250 mL for marine water and 179 mL for freshwater. The upper value of 250 mL of water ingested per swimming event has been selected as the worst case and therefore the most conservative and health protective option.

A default event frequency of 150 days per year is adopted based on the *Australian Exposure Factor Guide* (enHealth 2012a). This frequency is an upper estimate, so is likely to be protective in most scenarios.

The application of these default exposure assumptions for the various hazards in these guidelines is summarised in Table 2.

Table 2 - Default reference level of exposure in these Guidelines

Hazard	Acute or chronic	Default reference level of exposure	Rationale
Microbial pathogens[a] (*Chapter 3*)	Acute	The number of intestinal enterococci per 100 mL based on epidemiological studies. For site specific quantitative microbial risk assessment adopt 250 mL per event.	Primary exposure route is ingestion. Default intestinal enterococci concentrations adopted from WHO (2021) and NHMRC (2008).
Harmful algal and cyanobacterial blooms (*Chapter 5*)	Acute	Risk is assessed for a single event. The default bodyweight of a child and the volume of water unintentionally swallowed are 15 kg and 250 mL, respectively.	Primary exposure route is ingestion. Adopted from WHO (2021). Based on a worst-case situation of a 15 kg toddler swallowing 250 mL of water. Bodyweight of toddler assumed to be an older toddler (slightly over 2 years) who may be playing or paddling in water with limited supervision and swallowing a lot of water during this activity. The value of 15 kg is adopted from WHO (2021) and is consistent with the average weight of 2-4 year old from the *Australian Exposure Factor Guide* (enHealth 2012a).

Hazard	Acute or chronic	Default reference level of exposure	Rationale
Chemicals (*Chapter 6*)	Chronic	Default chemical hazard screening values based on worst case incidental ingestion volume of 250 mL of water by a child per swimming event and an estimated frequency of 150 swimming events per year in warmer waters. This equates to about 37.5 litres per year, representing approximately 5% of the volume of drinking-water ingested per year (based on 730 litres assuming 2 litres per day ingested).	Primary exposure route is ingestion. Reported upper 95th percentile for children (DeFlorio-Barker et al. 2018). Since children consume more water than adults, this is considered to be the most health protective estimate for all ages. Median frequency suggested by enHealth (2012a) is 52 days per year, upper estimate of 150 days per year for regular swimmers. Upper estimate is considered to be the most health protective estimate.

Selecting values for the risk assessment

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.

The default exposure assumptions are based on the ingestion exposure route via swimming, and although the ingestion volume is sufficiently conservative for most recreational settings, it may not accurately reflect water use in all contexts (i.e. surfing). Where there is site specific data available (e.g. event frequency data), its application in the risk assessment for that given water site should be undertaken in consultation with the relevant health authority or regulator.

Where there is evidence that dermal and inhalation are significant exposure routes for a specific hazard, a site specific risk assessment should be undertaken in accordance with the *Environmental Health Risk Assessment – Guidelines for assessing human health risks from environmental hazards* (enHealth 2012b).

The nature of the exposure requires consideration of potential exposure routes, as well as estimation of exposure durations and frequencies. Since exposure durations and frequencies may vary significantly among people, representative estimations must be made. The selection of representative estimations must account for people who have greater than 'typical' exposure to ensure broad protection across a population which may exhibit highly variable exposure patterns.

Selecting a quantitative value for each measure of exposure requires a decision, informed by the experimental and observational data and tailored to the purpose of the risk assessment. When data is limited, it may be necessary to select a value outside this range to ensure that the risk assessment is protective.

NHMRC

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Information sheet – Preparing a risk communication plan

Introduction

A risk communication plan can help prepare effective engagement with communities in response to water contamination or other environmental risks. It ensures people receive timely, accurate, and culturally appropriate information before, during, and after an incident. This guidance outlines practical steps to build public trust, coordinate with stakeholders, and deliver clear messages that support community safety and informed decision-making. A *Risk communication planning checklist* is also available.

Understanding risk communication

Risk communication is a critical component of recreational water quality management. It involves the timely, accurate, and culturally appropriate exchange of information to support informed decision-making and protective behaviours. It should begin early, continue throughout the incident lifecycle, and be tailored to the needs of diverse audiences.

Key principles

These principles provide a foundation for effective, inclusive and coordinated risk communication. They guide organisations in building trust, engaging communities, and responding to environmental health risks with clarity and cultural sensitivity. The *enHealth Risk Communication Principles, October 2021* outlines principles for good risk communications, including:

- **Be transparent and timely:** Share accurate information early and often. Acknowledge uncertainty where it exists and provide regular updates as the situation evolves.
- **Build and maintain trust:** Trust is earned through consistency, honesty, and respectful engagement. Use clear language, avoid jargon, and ensure messages are delivered by credible and authorised spokespeople.
- **Coordinate across agencies:** Establish clear roles and responsibilities for communication. Ensure messaging is consistent across departments, councils, and partner organisations.
- **Address public concern, not just hazard:** Recognise that perceived risks may be amplified by fear, uncertainty, or lack of trust. Respond to emotional drivers and community concerns, not just technical assessments.
- **Commit to continuous learning:** Build systems to capture lessons learnt and update tools and strategies regularly. Encourage staff development through training and creative workshops.
- **Celebrate effective practice**: Define what success looks like for different types of risk communication and recognise those who demonstrate excellence in inclusive, evidence-informed approaches.

Risk communication plans

A well-structured risk communication plan ensures that the public receives timely and accurate information about potential health risks and preventive measures. It prioritises outreach to vulnerable and at-risk groups. It also helps to foster trust and credibility through transparency and responsiveness and enables stakeholders to act confidently and collaboratively within their defined roles.

Key questions to consider when developing a risk communication plan

- How will your organisation raise public awareness of health risks and communicate personal preventive measures that the public can take to minimise their risk of exposure to water quality hazards?
- How will your organisation respond to reports of contamination?
- Who are the key authorities responsible for investigation and public advice?
- How will you notify the public about risks following an incident and when it is safe to return?
- Are you prepared to respond to any misinformation or disinformation campaigns?

Components of a risk communication plan

Define your audience

Identify all relevant stakeholder groups and target audience(s), including:

- water managers, health and environment agencies, media, internal organisational teams.
- members of the public including First Nations groups and other priority populations.

Consider how to reach each group effectively (i.e. engagement with specific communities, language needs, interpreters, accessibility).

Stakeholder mapping and role definition

Map key stakeholders involved in water management, emergency response, and community engagement. Clearly define their roles and responsibilities to support coordinated action and message delivery. Examples include:

- **local councils:** approve and distribute alerts.
- **health departments:** provide public health advice.

- **First Nations organisations:** offer cultural guidance and community engagement.
- **media outlets and social media channels:** disseminate public messages.

Establishing clear roles and responsibilities will help to ensure timely and coordinated responses and enable accurate, culturally sensitive messages to be delivered through the right channels.

Cultural sensitivity and engagement

Embed cultural considerations throughout the planning process to ensure respectful and effective engagement with First Nations communities. Key actions include:

- consulting with Aboriginal Land Councils or cultural advisors.
- involving trusted messengers such as Aboriginal Health Workers or Rangers.
- incorporating traditional knowledge and local language terms where appropriate.
- ensuring materials are accessible (e.g. plain English, visuals, oral formats).
- documenting community input and planning for ongoing engagement beyond the incident.

Develop key messages

Clear, consistent and tailored messaging is central to effective risk communication. Key actions include:

- preparing tailored messages for each audience/ stakeholder group
- using key message templates for common scenarios (e.g. changes to recreational water quality, contamination alerts)
- anticipating community concerns and prepare responses to frequently asked questions or potential criticisms, misinformation or disinformation campaigns.
- developing any educational materials that are required (e.g. to build awareness of how communities can help reduce contamination of waterways).

Select communication channels and assign roles

Choosing the right communication channels and clearly assigning roles ensures that messages are delivered efficiently and reach the intended audiences. Key actions include:

- choosing appropriate communication channels (e.g. website, social media, community meetings).
- planning for temporary or permanent signage (e.g. to warn the public of water quality risks or areas where access to water is restricted) and the appropriate formatting for the intended audience (e.g. quick response or QR codes, use of pictograms or text warnings, appropriate use of colours)

- identifying authorised spokespeople and define specific roles (e.g. communications, media, public health)

Table 1 - Example communication channels

Channel type	Description	Example
Website updates	Centralised source for incident information and frequently asked questions (FAQs)	Posting contamination alerts and safety advice
Social media	Rapid dissemination and community engagement	Sharing updates via council or agency accounts
Email	Direct communication with stakeholders and internal teams	Notifying water managers and health departments
Community signage	Physical notices in public spaces	Warning signs near affected water bodies
Community meetings	In person engagement	Explaining risks and response plans to local communities

Implement and monitor the risk communication plan

Once the risk communication plan is activated, it is essential to implement it with clear coordination and to monitor effectiveness in real time. This helps to ensure messages are delivered and supports adaptation if required. Key actions include:

- establishing internal contact points for message approval and dissemination.
- planning for alternative communication methods if standard channels are unavailable or ineffective.

