GUIDELINES ON RECREATIONAL WATER QUALITY

Volume 1 Coastal and Fresh Waters

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Guidelines on recreational water quality. Volume 1: coastal and fresh waters

This publication is the update of the Guidelines published in 2003 entitled "Guidelines for safe recreational water environments. Volume 1, Coastal and fresh waters".

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Foreword

Recreational use of water can have major benefits for health and well-being. From children playing in a river to families relaxing on a beach, from people taking part in water sports to observing waterside nature, all shapes and sizes of bodies – be they oceans, lakes or rivers – of water can uplift the spirit and enhance physical and mental well-being. Clean, well-managed waterfronts are also a focal point for communities and an economic draw for tourist and sporting events.

Yet, human activity and climate change are impacting the quality and safety of our waterways. Popular swimming locations may become contaminated by overflows of untreated sewage, runoff of animal excreta from nearby farms, or algal blooms triggered by high nutrient loads. Some sites may also be affected by chemical pollution from industrial activities or become polluted by beach users themselves though poor sanitation and litter. This contamination erodes the benefits to well-being and economic potential of the site, as well as potentially causing illness for water users.

In order to make waterside environments safe and fun for all users, now and in the future, these health risks must be carefully assessed and managed.

This update to the guidelines for safe recreational water environments provides health-based guidance for setting national water quality standards and implementing preventive risk management at the local level. Risk management approaches monitor and reduce sources of pollution, including tools to let users know in real time when it is safe to swim.

The guidelines should be implemented in conjunction with management of other beach-related health risks such as drowning and sun exposure and balanced against measures to protect native ecosystems.

Through implementation of these guidelines, we can all play a part to ensure that happy memories are made at the beach, the lake, and the river for generations to come.

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Acronyms and abbreviations

AFRI	acute febrile respiratory illness
ALF	alert levels framework
ATXs	Anatoxin-a
CFU	colony-forming unit
CSO	combined sewer overflow
CYNs	Cylindrospermopsins
FIO	faecal indicator organism
GDWQ	World Health Organization *Guidelines for drinking-water quality*
GI	gastrointestinal
HAB	harmful algal bloom
IRP	incident response plan
ISO	International Organization for Standardization
LC	liquid chromatography
LOAEL	lowest-observed-adverse-effect level;
MCs	Microcystins
MS	mass spectrometry
MST	microbial source tracking
NGO	nongovernmental organization
NOAEL	no-observed-adverse-effect level
PAM	primary amoebic meningoencephalitis
QMRA	quantitative microbial risk assessment
RWSP	recreational water safety plan
STXs	Saxitoxins
TCiW	*Toxic cyanobacteria in water* (WHO publication)
TP	total phosphorus
USA	United States of America
WHO	World Health Organization

Executive summary

The World Health Organization (WHO) *Guidelines on recreational water quality: volume 1 – coastal and fresh waters* aims to protect public health by ensuring that the quality of recreational waters is safely managed. These guidelines update substantial content from the 2003 WHO *Guidelines for safe recreational water environments: volume 1 – coastal and fresh waters* and its 2009 addendum.

Key changes are:
- emphasis on preventive risk management through site-specific recreational water safety plans at the centre of a water safety framework (Fig. 0.1); and
- an exclusive focus on water quality, meaning that hazards that are not related to water quality (drowning; exposure to sun, heat and cold; and dangerous aquatic organisms) are outside the scope of this guideline. References to relevant guidance, including other WHO guidelines, on these topics have been added.

Water quality management for swimming pools and spas is addressed in the *WHO Guidelines for safe recreational water environments: volume 2 – swimming pools and spas.*

Use of coastal, estuarine and freshwater recreational water environments has significant benefits for health and well-being, including rest, relaxation, exercise, cultural and religious practices, and aesthetic pleasure. It also provides substantial local, regional and national economic benefits from tourism. However, recreational water environments contain potential hazards, which must be weighed against the benefits. These guidelines focus on water quality management for coastal and freshwater environments.

Recreational water sites are ecosystems that support a range of aquatic organisms, including fish and shellfish, insects and birds. Some of these organisms can be nuisances during recreational use of the site, or may even cause injury and health hazards to humans. Protecting human health may need to be balanced against environmental protection targets. Application of these guidelines therefore needs to consider targets and measures for the protection of coastal and aquatic ecosystems.

These guidelines are mainly aimed at national and local authorities, and other entities with an obligation to exercise due diligence relating to the safety of recreational water sites. They may be implemented in conjunction with measures for environmental protection of recreational water use sites.