Evaluate and refine the risk communication plan

After an incident, evaluating the effectiveness of the communications plan is essential to identify what worked well, what could be improved, and how future messaging can be strengthened. Key actions include:

- evaluating communication effectiveness post-event (e.g. website/social media analytics, public feedback, media coverage).
- refining and updating the risk communication plan to incorporate feedback, improve clarity, and strengthen cultural and stakeholder engagement strategies.

Table 2 - Example Evaluation Methods

Method	Description	Examples
Community feedback surveys	Gather input from affected communities on clarity, relevance, and tone	Post-incident survey distributed via local councils

Method	Description	Examples
Stakeholder debriefs	Structured discussions with key partners and agencies to reflect on performance	Review meeting with water managers and health teams
Media and social media analysis/analytics	Assess public sentiment, message reach, and misinformation trends Use analytics to measure reach and interaction (e.g. website visits, shares)	Analysing engagement and comments on social media posts Reviewing traffic spikes during alert periods
Document lessons learned	Capture successes, challenges, and recommendations for future improvement	Internal report summarising communication outcomes

Other useful resources

A range of national and jurisdictional resources offer practical tools, frameworks, and guidance to support effective risk communication in environmental health contexts. Some useful resources include:

- enHealth: Communicating risks to health from environmental hazards (May 2025) provides foundational principles and practical strategies for communicating environmental health risks. It covers risk perception, message development, stakeholder engagement, and communication planning. It is tailored for environmental public health professionals working in government and related sectors.
- enHealth: Risk Communication Principles (October 2021) outlines the core principles of effective risk communication, including transparency, timeliness, empathy, and audience engagement. It serves as a quick reference for practitioners.
- enHealth: Risk Communication Assessment Tool and guidance (RCAT) and accompanying interactive tool (RCATi) help assess the level of public concern (or "outrage") in environmental health situations. It guides users in tailoring communication strategies based on the emotional and informational needs of affected communities.
- EPA South Australia - Community Engagement in Site Contamination (2018) outlines expectations for community engagement in cases of site contamination. It provides a framework for transparent, inclusive, and timely communication with affected communities.

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Risk communication planning checklist

Introduction

A local risk communication plan can help prepare your organisation to protect environmental waters from contamination or improve public awareness of any risks, incidents or emergencies they may encounter there.

Table 1 below describes information that should be included in a best-practice risk communication plan as a guide only. By following this checklist, organisations can strengthen their preparedness, improve community engagement, and support informed decision-making in times of uncertainty.

Refer to sections 2.27 and 2.28 of *Chapter 2 – Framework for the management of recreational water quality* and *Information sheet – Preparing a risk communication plan* for more information.

Table 1 - Preparing a risk communication plan - checklist

Description	Explanatory notes	Completed
Scope of the water quality risk management plan	Describe the water site/s and locations that the plan covers. Provide geographic details and maps if possible. Link to any broader Water Safety Plan in operation (for physical/animal threats) or any other relevant site plan or process.	☐
Publication details	List author/s of plan and date of implementation. List date of planned update/review.	☐

Description	Explanatory notes	Completed
Stakeholder contacts	List all key stakeholders involved in managing water resources or environments and may be be involved in responding to a pollution, emergency or other event/notification that may affect the health or safety of your community. • roles and responsibilities • contact details. Examples to include: • Water Managers at the local water catchment authority • Environmental Health Officers at council • Environment and Health Departments and EPA in your State or Territory • Managers/rangers of local parks • Local media outlets (e.g. TV and radio stations).	☐
Engagement with First Nations communities and Traditional Owners	Prepare a contact list for local First Nations health/community organisations and any other community organisations that can help in your outreach and messaging to the local community.	☐
Roles and responsibilities	Identify and list relevant roles/responsibilities: • how the public can report concerns • who assesses and monitors water quality • who communicates results and health advice • how risk management measures are evaluated.	☐
Target audience	Identify target audience, for example: • water managers • health and environment agencies • media outlets • managers within your organisation • members of the public including First Nations or other key stakeholders).	☐

Description	Explanatory notes	Completed
Stakeholder engagement	Detail plan to reach all relevant groups (i.e. engagement with specific communities, information in relevant languages, need for interpreters or sign language).	☐
Consultation/engagement with First Nations communities	Document details of how you: • engage with Local Aboriginal Land Councils or advisors • intend to incorporate traditional knowledge about water quality risks • develop accessible communication materials.	☐
Key messages	Develop key messages for each stakeholder group including on raising public awareness of health risks and personal preventive measures. Prepare key message templates to inform the public about changes to recreational water quality and emergency responses.	☐
Educational materials	Develop educational materials that promote waterway protection	☐
Sensitivity planning	Note any sensitivities and prepare responses in case further explanation is sought by the community List responses for possible questions that you may receive from your community (i.e. frequently asked questions or FAQs). Prepare responses to potential criticisms/concerns from the community about the event or its management by local authorities. Prepare responses for anticipated misinformation or disinformation campaigns.	☐
Spokespeople	Notify authorised spokespeople. Assign specific roles i.e. media/communications, public health, public health, State/Territory authorities, water utilities.	☐

Description	Explanatory notes	Completed
Communication channels	List proposed communication channels (website, social media, radio, TV). Prepare signage (temporary, permanent, templates for printing) for water quality issues and/or restricted access to water.	☐
Internal contacts	List internal contact details for those responsible for communication activities and approval of messages.	☐
Contingency plan	Develop alternative engagement or communication mechanisms if communications channels are narrow.	☐
Tools and resources	Refer to the latest enHealth guidance and tools: • Risk Communication Principles • Risk Communication Assessment Tool (RCAT) and RCATi • Communicating Risks to Health from Environmental Hazards	☐
Post-event evaluation	Track engagement and feedback. Review and evaluate your communication strategy post-event including website/social media views and public discussions/complaints on social media. Update your risk communication plan for future events. Develop educational materials to help reduce contamination/pollution of waterways during non-emergency periods.	☐

Information sheet – Resources on water quality and other hazards

This information sheet provides a summary of resources relating to water quality and other hazards associated with recreational water including:

- Australian guidance and resources on other hazards (Table 1). Other hazards that people may encounter when using recreational water environments that are not directly related to water quality include:
  - physical hazards
  - sun, heat and cold
  - animals and insects
- State and territory specific advice and resources on both water quality and other hazards in recreational water (Table 2).

In addition, the Water Quality Australia website summarises various national guidelines related to water management https://www.waterquality.gov.au/. The website is a product of the National Water Quality Management Strategy (NWQMS), an Australian Government initiative in partnership with state and territory governments. Under the auspices of the NWQMS are the *Australian and New Zealand guidelines for fresh and marine water quality*. These guidelines outline the principles and management framework for natural, semi-marine and freshwater resources in Australia and New Zealand (available at https://www.waterquality.gov.au/guidelines/anz-fresh-marine).

Australian guidance and resources on other hazards

The following table provides a summary of resources and Australian guidance relating to other hazards associated with the recreational and cultural use of water environments.

Table 1 - Summary of Australian guidance and resources relating to hazards associated with recreational and cultural use of water environments

Risk group	Types of risk	Australian guidance and resources
Physical hazards	• Drowning • Major impact injuries (including spine and head injuries) • Slip, trip and fall injuries	**Surf Life Saving Australia – Beachsafe program** (website and app) https://beachsafe.org.au/surf-safety Information on: • rip currents and waves • sun safety

Risk group	Types of risk	Australian guidance and resources
Physical hazards (cont.)	• Cuts, lesions, puncture wound (e.g. oyster shell cuts) • Sand, mud or submerged objects (e.g. quicksand, rocks and logs) • Watercraft (e.g. boats and jet skis) • Extreme tidal changes, rips and currents.	• risks associated with alcohol and drug use during recreational activities • safety tips for rock fishing, boating, watercraft use • dangerous marine life. **Royal Life Saving Society Australia** https://www.royallifesaving.com.au/ Information on: • extensive safety information for different communities (children, adults, disability, regional and remote, Aboriginal and Torres Strait Islander peoples, multicultural) • risks for water-based activities (e.g. personal/medical, flooding, hypothermia) • farm water safety • waterway safety in rivers, creeks, lakes and dams. Guidelines for Inland Waterway Safety provides information on managing potential hazards in inland waterways. https://www.royallifesaving.com.au/about/campaigns-and-programs/respect-the-river Royal Life Saving's "Respect the River" project educates the community about inland waterway safety and risks. **Australian and New Zealand Committee on Resuscitation (ANZCOR)** https://www.anzcor.org/home/new-guideline-page-3/ ANZCOR provides guidelines on first aid/emergency management for: • drowning • scuba diving accidents. **Healthdirect Australia** https://www.healthdirect.gov.au/beach-safety Information on:

Risk group	Types of risk	Australian guidance and resources
Physical hazards (cont.)		• beach rules, signs/flags, lifeguards and lifesavers • safety tips for children and rock fishers • dangers of large waves and rip currents • dangers of alcohol, drug and medicine use • sharks and stinging jellyfish.
Sun, heat and cold	Health risks associated with: • UV radiation • exposure to cold water (cold water shock and hypothermia) • heat exposure (hyperthermia, heat stroke).	**Cancer Council Australia – SunSmart program** https://www.cancer.org.au/cancer-information/causes-and-prevention/sun-safety Information on: • sun safety • sun exposure protection • skin checks • the UV index • vitamin D and • measures to prevent skin cancer. https://www.sunsmart.com.au/ Information on: specific sun safety advice for schools, early childhood centres, parents and carers, workplaces, healthcare professionals, sports groups, events, festivals and local government. https://www.sunsmart.com.au/ Phone apps are available from SunSmart and the Bureau of Meteorology to communicate the forecast UV index throughout the day relying on UV radiation monitoring by ARPANSA. **Bureau of Meteorology** http://www.bom.gov.au/uv/index.shtml Information on UV radiation/index forecasts. **ARPANSA (Australian Radiation Protection and Nuclear Safety Agency)** https://www.arpansa.gov.au/our-services/monitoring/ultraviolet-radiation-monitoring/ultraviolet-radiation-index

Risk group	Types of risk	Australian guidance and resources
		ARPANSA monitors UV radiation at select locations around Australia, publishes the UV index and summarises UV exposure risks. https://www.arpansa.gov.au/understanding-radiation/radiation-sources/more-radiation-sources/sun-exposure Overexposure to UV radiation can cause sunburn, skin damage, skin cancers or eye damage including cataracts. **The Royal Life Saving Society Australia** https://www.royallifesaving.com.au/stay-safe-active/risk-factors Provides information on risk of cold-water shock, hypothermia and drowning after swimming or accidental falls into cold waters (<15°C). **Australian and New Zealand Committee on Resuscitation (ANZCOR)** https://www.anzcor.org/home/new-guideline-page-3/ ANZCOR provides guidelines on first aid/emergency management for hypothermia and hyperthermia.
Animals and Insects Animals and Insects (cont.)	• Nonvenomous animals (e.g. sharks, crocodiles) • Venomous animals (e.g. jellyfish, octopus, bluebottles, snakes, insects) • Insects • Bites, stings and other injuries (including envenomation) from aquatic	The following organisations provide detailed information on identifying, the location, distribution of habitats and the seasonal appearance of animals and insects that may pose a risk on Australia's shores and waterways. Recommended first-aid measures for any injuries are also described. **Surf Life Saving Australia – Beachsafe program (website and app)** https://beachsafe.org.au/surf-safety Advice on dangerous marine animals including: • blue-ringed octopus • cone shells and stonefish • sea snakes • sharks

Risk group	Types of risk	Australian guidance and resources
	organisms or insects	• stingrays • saltwater crocodiles • stinging jellyfish. **Australian museum** https://australian.museum/learn/animals/dangerous-animals/ Advice on dangerous Australian marine animals including: • blue-ringed octopuses, blue-lined octopus • stinging jellyfish • bull, tiger and white sharks • freshwater, estuarine and saltwater crocodiles • snakes • stonefish, lionfish • stingrays Advice on dangerous jellyfish, anemones and coral. https://australian.museum/learn/animals/jellyfish/ **Australian and New Zealand Committee on Resuscitation (ANZCOR)** https://www.anzcor.org/ ANZCOR guidelines provide those involved in resuscitation education and practice with recommendations based on scientific evidence. First aid advice for bites, stings and envenomation by land and marine creatures including: • snakes, spiders, ticks, bees, wasps and ants • jellyfish stings • blue-ringed octopus, fish and coneshell • envenomation pressure immobilisation technique. **Healthdirect Australia** https://www.healthdirect.gov.au/jellyfish-stings

Risk group	Types of risk	Australian guidance and resources
		• advice on jellyfish stings – symptoms and treatment. https://www.healthdirect.gov.au/sea-creature-stings • first aid advice for bites and stings from jellyfish, Irukandji, stonefish, blue-ringed octopus, fish, coneshell, sea urchin and sponge, CPR, envenomation pressure immobilisation technique, anaphylaxis. https://www.healthdirect.gov.au/mosquito-borne-diseases • advice on mosquito-borne diseases. https://www.healthdirect.gov.au/insect-bites-and-stings • advice on first aid for insect bites and stings. CSL Seqirus (website and phone app) https://www.bitesandstings.com.au/educational-materials. • information on venomous creatures and treatment of bites and stings.

State and Territory specific resources on water quality and other hazards

The following table provides a summary of State and Territory specific advice on recreational water quality and other hazards.

Table 2 - Summary of State and Territory advice and resources on recreational water quality and other hazards

State/Territory	Contact details	Recreational water advice and resources
Australian Capital Territory	Health Protection Service, ACT Health Phone number: 02 5124 9700	The ACT government provides the following information and resources: https://www.act.gov.au/health/topics/water-quality • information about recreational water quality information in the ACT.

State/Territory	Contact details	Recreational water advice and resources
	Email: hps@act.gov.au	https://www.cityservices.act.gov.au/news/news-and-events-items/water_quality_in_our_lakes_and_ponds 1. information about recreational water quality assessments of designated swimming areas in ACT lakes and rivers. Healthy waterways program - ACT Government • information about ACT Healthy waterways program.
New South Wales	Water Unit, NSW Health Email: HSSG-WaterQual@health.nsw.gov.au Your local Public Health Unit can also provide information on water quality and health. See website or call 1300 066 055. To contact Beachwatch see the website.	NSW Health provides guidance and advice on the assessment and management of water quality risks associated with recreational water including: • https://www.health.nsw.gov.au/environment/water/Pages/water-recreational.aspx*Naegleria fowleri* risk management. https://www.health.nsw.gov.au/environment/water/Pages/naegleria-utilities.aspx • Recreational Water Quality. The NSW Department of Climate Change, Energy, the Environment and Water Beachwatch water quality monitoring program assesses swimming sites across NSW to help people make informed decisions about where and when to swim. Beachwatch water quality updates can be accessed via a website, RSS data feed or app. https://www.beachwatch.nsw.gov.au/home https://www.beachwatch.nsw.gov.au/contactUs?option=General%20Enquiry The NSW Department of Climate Change, Energy, the Environment and Water plays a lead role in protecting water quality in New South Wales waterways by managing and monitoring wetlands, rivers, floodplains, coasts and estuaries and by supporting local councils and other water managers to manage potential impacts on waterways. https://www.environment.nsw.gov.au/topics/water

State/Territory	Contact details	Recreational water advice and resources
Northern Territory	Health Protection Branch, Department of Health email: envirohealth@nt.gov.au or phone (08) 8922 7152	The Northern Territory Government provides information on: https://nt.gov.au/emergency/community-safety/recreational-water-and-your-health • environmental water quality https://nt.gov.au/__data/assets/pdf_file/0010/936226/guidance-notes-for-recreational-water-quality-in-the-nt.pdf • *Guidance notes for recreational water quality in the Northern Territory*, 2020, for water managers of recreational water bodies / swimming sites. https://nt.gov.au/environment/water/water-in-the-nt/aquatic-ecosystems/freshwater-ecosystems • monitoring freshwater ecosystems. https://depws.nt.gov.au/water/water-publications/darwin-harbour/darwin-harbour-region-report-cards • Darwin Harbour water quality monitoring program and associated report cards. https://nt.gov.au/emergency/community-safety/crocodile-safety-be-crocwise • crocodile safety: Be Crocwise campaign. https://nt.gov.au/wellbeing/health-conditions-treatments/parasites/naegleria-fowleri • symptoms, treatment and prevention of *Naegleria fowleri*. https://nt.gov.au/wellbeing/health-conditions-treatments/heat-stress • heat stress
Queensland	Queensland Health Phone 13 HEALTH (13 43 25 84), or contact a Local Public Health	https://www.health.qld.gov.au/public-health/industry-environment/environment-land-water/water/quality Queensland Health water quality information and resources. Queensland Health is involved in investigating water contamination events to determine the presence and

State/Territory	Contact details	Recreational water advice and resources
Queensland (cont.)	Unit https://www.health.qld.gov.au/system-governance/contact-us/contact/public-health-units regarding water quality issues.	extent of public health risk associated with the contamination as well as providing direction or guidance in the management of these risks. Information on some recreational water quality related health risks has been provided on the following topics: Harmful algae | Environment, land and water | Queensland Government (www.qld.gov.au) • Harmful algae/cyanobacterial blooms Cryptosporidiosis | Queensland Health • *Cryptosporidium* parasites that can cause acute diarrhoea in young children and infection can be related to contaminated recreational water. https://www.qld.gov.au/health/condition/infections-and-parasites/parasites/primary-amoebic-meningoencephalitis-pam • Primary amoebic meningoencephalitis (PAM) is a rare but severe illness caused by the *Naegleria fowleri* amoeba which occurs naturally in untreated freshwater and prefers growing temperatures between 25°C and 40°C. http://conditions.health.qld.gov.au/HealthCondition/condition/14/33/455/melioidosis • Melioidosis is a rare tropical disease caused by bacteria *Burkholderia pseudomallei* which are commonly found in soil and water in northern Australia. Queensland Health has published *Safe water on rural properties, Technical advice version 1.1, 2015*. This booklet provides advice on identifying and managing risks to human health arising from water use on rural properties in Queensland focusing on both drinking and recreational water. The publication notes "Water drawn from deep artesian bores in rural Queensland is particularly at risk from *Naegleria fowleri*. This type of groundwater often exits the ground at elevated temperatures and is typically cooled in open dams before being transported via above ground pipelines to homesteads and tank storage."