Unless otherwise noted, the guidelines apply to the general population participating in all types of recreational water use entailing direct water contact, inhalation of sea spray and beach use. Immunocompromised individuals should seek medical advice on their individual ability to tolerate exposure to surface recreational waters. The guidelines:
- describe the current state of knowledge about the possible adverse health impacts of recreational use of coastal, estuarine and freshwater environments; and
- set out recommendations for setting national health-based targets; conducting risk assessments; and putting in place management approaches to identify, monitor and control these hazards, and associated public health surveillance and communication.

Core recommendations for implementation by national authorities and personnel responsible for implementation of recreational water safety plans (RWSP) are summarized below. The summary also includes management advice for each type of risk, including indicators, guideline values and information on system assessment, monitoring and management communications relevant for RWSPs. In-depth scientific rationale, supporting data and case studies are in Chapters 1–9.

Recommendations

National authorities should formulate a national recreational water safety framework, encompassing policies, plans, regulations, guidelines and tools, aligned with the **recommendations and management advice for specific risks.** If not already established, clear roles and responsibilities among national and local authorities need to be defined for each element of the framework.

Recommendations below should be read in conjunction with detailed descriptions in Chapters 1–3.

Fig. 0.1
Recreational water safety framework for recommendations and management advice

Recommendation 1: Set national health-based targets for recreational water bodies

Subrecommendations

1.1 Express targets as **microbial water quality standards** for sources of faecal contamination based on the guideline values in Table 2.1.[1]

1.2 Develop additional water quality standards for cyanotoxins or biovolume indicators from harmful algal blooms based on guideline values in Fig. 5.1.

1.3 Consider additional standards based on provisional guideline values for beach sand and chemicals, operational monitoring limits for other microbial hazards, and aesthetic and nuisance aspects if justified by national or local risk assessment and resource availability for monitoring and control measures.

Table 0.1
Guideline values for microbial quality of coastal and freshwater recreational waters

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

A–D: microbial water quality assessment categories (refer to section 4.3) used in the classification procedure; AFRI: acute febrile respiratory illness; GI: gastrointestinal; LOAEL: lowest-observed-adverse-effect level; NOAEL: no-observed-adverse-effect level.

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[1] Where high-quality, locally relevant epidemiological studies are available, national authorities may adapt Table 2.1 to develop nationally relevant health-based targets, as described in section 2.1.2.

Fig. 0.2
Alert level framework for monitoring and managing cyanobacteria in recreational water bodies

Pre-screening water-bodies for elevated risk of blooms and exposure to cyanotoxins:
- Total phosphorus concentrations >20 µg/L and/or experience of cyanobacterial occurrence,
- Intensive recreational activity.

(Section 5.2.3)

Alternative or complementary entry point for assessment at intervals of about 2 weeks.

Assessment by visual site inspection

Assessment supported by laboratory analysis

Fairly clear water, slightly turbid, greenish discolouration.

Secchi disc transparency < 1-2 m

YES → **VIGILANCE LEVEL** ← **YES**

Microscopy showing dominance of cyanobacteria with up to 1-4 mm3/L,
or
Up to 3-12 µg/L chlorophyll-a with dominance of cyanobacteria.

Assess further characteristics determining its potential to support blooms or scums.
Assess for cyanobacteria known to be toxin producers *(Fig. 5.2)*.
If yes, intensify monitoring and/or inform site users about toxic cyanobacteria and how to recognize them. *(Fig. 5.3)*.
Inform relevant authorities.

Vigilance level

NO

Vigilance level

NO

Pronounced greenish turbidity; feet barely visible when standing in knee deep water *(Fig. 5.3)*.

Possibly minor thin green film or streaks on part of the surface *(Fig. 5.2)*.

Secchi disc transparency < 0.5-1 m.

YES → **ALERT LEVEL 1** ← **YES**

Cyanobacterial biovolume > 4-8 mm3/L,
or
Up to 12-24 µg/L chlorophyll-a with dominance of cyanobacteria.
If toxins are analysed;
> 24 µg/l MCs
> 6 µg/L CYN
> 60 µg/L ATX
> 30 µg/L STX

Watch for scums.
Investigate further (if possible, conduct toxin analysis).
Inform site users to watch for scums and avoid activities that can lead to uptake through mouth or nose, particularly for children; if this cannot be controlled, keep children out of the water.
Inform relevant health authorities.

Alert level 1

NO

Alert level 1

NO

Visible thick cyanobacterial scum covering most of the water surface in areas used for recreation

Secchi disc transparency < 0.5-1 m.

YES → **ALERT LEVEL 2** ← **YES**

Cyanobacterial scum and;
> 24 µg/L MCs
> 6 µg/L CYN
> 60 µg/L ATX
> 30 µg/L STX

Immediate action to prevent contact with scums; possible temporary prohibition of swimming and other water contact activities.
Inform site users to stay out of the water and to avoid sports activities 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.

Source: Chorus & Testai (*Toxic cyanobacteria in water*, 2021).

Recommendation 2: Develop and implement recreational water safety plans (RWSPs) for priority bathing sites

Subrecommendations (also refer to Box 3.4 checklist for developing RWSPs)

2.1 Identify the lead entity and **assemble a team to develop the RWSP.**

- Identify the lead entity and key stakeholders, and form a coordination committee that includes relevant stakeholder representatives with clear roles and responsibilities.

2.2 Undertake a **system assessment** for each existing priority recreational water site (or group of sites within the same catchment) and before developing new sites.

- Describe the recreational water environment — by combining a sanitary survey of adjacent land and water drainage with an initial microbial quality assessment to assign a beach classifications (refer to sections 4.1–4.3).
- Identify hazards and hazardous events, considering seasonality and predicted local climate change scenarios.
- Assess and prioritize the risks.
- Identify existing control measures, assess risks and prioritize risks that are insufficiently controlled.
- Establish plans, with sustainable funding, for managing currently effective control measures.
- Establish improvement plans, with sustainable funding, for incrementally implementing control measures where priority risks are insufficiently controlled.

2.3 Conduct and maintain **system monitoring.**

- Establish and implement an operational monitoring regime for priority control measures in the catchment to give rapid warning when operational limits are exceeded.
- Establish and implement corrective actions for exceedances of operational limits.
- Conduct ongoing verification monitoring of water quality.
- Establish procedures to verify effectiveness of the RWSP.

2.4 Establish coordinated **management and communication** strategies to support effective pollution control and public communications.

- Document management procedures for normal and incident conditions, including incident response plans.
- Where feasible, develop predictive models to support timely communication to water users.
- Develop supporting programmes — for example, training, research and development, standard operating procedures, quality control activities, procedures for visual inspections, sample collection and equipment calibration.
- Establish communication protocols between responsible organizations and agencies.
- Establish mechanisms for communication with users and managers of the site.

2.5 **Review and update** RWSPs.

- Meet periodically and after incidents to review performance of plans, including operational monitoring and water quality results, an updated sanitary survey and beach classification, the occurrence of incidents, communication and complaints; if necessary, update the risk assessment.

Fig. 0.3
Flowchart for assessing recreational water environments
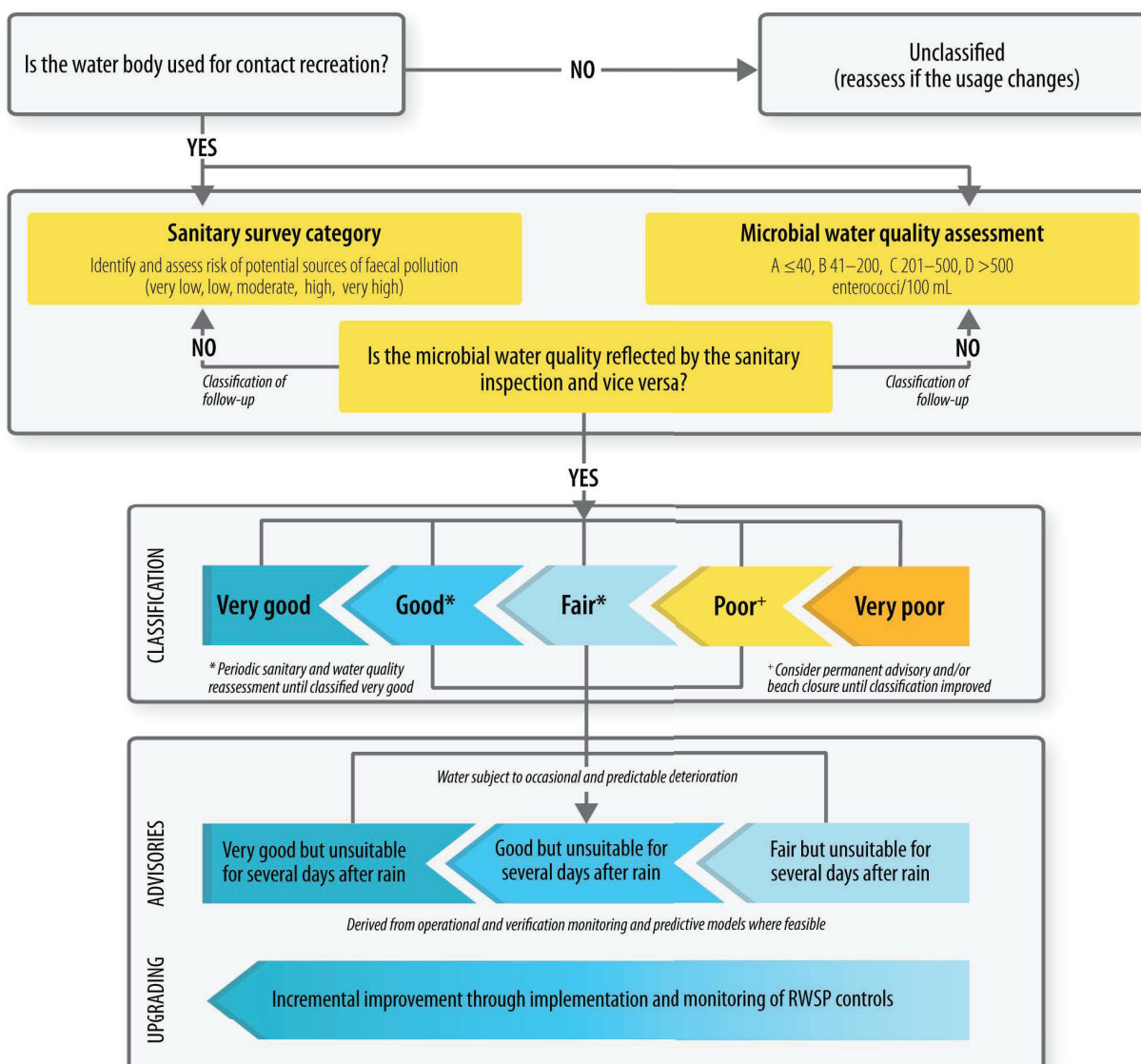
Recommendation 3: Conduct ongoing surveillance and risk communication of recreational water–related illness