State/Territory	Contact details	Recreational water advice and resources
Queensland (cont.)		• https://www.health.qld.gov.au/__data/assets/pdf_file/0025/444616/safe-water-rural-properties.pdf The Queensland Government provides information on: https://www.qld.gov.au/emergency/safety/recreation • Recreational water safety. https://www.qld.gov.au/emergency/safety/recreation/dangerous-marine • Dangerous marine life. https://www.qld.gov.au/environment/plants-animals/animals/living-with/crocodiles/becrocwise • Crocodiles.
South Australia	SA Health Water team Phone: 1300 558 657 or (08) 8226 7100 waterquality@sa.gov.au	The South Australian Government provides information on: • https://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/public+health/water+quality/water+quality • water quality alerts, recreational water, cyanobacterial blooms, bore water and *Naegleria fowleri.* https://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/healthy+living/protecting+your+health/yourself/fight+the+bite/fight+the+bite • mosquito-borne diseases via its *Fight the bite* campaign website. https://www.sa.gov.au/topics/emergencies-and-safety/types/water-safety • general water safety information. https://www.epa.sa.gov.au/environmental_info/water_quality/water_quality_monitoring/beach_water_advice • beach water quality alerts via the South Australian Environment Protection Authority.

State/Territory	Contact details	Recreational water advice and resources
Tasmania	Tasmanian Public Health Hotline (Department of Health) Phone: 1800 671 738 Email public.health@health.tas.gov.au	Local Tasmanian Councils and Tasmanian Government agencies are involved in ensuring waterways and oceans are safe for recreational and cultural use, such as swimming, canoeing, sailing and fishing. Under the *Public Health Act 1997*, the *Tasmanian Recreational Water Quality Guidelines 2007* require local councils to monitor the quality of popular natural recreational water bodies and aquatic facilities within their jurisdictions. Further information is provided at the following website: https://www.health.tas.gov.au/health-topics/environmental-health/recreational-water-quality *Tasmanian Recreational Water Quality Guidelines 2007* are issued by the Director of Public Health under the *Public Health Act 1997.*

State/Territory	Contact details	Recreational water advice and resources
Victoria	Water Unit, Department of Health. Phone 1300 761 874 (business hours) water@health.vic.gov.au Local Public Health Units can also provide information on water quality and health EPA Victoria Contact us | epa.vic.gov.au	EPA Victoria • sets and reviews standards for recreational water quality Environment Reference Standard | epa.vic.gov.au 2. monitors recreational water quality in Victoria How we monitor water quality | epa.vic.gov.au • provides water quality forecasts and information to help the public make informed decisions about swimming and other water-based activities. Check air and water quality | epa.vic.gov.au The Victorian Department of Health provides health-related risks associated with recreational water including harmful algal bloom on its website and through its Better Health Channel: • https://www.health.vic.gov.au/water/recreational-water - Harmful algal blooms | Better Health Channel - Beaches and water quality | Better Health Channel The Victorian Department of Health provides information on the risks of mosquito-borne disease and how to avoid getting bitten by mosquitoes: • Mosquito-borne diseases | health.vic.gov.au • Mosquitoes can carry diseases | Better Health Channel The Victorian Government also has information on recreational water safety as part of its water safety campaign, *Play it Safe by the Water*. https://www.vic.gov.au/water-safety The Department of Energy, Environment and Climate Action oversees the governance arrangements for monitoring and responding to harmful algal blooms in Victoria Blue-green algae

State/Territory	Contact details	Recreational water advice and resources
Western Australia	Environmental Health Directorate, Department of Health Phone: (08) 9222 2000 Email: ehinfo@health.wa.gov.au	The Western Australian Department of Health provides information on environmental water quality. https://www.health.wa.gov.au/Health-for/Environmental-Health-practitioners/Water • algal/cyanobacterial bloom monitoring • bacterial water quality • beach grades for Western Australia. https://www.health.wa.gov.au/Articles/A_E/Environmental-waters-publications • fact sheets, pamphlets, guidelines templates relevant to environmental water quality. https://www.healthywa.wa.gov.au/Safety-and-first-aid/Water

All hyperlinks to websites were accurate when accessed in October 2025 but may change with future website updates.

Water Quality Risk Management Plan template

Purpose

The purpose of this template is to help you develop a Water Quality Risk Management Plan that aligns with the 12 elements of the *Framework for managing recreational water quality* as outlined in Chapter 2 of the Australian Recreational Water Quality Guidelines (the Guidelines). A high level checklist of the recommended steps is provided in the *Water quality risk management planning checklist*.

These elements promote proactive risk management, transparency and accountability in the assessment and management across all stages of water quality management, from community and system analysis to communication, evaluation and continuous improvement. Developing a Water Quality Risk Management Plan that focuses on prevention of contamination and exposure, supports responsible authorities in implementing best practice strategies that are adaptable to local conditions and responsive to emerging risks.

12 Elements of the Framework

Element	Framework step
Element 1	Commitment to Recreational Water Quality Management
Element 2	Risk assessment *(System analysis and management)*
Element 3	Risk management *(System analysis and management)*
Element 4	Implement operational procedures and maintenance programs *(System analysis and management)*
Element 5	Set up processes to monitor and verify water quality *(System analysis and management)*
Element 6	Planning for incidents and emergencies *(System analysis and management)*
Element 7	Communications and training *(Supporting Requirements)*
Element 8	Community involvement and awareness *(Supporting Requirements)*
Element 9	Validation, research and development *(Supporting Requirements)*
Element 10	Documentation and reporting *(Supporting Requirements)*

Element 11	Evaluate and audit *(Review)*
Element 12	Review and improve *(Review)*

Instructions

This template is designed to establish a site specific, flexible Water Quality Risk Management Plan that is tailored to the unique environmental conditions, usage pattens and cultural significance of each water site. Some sections may not be applicable to all sites, while others may need to be expanded or supported by additional work. Further advice should be sought from the relevant health authority and/or water site regulator for local procedures and requirements.

Where a checklist item is marked 'no', it is important to carefully evaluate alternative approaches for achieving an outcome that aligns with the principles of the Framework. To ensure the plan remains relevant and effective, all sections should be periodically reviewed and updated as necessary.

1. Getting started

- Begin by reviewing the Framework for managing recreational water quality to understand the principles and structure that underpin the Water Quality Risk Management Plan.

2. Completing the template

- Follow the structure of the template section by section. Each section corresponds to a key element of the Framework (e.g. risk assessment, operational procedures, incident response).
- Complete tables where provided, using guiding questions and examples provided in each section to shape your responses. These are designed to ensure all relevant aspects are addressed.
- Add lists or procedures where prompted.
- Use the checklist at the end of the template to confirm all sections are complete. Where a checklist item is marked 'no', it is important to evaluate alternative approaches for achieving an outcome that aligns with the principles of the Framework.

3. Customising the template

- The template is flexible. You are encouraged to:
    - add additional sections or records as needed.
    - tailor language and content to reflect your site's specific context, including cultural and environmental considerations.
    - involve relevant stakeholders (e.g. First Nations representatives, local councils, environmental officers) in completing and reviewing the plan.

5. Maintaining and updating the Water Quality Risk Management Plan

- Store the completed Water Quality Risk Management Plan in a central, accessible location for staff and regulatory authorities.
- Review and update the Water Quality Risk Management Plan regularly, especially after:

- incidents or exceedances
- changes in site use or infrastructure
- new monitoring data or research findings are available.

- To ensure the Water Quality Risk Management Plan remains relevant and effective, all sections should be periodically reviewed and updated as necessary. Document all updates and version changes in the designated section.

Tips for completing this template

- You may need to involve other people on how to best manage your recreational water site as you complete each section of this template.
- You can add additional sections, information or records to those in this template to make your Water Quality Risk Management Plan complete.
- Ensure any changes or new risks identified through observations, incidents, or monitoring are added to the relevant section of the Water Quality Risk Management Plan.

1. Commitment to recreational water quality management (element 1)

Completion date:		Review date:	

This section helps you to establish the foundational governance, policy, and capability structures necessary to support a preventive approach to managing risks associated with recreational and cultural water use. The intent is to embed water quality management as a core organisational commitment to ensure that recreational water sites are managed in a way that protects public health and respects cultural values.

For further information, refer to section 2.2.1 of the *Framework for managing recreational water quality* (Chapter 2).