Subrecommendations

3.1 Collect, analyse and interpret **health-related data** on suspected or confirmed illness in humans and/or animals, and systematically document outbreaks associated with recreational waters.

3.2 Provide the public with timely **information about the status of health risks**, and provide water users with advisory warnings before, during and after a public health incident, in conjunction with RWSPs.

Management advice and guideline values

Management advice is summarized below for each of the chapters on specific hazards (Chapters 4–9) according to the relevant water quality indicator(s) and their guideline values (where applicable), and the three elements of an RWSP:

- system assessment
- monitoring
- management and communication.

This management advice should be read in conjunction with the detailed descriptions in Chapters 4–9.

Chapter 4: Faecal pollution

Faecal indicator organism (FIO)

Intestinal enterococci in both marine water and fresh water[a,b]

[a] Guideline values provide a precautionary level of protection in fresh water since gastrointestinal illness occurs at a higher rate in seawater than in fresh water at a given FIO level.

[b] No statistical relationship has been established for *Escherichia coli* that can support a dose–response guideline value. Many jurisdictions use *E. coli* in fresh water with a 100 cfu/ 100 mL threshold of risk, based on findings of Wiedenmann et al. (2006). The study is less characteristic of waters globally, and use of two FIOs introduces avoidable complexity in analysis and interpretation of results. As further empirical epidemiological data become available, it may be possible to use *E. coli*, microbial source tracking markers and viral pathogens or their indicators (e.g. phages), protozoa or helminths to assess health risk in recreational waters.

Guideline value

200/100 mL (upper 95th percentile)[a,b]

[a] Upper range for Category B microbial water quality classification; 5% risk of gastroenteritis (refer to section 2.1 and Table 2.1).

[b] If necessary, adapt guideline values in national standards based on high-quality local epidemiology (refer to section 2.1.2.2).

System assessment and beach classification

- Classify beaches by combining water quality testing and sanitary surveys (refer to sections 4.1–4.3).
  - Undertake a sanitary survey to identify all sources and conditions leading to faecal pollution (refer to section 4.1.2).
  - Determine recreational water quality from an initial microbial water quality assessment (refer to section 4.2.1).
  - Combine results from the sanitary survey and the microbial water quality assessment to classify the recreational water environment as very good, good, fair, poor or very poor (refer to section 4.3).
- Undertake further assessment, and possibly on-site empirical investigations, if there is discrepancy between the results of the microbial water quality assessment and the sanitary survey.
- Consider upgrading the beach classification to a more favourable level if local management actions (e.g. advisories) are effective.

Operational and verification monitoring

- Undertake initial microbial water quality assessment to inform beach classification (as described above).
- When unacceptable levels of FIOs are detected and sewage is not the likely source, identify the faecal source(s) contributing FIOs (e.g. through sanitary surveys of the catchment or where resources permit microbial source tracking).
- Monitor the functioning of control measures using operational (microbial and nonmicrobial) parameters (e.g. warnings from release of poorly treated sewage or faecal sludge from a utility or service provider, rainfall that may affect runoff, changes in wind speed or direction, water temperature, water quality testing) and predictive modelling to allow timely warnings to water users.
- Conduct ongoing verification monitoring to check whether water quality is likely to be high enough to meet health-based targets (refer to Table 4.2 for recommended verification monitoring schedule).