1.1. Responsible authorities

Provide details of the recreational water site and identify key governance roles and responsibilities involved in its management.

Table 1.1 - Recreational water site details

Name	

Location	
Type of water body	
Activities/uses	
Site manager	

Table 1.2 - Key governance roles and responsibilities

Individual/ organisation	Contact details	Role	Responsibilities
[Add name/organisation]	*[Add name/organisation*	*E.g. Site manager*	*Manage water quality and public health.*
[Add name/organisation]	*[Add name/organisation*	*E.g. Coordination*	*Oversee risk management actions.* *Emergency response*

1.2. Regulatory and formal requirements

Document all relevant regulatory and formal requirements, not limited to legislations, operating licences, agreements (including policies relating to First Nation traditions and local customs). Identify the relevance of each requirement and how it helps to protect water quality and public health.

Table 1.3 - Regulatory and formal requirements

Legislations/ regulations	Relevance to water quality/ public health
Operating licences	**Relevance to water quality/ public health**
Agreements	**Relevance to water quality/ public health**

CHECKLIST 1.2 ☑

Have these regulatory requirements been reviewed in the last 12 months? ☐ YES ☐ NO

1.3 Engage stakeholders

Document the roles, responsibilities and contact details of all key stakeholders involved in managing water resources. This includes all parties affecting, or affected by, decisions or activities related to the use of the water site/s, including members of the public.

Table 1.4 - Stakeholder contact details and responsibilities

Name	Email address	Phone number	Roles/ responsibilities

Establish the profile of water users: type of recreational and cultural activities undertaken, exposure pathways, exposure volumes, duration and frequency.

Table 1.5 - Profile of water users

Recreational/ cultural activities	Exposure pathways	Exposure volumes	Duration	Frequency

Note the preferred methods for communicating with stakeholders and water users:

-
-

CHECKLIST 1.3 ☑

Has this stakeholder list and associated details been reviewed in the last 12 months?	☐ YES	☐ NO
Have relevant stakeholders been advised of their obligations as outlined in Section 1.2 of the Water Quality Risk Management Plan?	☐ YES	☐ NO

1.4. Recreational water quality policy

Use the below guide to support the establishment of a water safety policy that clearly demonstrates a commitment to effective water quality management.

1. Development	• Address broader issues and requirements, for example - responsible management of water environments - application of a risk management approach - compliance with relevant regulations and standards - engagement with agencies, stakeholders and water users - commitment to best-practice and multiple barrier approach - continuous improvement in water quality management. • Keep the policy clear and succinct.

2. Endorsement	• Secure endorsement from senior management and the board. • Allocate appropriate resources for implementation.
3. Supporting agreements	• Create joint agreements and statements of commitment to establish partnerships with relevant agencies or organisations. • Clearly define roles, responsibilities and accountabilities.
4. Communication	• Ensure the policy is visible and accessible to all employees and contractors. • Confirm the policy and responsibilities are understood across all levels of the organisation.
5. Implementation	• Integrate the policy into operational procedures, site management plans and other guiding principles. • Engage water users and clarify their responsibilities.
6. Review	• Establish protocols for regular review and updates.

1.5. Ensure capability

Outline the expertise and training required to manage water quality risks, including the selection, development, management and regulation of the relevant recreational water bodies.

Table 1.6 - Expertise and training requirements

Area	Expertise	Training
Site level (local water environment management)	• *Site operations and management* • *Public communication and advice*	

2. Risk assessment (element 2)

Completion date:		Review date:	

This section helps to outline the foundational steps for assessing risks, drawing on local context, environmental data, and stakeholder expertise. Risk assessment involves identifying the characteristics of the water environment, collecting relevant data, and evaluating hazards, hazardous events, and associated risks. It is designed to be flexible and scalable. The outcome of this process will inform the development of targeted risk management strategies, including preventive measures and critical control points, which are addressed in section 3 of this template.

For further information, refer to section 2.2.2 of the *Framework for managing recreational water quality* (Chapter 2).

2.1. The water environment and its context

2.1.1. Risk assessment team

Assemble a risk assessment team with appropriate knowledge and expertise. Depending on requirements, the risk assessment team may serve as a standing committee with ongoing roles in water management or operate on as ad hoc group and be involved in the initial and periodic review the Water Quality Risk Management Plan.

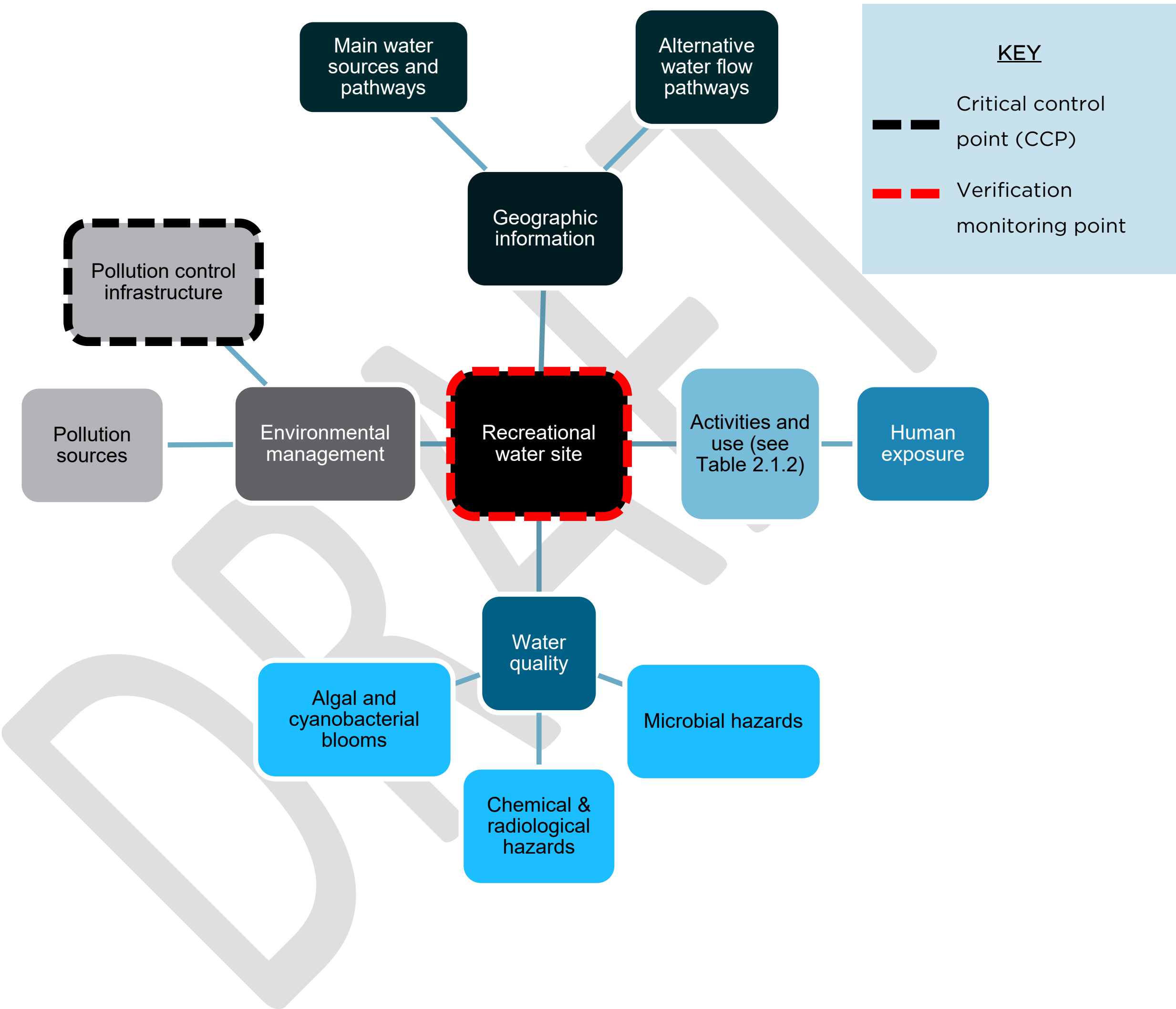
Table 2.1 - Risk assessment team

Individual/ groups	Role/ expertise
	Coordinating entity
	Site manager
	First Nations community representatives and Traditional Owners who care for the water on Country
	Water quality expert
	Operations expert

2.1.2. Identify and document key characteristics

Produce a conceptual flow diagram (example shown in Figure 2.1) to illustrate key characteristics of the recreational water site and surrounding environment, with a focus on components reasonably expected to impact the site.

Figure 2.1 - Flow diagram of the key characteristics of the water site and surrounding environment



2.1.3. Identify intended and other potential uses of water site/s

Identify the intended and other potential uses of the recreational water site, giving due consideration to exposure and use by vulnerable or sensitive populations.

Table 2.2 - Activities and uses of the recreational water site

Activities	Exposure degree (e.g. primary contact, secondary contact, no contact)	Nature of exposure (e.g. voluntary or involuntary)	Population/s impacted (e.g. life stage and immunological status)

CHECKLIST 2.1.1 ☑

Have both intended/ nominated activities and unintended activities been recorded?	☐ YES	☐ NO
Is a specific risk assessment required (e.g. due to cultural practices or activities that involve spraying of water under pressure, or environments with water temperature extremes)?	☐ YES	☐ NO
Have vulnerable or sensitive populations been considered, especially with activities at that may disproportionately affect them?	☐ YES	☐ NO

CHECKLIST 2.1.2 ☑

Have both baseline conditions and seasonal events/ triggers of change been considered?	☐ YES	☐ NO
Have critical control points and other high priority preventive measures been identified?	☐ YES	☐ NO
Has the flow diagram been evaluated by experts and verified by field audits?	☐ YES	☐ NO
Has the flow diagram been subjected to periodical review (i.e. at intervals of several years or in response to significant changes)	☐ YES	☐ NO

2.2. Collect relevant data

Use the below guide to support the collection of relevant data for specific water sites and the surrounding environments, to inform the risk assessment of the selected water site/s.

Water quality hazard/s	*Review chapters in the Guidelines on relevant water quality hazard* *(e.g. microbial pathogens/ risks, harmful algal blooms, chemical hazards, aesthetic hazards, radiological hazards) for information on which specific data sets to collect (e.g. indicators, antecedent conditions such as rainfall, flowrates/dilution, water body depth, stratification).*
Water use	*Record data on water use, not limited to:* • *risk profile of water use (e.g. population groups with underlying health conditions or life stages)* • *visitation rates* • *activities, including location, timing and behaviours related to exposure.*

CHECKLIST 2.2 ☑

Has the data been carefully assessed, screened and prioritised based on its quality?	☐ YES	☐ NO
Has the data been reviewed and summarised for use in the subsequent risk assessment?	☐ YES	☐ NO
Have gaps in the data been identified, and if so, has a process started to address these gaps?	☐ YES	☐ NO

2.3. Assess hazards, hazardous events and risks

There are multiple tools and guidelines that can be used for conducting risk assessments. The approach described in this Water Quality Risk Management Plan is based on the Guidelines and a simple, qualitative example guided by the principles of AS/NZS ISO 31000:2009.

Assess the relevant hazard/ hazardous events using the table below, to estimate the level of risk to water users.

Table 2.3 - Assessment of hazards and risk estimation*

Hazard details (include hazardous events and risk assessment approach)	Exposure pathway	Risk Likelihood	Risk Consequence	Risk level without preventive measures	Risk level with preventive measures**

* Appendix A provides tables for determining *risk likelihood*, *risk consequence* and *risk level*.

**Section 3 Risk Management (Element 3) provides further guidance on preventive measures

CHECKLIST 2.3 ☑

Has the reliability of the preventive measures for each hazard/ hazardous event been duly considered?	☐ YES	☐ NO
Have the most significant risks been highlighted, summarised and reviewed by key stakeholders to ensure understanding?	☐ YES	☐ NO

3. Risk management (element 3)

Completion date:		Review date:	

This section outlines the strategies and actions required to manage identified water quality risks in recreational and cultural water environments. Building on the outcomes of the risk assessment process, it focuses on implementing preventive measures, establishing critical control points if feasible, and developing operational procedures that reduce or eliminate risks to public health.

For further information, refer to section 2.2.3 of the *Framework for managing recreational water quality* (Chapter 2).

3.1. Preventive measures and residual risk

Document the preventive measures and strategies for significant hazard/ hazardous events.

Table 3.1 - Preventive measures and strategies for hazards/ hazardous events

Hazard/ hazardous event	Risk rating	Is the hazard controlled?	If yes, what is the control/ preventive measure?	How is this control/ preventive measure monitored?	What additional measures will reduce the risk?	Timeframe for action

CHECKLIST 3.1 ☑

Are the preventive measures effective in reducing the risk to acceptable levels (i.e. residual risk)?	☐ YES	☐ NO

3.2 Plans and strategies for preventive measures

Prioritise the preventive measures (e.g. high, medium or low priority) and identify any critical control points. Establish appropriate performance targets to assess the effectiveness of the chosen preventive measure.

Table 3.2 - Prioritisation and performance targets of preventive measures

Preventive measure	Priority (high, medium low)	Critical Control Point (if yes, provide details)	Performance target details

CHECKLIST 3.2 ☑

Have the performance targets been formally validated and documented?	☐ YES	☐ NO
Have all preventive measure incidents been documented, along with the appropriate response actions and corrective actions?	☐ YES	☐ NO

4. Operational procedures and maintenance programs (element 4)

Completion date:		Review date:	

This section outlines the operational procedures and maintenance programs that support the effective implementation of preventive measures identified in the risk management process. These procedures are essential to ensuring that water quality risks are consistently managed across recreational and cultural water environments. They enable early detection of issues, timely corrective actions, and continuous improvement through performance evaluation and stakeholder feedback.

For further information, refer to section 2.2.4 of the *Framework for managing recreational water quality* (Chapter 2).

Establish operational procedures for monitoring the performance of preventive measures, and document actions to be taken when deviations from performance targets arise.

Table 4.1 - Operational procedures for evaluating and managing performance of preventive measures

Preventive measure	Operational monitoring	Operational corrections	Maintenance programs

NHMRC

CHECKLIST 4.1 ☑

Are the operational procedures integrated into formal operational management systems, readily accessible to relevant personnel?	☐ YES	☐ NO
Were daily users of the operational procedures involved in its development, documentation and verification to ensure relevance, improve training and foster commitment?	☐ YES	☐ NO

5. Processes to monitor and verify water quality (element 5)

Completion date:		⏱ Review date:	

Monitoring and verification are essential components of a preventive risk management approach to recreational and cultural water quality. This section outlines the procedures for assessing water quality characteristics, interpreting monitoring data, and responding to exceedances or anomalies that may pose risks to public health.

For further information, refer to section 2.2.5 of the *Framework for managing recreational water quality* (Chapter 2).

5.1. Monitor water quality characteristics

Determine the water quality characteristics to be monitored (based on characteristics identified in Figure 2.1.1) and design an appropriate sampling program.

Table 5.1 - Overview of water quality characteristics to be monitored

Water quality characteristic	Monitoring location	Monitoring timing	Reliability checks
			Sample analysis completed by NATA-accredited lab

CHECKLIST 5.1 ☑

Using Table 5.1, has a dedicated sampling program been developed (guided by AS/ NZS 5667.1:1998)?	☐ YES	☐ NO

Has a system/ program been implemented for water users to provide feedback on water sites and surrounding environments?	☐ YES	☐ NO

5.2. Report on monitoring data/ feedback and respond to exceedances

Report on the monitoring data and feedback from water users, and document corrective responses to any exceedances.

Table 5.2 - Monitoring data review and responses to exceedances

Monitoring parameter/ classification	Trigger value (including guideline values)	Monitoring/ reporting frequency	Outcome	Corrective action (including date)	Notes/ follow up required?
Enterococci	*> X CFU/ X ml*	*Weekly*	*Exceeded*	*Site closed, retesting (date of action - 1/8/2025)*	*Retest scheduled for 5/8/2025*
Cyanotoxins	*> X µ/L*	*Monthly*	*Within limits*	*N/A*	*Continue routine monitoring*
Nutrients					

CHECKLIST 5.2 ☑

Have protocols been established for the review of monitoring data and feedback from water users?	☐ YES	☐ NO
Have procedures been established to action corrective responses for trigger value exceedances?	☐ YES	☐ NO
Have rapid communication systems been developed to handle unexpected events (refer to incident response protocols as described in Section 6)?	☐ YES	☐ NO

6. Incident and emergency plans (element 6)

Completion date:		Review date:	

This section outlines the procedures and protocols for responding to incidents and emergencies that may compromise water quality and public health. While preventive measures and routine monitoring form the backbone of water quality risk management, it is equally important to have robust contingency plans in place to manage unexpected events.

> For further information, refer to section 2.2.6 of the *Framework for managing recreational water quality* (Chapter 2).

6.1. Incident and emergency response protocols

Establish a response protocol to address potential incidents and emergencies that could compromise water site operations.

Table 6.1 - Incident and emergency response protocol

1. Describe potential incidents and emergencies that may affect water site operations		
E.g. Outbreak of illness leading to increased pathogen risks at water sites		
2. Outline authorities with internal and external responsibilities for managing the response		
Authority	Roles/ responsibilities	Contact details
3. Document predetermined agreements on lead agencies that are responsible for decisions with health impacts		
4. Provide plans for alternative water sites to facilitate continuity of operations		

5. Detail notification procedures and communication strategies for internal, regulatory bodies, media and public stakeholders *(also refer to Section 7 – Communication and training)*				
Communication channel	**Key messages**	**Stakeholder**	**Timeframe**	**Responsibility**

6. Describe mechanisms for increased health or environmental surveillance during and after an incident or emergency.

CHECKLIST 6.1 ☑

Has consultation with relevant authorities and key agencies been undertaken during the development of the response protocol?	☐ YES	☐ NO
Is the response protocol consistent with existing government emergency response arrangements?	☐ YES	☐ NO
Have employees received training on the incident and emergency response protocol?	☐ YES	☐ NO

6.2. Investigation and reporting of incidents and emergencies

The factors listed below should be considered to support an investigation following any incident or emergency situation. Ensure appropriate documentation and reporting of the incident or emergency situation is established.