Examples of management and communication

- Enforce compliance with regulations. For catchment pollution from human or nonhuman sources, identify major sources of pollution and develop a catchment-wide pollution abatement programme (refer to section 4.4).
- Manage pollution of recreational waters by human or animal wastes containing faecal bacteria or pathogens through system upgrades (e.g. tertiary treatment of human effluent for direct point-source pollution and/or appropriate disposal of human effluent through long outfalls to separate discharges from water users).
- Public health authorities should be engaged in defining water quality standards or appropriate triggers relevant to exceptional circumstances (e.g. sewer breaks, extreme floods and rainfall events with a recurrence interval of more than 5 years).
- Develop predictive models for real-time operational monitoring and public communications, where feasible (refer to section 4.2.3).
- Post advisory notices of likely adverse water quality if:
  - weather events, such as high rainfall, lead to elevation of FIOs in recreational waters;
  - a rare or extreme event causes gross pollution of the bathing water; or
  - sewage, septic tank effluent and/or faecal sludge discharges occur that are unrelated to weather events.

Chapter 5: Harmful algal blooms (HABs)

Indicators and guideline values

Freshwater and brackish water bodies[a]

[a] Available only for freshwater HABs because of lack of data for recreational exposure to marine HAB toxins.

Cyanobacterial biomass indicator values (thresholds in Fig. 5.1 alert level framework):
- Vigilance level – 1–4 mm³/L biovolume or 1–12 µg/L chlorophyll *a* (with dominance of cyanobacteria).
- Alert Level 1 – 4–8 mm³/L biovolume or 12–24 µg/L chlorophyll *a* (with dominance of cyanobacteria).
- Alert Level 2 – scum or transparency <0.5–1 m.

Note that 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.

Cyanotoxin guideline values (thresholds in Fig. 5.1. alert level framework):
- Microcystin $GV_{recreation}$ – 24 µg/L (provisional).
- Cylindrospermopsin $GV_{recreation}$ – 6 µg/L (provisional).
- Anatoxin-a $GV_{recreation}$ – 60 µg/L (conservative health-based reference value due to lack of effects in chronic studies).
- Saxitoxin $GV_{recreation}$ – 30 µg/L

System assessment

- Develop a surveillance strategy that gives priority to the highest-risk sites based on the likelihood of toxic blooms and patterns of recreational use (refer to Table 5.2).
- Develop an understanding of water body conditions (including under predicted local climate change scenarios), as the basis for assessing risks of bloom occurrence and thus of exposure during recreational activities (e.g. excluding fast-flowing rivers where blooms cannot form and lakewater aerosols).
- Compile an inventory of activities in the catchment causing nutrient loads that sup-port HABs.

Fresh water:
- Use total phosphorus concentrations above 20 µg/L and/or cyanobacterial occur-rence as a screening level for water bodies at risk of planktonic HABs, taking note of the possibility of HABs growing on surfaces in clear water bodies with lower total phosphorus concentrations.
- Choose parameters (e.g. biovolumes) that indicate potential levels of cyanotoxins, and define the levels that trigger specific actions.

- Interpret laboratory data in conjunction with visual information from site inspec-tion, observation of scums and water transparency, and qualitative microscopy.

Coastal and estuarine water:
- Assess the potential for bloom development based on nutrient input causing eu-trophication (i.e. nutrient enrichment that promotes blooms), water temperature and water flow dynamics (noting that most marine HABs primarily affect health through ingestion of contaminated seafood); adverse effects may occur from inha-lation of spray from marine water or scum containing algal species, or at tropical and subtropical beaches from skin contact with filamentous tropical cyanobacteria growing on surfaces causing severe skin lesions (*Moorea*, formerly called *Lyngbya*).

Operational and verification monitoring for fresh, coastal and estuarine waters

- For activities in the catchment causing nutrient-rich fluxes to water bodies used for recreation, work with relevant operators to develop methods to control and monitor nutrient release.
- Specify the aims of monitoring, and decide on the sampling sites, intensity of monitoring and analytical targets (refer to Table 5.4).
- Use long time series of data records on phytoplankton populations to improve understanding of the dynamics of HAB growth, predict the appearance of potentially toxic HABs, and allow recognition of new species in the area.
- Apply visual, biological, biochemical and physicochemical methods to determine the likelihood and presence of HABs and concentrations of cyanotoxins.
- Conduct water quality analysis based on visual examination (e.g. scum, coloured turbidity, biovolumes or chlorophyll a concentration, remote sensing) or toxin analysis in situations where health risks are likely (for fresh and brackish water, refer to Fig. 5.1 alert level framework).
- Mobilize citizen science for data collection, where feasible.
- Intensify monitoring activities when conditions favourable to HAB development are recognized.
- Document the occurrence of HABs and inform public health authorities when they occur.
- In the event of illness (including animal deaths) that is possibly associated with HABs, undertake verification monitoring. Establish communication lines for rapid water quality analyses of the recreational water body and toxin analysis to provide information for diagnosis and for immediate management actions.