Cause	• *What was the initiating cause of the problem?*
Identification	• *How was the problem first identified or recognised?*
Critical actions	• *What were the most critical actions required?*
Communication	• *What communication problems arose and how were they addressed?*
Consequences	• *What were the immediate and longer-term consequences?*
Response protocol	• *How well did the response protocol function?*
Improvements	• *What can be learnt from any incidents and emergencies about the preventive actions to assess and improve their effectiveness?* - *Consider if the existing response protocol should be updated or modified.*

7. Communication and training (element 7)

Completion date:		⏱ Review date:	

This section outlines the strategies for building awareness, capability, and engagement among all stakeholders involved in managing recreational and cultural water environments. Embedding effective communication and training is essential to the successful implementation of a Water Quality Risk Management Plan.

For further information, refer to section 2.2.7 of the *Framework for managing recreational water quality* (Chapter 2).

7.1. Communications planning

Use the below guide to develop a communications plan that supports the responsible management of water sites. All communications should be clear, appropriate and tailored to the intended audience.

Internal communication	• Establish notification and reporting processes for normal operations, and incidents and emergencies. • Assign responsibilities and authorities.
External communication	• Establish notification, media strategies and public messaging for normal operations, and incidents and emergencies. • Develop a **public and media communication strategy:** - train personnel involved in public communication during incidents - inform water users when an incident has ended and explain the cause and corrective action - conduct post-incident surveys, and use feedback to improve future communication and response protocols.
Stakeholder engagement	• Maintain a current contact list of key people, agencies and stakeholders *(refer to Section 1.3 – Engage stakeholders).* • Plan and implement risk awareness/ risk communication campaigns and consultation activities as needed.

See *Information sheet - Preparing a risk communication plan* and *Risk communication planning checklist*

7.2. Training

Document and maintain records for training undertaken by operators, contractors and water users.

Table 7 - Training record for operators, contractors and water users

Participant details	
Name:	Role:
Training details	
Training program/ topic:	**Roles/ responsibilities** **Contact details**
Date:	
Provider/ accreditation body:	
Outcome **(e.g. pass/ below standard)**	
Certification status	
Follow up action required	

CHECKLIST 7.1 ☑

Are personnel responsible for managing preventive measures and operational monitoring aware of key factors affecting water quality and public health, including relevant policies, risk management principles, legal and regulatory requirements, and roles and responsibilities?	☐ YES	☐ NO
Are water users aware of activity restrictions, management requirements, personal preventive measures and behaviours that may threaten human health?	☐ YES	☐ NO
Has the effectiveness of training undertaken for operators, contractors and water users been regularly evaluated, with updated training dates scheduled as needed?	☐ YES	☐ NO

8. Community involvement and risk awareness (element 8)

Completion date:		⏱ Review date:	

This section outlines the strategies for engaging stakeholders and the broader community in water quality risk management through transparent communication and inclusive involvement. Building awareness and fostering shared responsibility helps to empower communities to contribute to safer water environments.

For further information, refer to section 2.2.8 of the *Framework for managing recreational water quality* (Chapter 2).

Maintain a central repository for community involvement and risk awareness material (including site specific guidance documents) for regular review and evaluation of effectiveness.

Table 8 - Central repository for community involvement and risk awareness communication material

Title	Summary	Publication date	Audience	Access location	Review date

CHECKLIST 8.1 ☑

Was the intended audience involved in or consulted during the development of the communication materials?	☐ YES	☐ NO
Has a plan been established to routinely monitor and evaluate the effectiveness of the communication materials?	☐ YES	☐ NO

9. Validation, research and development (element 9)

Completion date:		⏱ Review date:	

This section outlines the processes for confirming that preventive measures and operational procedures are functioning as intended, and for advancing knowledge through targeted research and innovation. Validation, research and development are essential to ensuring that a Water Quality Risk Management Plan remains effective, evidence-based and responsive to emerging risks.

For further information, refer to section 2.2.9 of the *Framework for managing recreational water quality* (Chapter 2).

Validate that processes and procedures for preventive measures and response actions are effective in mitigating risks. Note the method used to validate the preventive measure/ response action and outcome in terms of effectiveness.

Table 9 - Validation of the effectiveness of preventive measures/ response actions

Preventive measures/ response actions	Validation method	Outcome

CHECKLIST 9.1 ☑

Has a plan been established to conduct research to validate new processes and procedures?	☐ YES	☐ NO
Has a plan been established to undertake collaborative research to increase understanding of water environments?	☐ YES	☐ NO

10. Documentation and reporting (element 10)

Completion Date:		🕐 Review Date:	

This section outlines the systems and protocols for recording, managing, and communicating information related to water quality risk management activities. A robust documentation system ensures that aspects of the Water Quality Risk Management Plan, such as risk assessments, preventive measures, monitoring results, incident responses, and stakeholder communications, are accurately recorded and readily accessible.

For further information, refer to Section 2.2.10 of the *Framework for managing recreational water quality* (Chapter 2).

Develop a document-control and record-keeping system for managing and updating relevant information, to promote transparency and accountability.

CHECKLIST 10.1 ☑

Has a document-control system been developed to ensure only current and approved documents are in use (e.g. periodic review and update)?	☐ YES	☐ NO
Are mechanisms in place to ensure that personnel read, understand and adhere to appropriate documents?	☐ YES	☐ NO
Are records of all activities easily accessible, and protected against damage, deterioration and loss?	☐ YES	☐ NO

Establish processes for conducting internal and external reporting of activities relating to water quality management, including the preparation of an annual report.

CHECKLIST 10.2 ☑

Have internal reporting requirements been clearly defined, including procedures for summarising monitoring data, evaluating performance and reviewing significant operational problems?	☐ YES	☐ NO
Have external reporting requirements been established in consultation with water users and the relevant regulatory authorities?	☐ YES	☐ NO
Does the annual report contain sufficient information (e.g. water quality data, system failures, corrective actions) for individuals/ groups to make informed judgements about the water quality of a water site?	☐ YES	☐ NO

11. Evaluation and audit (element 11)

Completion date:		Review date:	

This section outlines the processes for systematically reviewing the performance of the Water Quality Risk Management Plan, identifying areas for improvement, and verifying that water quality risks are being managed appropriately. Including evaluation and audit components in ensures a Water Quality Risk Management Plan remains effective, responsive, and aligned with best practice standards and regulatory requirements

> **For further information, refer to section 2.2.11.1 of the *Framework for managing recreational water quality* (Chapter 2).**

Evaluate long-term data to assess whether preventive strategies are effective and whether they are being implemented appropriately.

CHECKLIST 11.1 ☑

Does the long-term data evaluation include an assessment of performance against standards, identify trends or emerging issues, and set priorities for improving water quality management.	☐ YEs	☐ NO
Is there an active reporting system in place to identify and report near misses in real time?	☐ YES	☐ NO
Have senior managers, water users, stakeholders and regulatory authorities received evaluation reports in accordance with established requirements?	☐ YES	☐ NO

Establish processes and requirements for internal and external audits, to be considered as part of the review by senior executives (see Section 12).

CHECKLIST 11.2 ☑

Have the audit frequency, schedule, responsibilities, requirements, procedures and reporting mechanisms been defined in accordance with relevant standards, including ISO 19011:2019?	☐ YES	☐ NO

12. Review and improve (element 12)

Completion date:		Review date:	

This section outlines the processes for reviewing the performance of the Water Quality Risk Management Plan and identifying opportunities for refinement and enhancement. It ensures that the plan remains responsive to changing conditions, emerging risks, stakeholder feedback, and evolving best practices.

For further information, refer to section 2.2.11.2 of the *Framework for managing recreational water quality* (Chapter 2).

Establish a process to review risk assessment and risk management systems and evaluate the need for change.

CHECKLIST 12.1 ☑

Is there an established action plan with allocated resources to support the regular review of assessment and risk management systems?	☐ YES	☐ NO
Has the review of the risk assessment and risk management systems by senior managers been documented?	☐ YES	☐ NO

Develop a water quality management improvement plan to address areas and needs identified in the review.

CHECKLIST 12.2 ☑

Do the improvement plans include objectives, actions to be taken, accountability, timelines and reporting?	☐ YES	☐ NO
Have the improvement plans been endorsed by senior executive?	☐ YES	☐ NO
Is there a mechanism in place to monitor the implementation of the improvement plan; to confirm that the improvements have been made and are effective?	☐ YES	☐ NO

Appendix A – Risk assessment

Estimate the level of risk to water users

Once potential hazards and their sources have been identified, the level of risk associated with each hazard or hazardous event should be estimated so that priorities for risk management can be established and documented.