Examples of management and communication

Fresh water and brackish water:
1. Implement an alert level framework (refer to Fig. 5.1).
2. Inform public health authorities when blooms occur. Lifeguards, where present, and beach managers can provide information on bloom occurrence.
3. Develop an incident response plan to ensure a rapid and coordinated reaction in the case of a heavy bloom or incident (e.g. death of pets or livestock, or human illness) caused by a bloom.
4. Ensure that users of recreational water bodies have sufficient information and are actively engaged in assessing whether it is safe to swim (e.g. through signs, social media and hotlines).
5. Reduce nutrient (often phosphorus) input from the catchment to the water body from human excreta from sewage and wastewater, fertilizers, manure and slurry spread on land, and wastewater from industries and manufacturing enterprises (refer to Fig. 5.4).
6. If HAB toxin concentrations or biomass volumes remain too high and blooms still occur, or if more immediate success is needed, consider implementing an internal measure that makes conditions less favourable for cyanobacteria, noting some may not be practical or may have adverse ecological effects (refer to Table 5.3).

Coastal and estuarine water:
- For planktonic HABs, implement points 2–4 above. Consider also developing a similar alert level framework.
- For tropical/subtropical beaches with filamentous cyanobacteria (*Moorea*, formerly called *Lyngbya*) growing on surfaces, removing detached filaments accumulating on beaches and providing information to site users (refer to point 4 above) are the only options known to be effective.

For health authorities and water managers:
- Develop outreach materials explaining causes of HABs, and options and responsibilities for controlling them.

For recreational water users:
- Inform the public and policy communities how to recognize HABs and avoid exposure – and who to notify in cases of concern.

For medical practitioners:
- Inform medical practitioners about the symptoms HAB toxins may cause, their often mild and self-limiting nature, the conditions under which severe illness needs to be considered, measures to take if exposure to HAB toxins may have been substantial, and the communication lines to use if an HAB is suspected as the cause of symptoms, to immediately trigger water sampling and analyses (which are crucial to confirm a diagnosis and to prevent further exposure).

Chapter 6: Other microbial hazards

Indicator

None (refer to "Operational and verification monitoring" below).

Guideline value

Not applicable – no dose–response relationship can be established for these organisms.

System assessment

Incorporate risk factors for the other microbial hazards of concern for the catchment within the RWSP system assessment by preparing an inventory of microbial hazards that have been observed or are likely to be present and incorporating risk factors likely to promote their proliferation.

Operational and verification monitoring

- For organisms whose prevalence is strongly dependent on environmental conditions, incorporate indirect operational monitoring of environmental conditions (e.g. temperature) into RWSPs.
- Undertake verification monitoring and surveillance of illness at a national level, to enable analysis of information on symptoms, severity, pre-existing conditions and the likely recreational source of infection.
- Regular pathogen monitoring is not recommended except under exceptional circumstances (and if site-specific guideline values are established) – for example, before and after a water sports event, or during heatwaves in locations with a history of *Vibrio* infections. Targeted screening can be used for investigative and research purposes.

Examples of management and communication

For health authorities and water managers:
- In catchments and bathing sites where severe infections (e.g. primary amoebic meningoencephalitis, severe leptospirosis) are suspected, incorporate pathogen-specific management and communication measures into the RWSP.
- Potential control measures include site management (e.g. control of vectors or macrophyton) and behaviour change approaches (e.g. hygiene measures for water users).
- Where non-native animal carriers play a role in disease transmission, manage the recreational site to control these animals.
- Where a site has been linked to infection or has conditions that are suitable for the causative organism, inform site users to allow them to make an informed decision.