The level of risk for each hazard or hazardous event can be estimated by identifying the **likelihood** of occurrence and evaluating the severity of **consequences** if the hazard were to occur. The aim should be to distinguish between very high and low risks. AS/NZS 4360:2004 (Risk Management) describes qualitative measures for likelihood and consequence in risk assessment and the process for developing a risk matrix combining the outcomes of the likelihood of the event occurring and consequence if the event did occur. Each hazard-hazardous event combination is assigned a qualitative risk estimation (i.e. a risk level or rating of low, medium, high or very high).

An example of a qualitative approach to estimating the level of risk, adapted from AS/NZS 4360:2004 (Risk Management) is provided in the tables below can be modified to meet the needs of an organisation.

The risk should be considered for the full range of conditions that may exacerbate the risk, including worst case scenarios and foreseeable risks.

It is good practice to assess the level of confidence or uncertainty, and evaluate the major sources of uncertainty, associated with each risk estimate and consider actions to reduce uncertainty to help drive continuous improvement.

Illustrative example of qualitative measures of likelihood

Level	Descriptor	Example description
A	Rare	May occur only in exceptional circumstances. May occur once in 100 years (1% chance of an event occurring in any given year)
B	Unlikely	Could occur within 20 years or in unusual circumstances (5% chance of an event occurring in any given year)
C	Possible	Might occur or should be expected to occur within a 5- to 10-year period (10-20% chance of an event occurring in any given year)
D	Likely	Will probably occur within a 1- to 5-year period (20-100% chance of an event occurring in any given year)
E	Almost certain	Is expected to occur with a probability of multiple occurrences within a year (100% chance of an event occurring in any given year)

Note to Table: Likelihood is expressed as the chance of an event occurring in any given year. It describes the long-term average probability of an event. For example, once in 100 years means that there is a 1% chance of the event occurring in any given year. It does not mean that the event will only happen once every 100 years. The long-term average probability of an event may be subject to change over time due to influencing factors such as climate change. This is why risk assessments should be periodically reviewed.

Illustrative example of qualitative measures of potential consequence or impact

Level		Descriptor	Example of potential adverse health outcome*
1		Insignificant	Insignificant impact or not detectable
2		Minor	Mild self-limiting symptoms (e.g. rash or irritation)
3		Moderate	Isolated illness (e.g. isolated *Cryptosporidium* case)
4		Major	Serious illness (e.g. *Campylobacter* outbreak)
5		Catastrophic	Fatality (e.g. *Naegleria* death of a young child)

*Note that defining consequences using identified illness may underestimate the risk and the potential for illness may be more appropriate.

Illustrative example of qualitative risk estimation

Likelihood	Consequences				
	1-Insignificant	2-Minor	3-Moderate	4-Major	5-Catastrophic
A Rare	Low	Low	Low	High	High
B Unlikely	Low	Low	Moderate	High	Very high
C Possible	Low	Moderate	High	Very high	Very high
D Likely	Low	Moderate	High	Very high	Very high
E Almost certain	Low	Moderate	High	Very high	Very high

Acronyms and abbreviations

AFRI	acute febrile respiratory infection
ANZECC	Australia and New Zealand Environment and Conservation Council
CCP	critical control point
CFU	colony forming unit
EHO	Environmental Health Officer
GI	gastrointestinal infection
GIS	geographic information system
HACCP	hazard analysis critical control points
LOAEL	lowest observed adverse effect level
NHMRC	National Health and Medical Research Council
NRMMC	Natural Resource Management Ministerial Council
PFAS	per- and poly-fluoroalkyl substances
PFU	plaque forming unit
PSP	Paralytic Shellfish Poisons
PPM	priority preventive measure
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
WQRMP	Water Quality Risk Management Plan

Glossary

Alert limit	A threshold providing early warning that a process is out of control or trending out of control, allowing corrective action before an unacceptable health risk arises.
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 defence 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 of cyanobacteria in an environmental sample.

Brevetoxins	Lipophilic 10- and I I-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 water bodies 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 (i.e. integrating) a number of separate samples collected separately over time or over space.
Conjuctiva	A thin clear moist membrane that coats the inner surfaces of the eyelids and the outer surface of the eye.
Coordinating entity	The group or agency responsible for leading and overseeing risk management actions.
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 (i.e. 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.
Diarrhoetic 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
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).
Eutrophic/Eutrophication	Used to describe the process whereby a water body degrades as it becomes enriched over time by high levels of plants nutrients, particularly phosphorus and nitrogen. This results in excessive algal growth and decay and often with low dissolved oxygen in the water. 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 (e.g. 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.
Idiosyncratic	Abnormal susceptibility to a stimulus or substance peculiar to the individual.
Incidental contact	Recreational or cultural activity in which only the limbs are regularly wetted and greater contact (including swallowing water) is unusual (e.g. boating, fishing, wading) (WHO 2021). Sometimes referred to as secondary contact (NHMRC 2008).
Indicator	A specific contaminant, group of contaminants or constituent that signals the presence of something else (e.g. *E. coli* indicate the possible presence of pathogenic bacteria).
Indicator organisms	Microorganisms whose presence is indicative of pollution or of more harmful microorganisms.
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.
Investigative or research monitoring	Used to provide additional data or information to fill identified knowledge gaps and uncertainties to answer the question "*what will the investigation or research reveal?*"
Irritation	An observable physiological reaction by the body (i.e. 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.
Lyngbya majuscula	*Lyngbya majuscula* (Lyngbya) is a naturally occurring, filamentous, blue-green 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.*
Lyngbyatoxin	An indole alkaloid toxin produced by *Lyngbya majuscula*.
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.
Multiple barrier approach	A risk management principle involving several preventive measures to protect public health, rather than relying on a single barrier.
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.
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.
Nodularins	Cyclic nonribosomal peptides produced by cyanobacteria that can be very toxic for plants and animals including humans.
Non-atopic	A tendency not to be atopic.
Operational monitoring	Used to assess whether preventive measures are working in real time to answer the question "*is it working?*".
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 (e.g. bacteria, viruses, protozoa and helminths).
Peptides	Molecules that hydrolyze into amino acids and form the basic building blocks of proteins.
Per- and poly-fluoroalkyl substances (PFAS)	A class of more than 4,000 manufactured chemicals that are not found naturally in the environment and have been widely used in industrial and consumer products.

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.
Procaryote	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).

Reference level	A measure of annual effective radiation dose to a representative person as a result of radiation exposure from all exposure pathways during leisure in or around recreational water. Under the system of radiation protection, reference levels serve as a benchmark to determine if protective measures are necessary and are not mandatory limits. [see Chapter 8, Section 8.4]
Residual risk	The risk remaining after consideration of existing preventive measures.
Responsible entity	The organisation or agency ultimately accountable for managing water quality risks and protecting the public.
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.
Sanitary inspection	A tool that enables the systematic qualitative assessment of a recreational water catchment's susceptibility to microbial, chemical and radiological hazards. Sanitary inspections formally identify and investigate possible sources of pollution, assess the extent of the pollution, and help inform water quality monitoring and development of models to predict recreational water quality [see Information sheet – Sanitary inspections]
Saxitoxins	An alkaloid neurotoxin originally isolated from shellfish where they are concentrated from marine dinoflagellates. Also commonly known as Paralytic Shellfish Poisons (PSPs)

Screening value	Indicate concentrations for chemical hazards in recreational water bodies that are sufficiently protective of human health across a broad population. Chemical screening values are a tool to help inform decisions on prioritising chemical hazards requiring further investigation and managing risks, rather than a 'pass'/'fail' measure.
Self-limiting	Limited by its own peculiarities and not by outside influence.
Sensitisation	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 (e.g. 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 yanobacterium which sometimes forms large blooms. The blooms are sometimes called 'sea sawdust'.
Trigger level	A predetermined value or threshold for a water quality parameter which, when exceeded, prompts a specific management response or further investigation to protect public health or the environment.
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.

Upwelling	Upwelling is a natural oceanographic process where winds or currents push surface water away, allowing deep, cold, and nutrient-rich water to rise to the surface. This influx of nutrients from the ocean depths stimulates the growth of phytoplankton, forming the base of highly productive marine food webs and leading to rich fishing grounds and diverse ecosystems.
Validation monitoring	Used to test preventive measures to determine whether they will work in theory to answer the question "*will it work?*"
Verification monitoring	Used to determine whether management systems have worked and have successfully achieved safe water quality that is fit-for-purpose to answer the question "*did it work?*"
Viruses	Molecules of nucleic acid (RNA or DNA) that can enter cells and replicate in them.
Water Quality Risk Management Plan	Describes how responsible entities will protect public health by managing water quality risks [see Chapter 2, Section 2.1.3.6].
Whole body contact	Recreational or cultural activity in which the whole body or the face and trunk are frequently immersed, or the face is frequently wetted by spray, and where it is likely that some water will be swallowed (e.g. swimming, diving, surfing, sailboarding, kiteboarding, whitewater canoeing). Inadvertent immersion, through being swept into the water by a wave or slipping, would also result in whole-body contact (WHO 2021). Sometimes referred to as primary contact (NHMRC 2008).