For recreational water users:
- General precautions
  - Cover existing skin lesions with waterproof dressings before entering the water. If an injury is sustained while in the water or at the recreational site, wash the wound thoroughly with soap and water.
  - Remove wet swimwear; shower and towel dry after water exposure.
  - Remove contact lenses before bathing in warm fresh water.
  - For water sports, wear protective clothing where the risk of infection is high.
  - If an infection develops after recreational water exposure, seek medical advice.
- Specific precautions
  - Protect against swimmer's itch by avoiding high-risk areas (shallow water with dense vegetation) and high-risk periods (early morning at some sites).
  - Reduce exposure to *Naegleria fowleri* by minimizing the amount of naturally warm fresh recreational water entering the nose (e.g. keeping the head above water, holding the nose shut, using a nose clip).
  - People with underlying medical conditions (especially hepatic disease or other chronic illness) should limit their exposure to brackish water or seawater.
  - Seek medical advice if planning to engage in recreational water activities in areas where human schistosomiasis and leptospirosis are endemic.

For medical practitioners:
- Pay attention to risk behaviours such as travel to endemic areas, adventure travel and extreme water sports.

Chapter 7: Beach sand

Indicator

Intestinal enterococci in both marine water and fresh water (where justified by national or local risk assessment, and resource availability for monitoring and control measures).

Provisional guideline value

60 CFU/g[a,b]

[a] Where resources allow, adapt the provisional guideline value in national standards based on local epidemiological and quantitative microbial risk assessment studies. In the absence of guideline values, efforts should focus on preventive measures described under "Examples of management and communication" below.
[b] Preliminary evidence based on a pan-European average also suggests an indicative reference value of 90 CFU/g of wet weight for fungi.

System assessment

Incorporate risk factors for pathogens of concern in beach sand into RWSP system assessment, paying particular attention to beaches that are vulnerable from a physical and geomorphological perspective (enclosed beaches with minimal wave action).

Operational and verification monitoring

- Undertake pathogen sampling and analysis (refer to section 7.2.3).
- Undertake operational monitoring of priority sources of sand pollution (e.g. dogs and birds on beaches).

Examples of management and communication

For health authorities and water managers:
- Limit access to the beach by dogs and feral animals, such as cats.
- Prepare management plans for birds.
- Provide properly designed solid waste disposal facilities.
- Provide toilet facilities, appropriate wastewater and sludge treatment, and stormwater drainage.
- Conduct beach grooming to eliminate visible solid waste (taking care to minimize impacts on sand ecology).
- Check the quality of source sand if beach sand renourishment is used to build artificial beaches or restore natural beaches.

- Apply additional strategies for beaches that are vulnerable from a physical and geomorphological perspective (enclosed beaches with minimal wave action).

For recreational water and beach users (in the absence of environmental measurements):
- Use a towel when sitting on the beach.
- Wear shoes to minimize cuts when walking on the beach.
- Protect open wounds from water and sand exposure.
- Beach clean-up workers may be encouraged to wear protective clothing, including gloves and possibly dust masks.
- Shower upon leaving the beach.

For public health authorities:
- Stay in contact with lifeguards for potential reports of on-site outbreaks.
- Proactively intervene by contacting medical centres – remind staff to be alert to possible beach-related outbreaks and ailments.

Chapter 8: Chemicals

Indicator

None – except for specific chemicals where justified by national or local risk assessment, and resource availability for monitoring and control measures.

Guideline value

As a screening approach, investigate substances occurring in recreational water at a concentration 20 times higher than the guideline value in the WHO *Guidelines for drinking-water quality*.

Risk assessment

Incorporate assessment of chemical hazards in recreational waters into RWSPs, using information on potential sources of chemical hazards within the catchment, and the frequency, extent and likelihood of exposure.

Operational and verification monitoring

- Undertake operational monitoring for the highest-risk chemical discharges (e.g. discharge permit compliance, flow rate); monitor fencing and signage, if installed, to prevent access to water bodies (e.g. quarry lakes) that are permanently unsuitable for recreational use; monitor soil and groundwater downstream of contaminated sites.
- Use chemical analysis to support a quantitative risk assessment if contamination is present or suspected and there is significant exposure of users.

Examples of management and communication

For health authorities and water managers:
- Manage pollution events, and provide timely and effective information (e.g. issue media advice, communicate with community or resident groups, install warning signs) about recreational water environments affected by chemical hazards.

For recreational water users:
- Provide information about the nature of the contamination, potential health risks, activities to be avoided and planned remedial action.

Chapter 9: Aesthetics and nuisance

Indicator

None (refer to "Operational and verification monitoring" below).

Guideline value

Not applicable.

System assessment

Incorporate aspects of aesthetics and nuisance into RWSP system assessment.

Operational and verification monitoring

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.

Examples of management and communication

For health authorities and water managers:
- Provide solid waste disposal facilities.
- Undertake beach grooming and litter clean-ups for beaches receiving litter or excessive macroalgae from offshore.
- Provide information to beach users on proper solid waste disposal, and avoiding nearshore nuisances such as jellyfish.
- Undertake insect control for sites with excessive mosquitoes, flies and other nuisance insects.
- Develop policies and management for non-native animals on the beach (e.g. discourage pets and feeding of birds, keep solid waste inaccessible). If dogs are permitted, put in place policies and procedures to minimize their impacts on the aesthetic quality of the beach.

1 Introduction

The World Health Organization (WHO) *Guidelines on recreational water quality: volume 1 – coastal and fresh waters* aims to protect public health by ensuring that the quality of recreational waters is safely managed. These guidelines update substantial content from the 2003 WHO *Guidelines for safe recreational water environments: volume 1 – coastal and fresh waters* and its 2009 addendum.

Key changes are:
- emphasis on preventive risk management through recreational water safety plans (RWSPs) at the centre of a water safety framework (Fig. 1.1); and
- an exclusive focus on water quality, meaning that hazards that are not related to water quality (drowning; exposure to sun, heat and cold; and dangerous aquatic organisms) are outside the scope of this guideline. References to relevant guidance, including other WHO guidelines, on these topics have been added.

Use of coastal and freshwater recreational water environments has significant benefits for health and well-being, including rest, relaxation, exercise, cultural and religious practices, and aesthetic pleasure (Crouse et al., 2018; White et al., 2020). It also brings substantial local, regional and national economic benefits from tourism. However, recreational water environments contain potential hazards, which must be weighed against the benefits.

The benefits of recreational water use have increased competition for use of coastal waters and beach areas, leading to the need for clear regulations and codes of conduct. Management of recreational waters must carefully balance possible hazards against the benefits.

Recreational water sites are ecosystems that support a range of aquatic organisms, including fish and shellfish, insects and birds. Some of these organisms can be a nuisance or cause injury (e.g. jellyfish) or other health hazards (e.g. bird excreta, dangerous aquatic animals) to humans. Protecting human health may need to be balanced against environmental protection targets. Application of these guidelines therefore needs to consider targets and measures for the protection of coastal and aquatic ecosystems.

These guidelines:
- describe the current state of knowledge about the possible adverse health impacts of recreational use of coastal and freshwater environments; and
- provide recommendations for setting national health-based targets, conducting risk assessments, and putting in place management approaches to identify, monitor and control these hazards, and associated public health surveillance and communication.

To apply the guidelines to local conditions, the social, cultural, environmental and economic characteristics of the country and recreational water site should be considered, as well as the activities undertaken, routes of exposure, and the nature and severity of hazards. Because these factors differ between sites, local, national and international standard-setting bodies may develop standards that differ between and within regions.

Recognizing the diversity of recreational water environments and users, these guidelines emphasize a flexible, proactive risk management approach that can be adapted to local hazards, conditions and priorities. This version has also been streamlined to focus more directly on hazards associated with (and near) water.

1.1   Scope

These guidelines focus on water quality management for public health protection for coastal and fresh water. Other WHO guidelines address treatment of swimming pools and spas, and recreational water hazards such as drowning; exposure to sun, heat and cold; and dangerous aquatic organisms. Resources for hazards that are not addressed in the guidelines are listed in Table 1.1.

Table 1.1
References for hazards indirectly related to coastal and fresh water quality for recreational water users

Hazard	Resources and references[a]
Drowning and injury	*Preventing drowning: an implementation guide,* WHO, www.who.int/violence_injury_prevention/drowning/drowning_prevention_guide/en/
Sun exposure	*Sun protection,* WHO, www.who.int/uv/sun_protection/en/ *Sunshine and health: how to enjoy the sun safely,* WHO, https://apps.who.int/iris/handle/10665/69771 *Heat safety tips and resources,* National Weather Service (USA), www.weather.gov/safety/heat
Treated recreational waters (e.g. pools, spas)	*Guidelines for safe recreational water environments: volume 2 – swimming pools and similar environments,* WHO
Safe management of sanitation systems	*Guidelines on sanitation and health,* WHO https://apps.who.int/iris/bitstream/handle/10665/274939/9789241514705-eng.pdf?ua=1
Occupational exposure to water	*Commercial fishing safety,* National Institute for Occupational Safety and Health (USA), www.cdc.gov/niosh/topics/fishing/default.html
Shellfish and other aquatic food sources	*Safe management of shellfish and harvest waters: minimizing health risks from sewage-contaminated shellfish,* WHO, www.who.int/water_sanitation_health/publications/shellfish/en/
The bends, decompression sickness and hazards related to deep-sea diving	Divers Alert Network (USA), https://dan.org/health-medicine/health-resources/health-safety-guidelines/
Dangerous aquatic organisms (e.g. sharks, jellyfish)	*Nine dangers at the beach,* National Ocean Service (USA), https://oceanservice.noaa.gov/hazards/beach-dangers/
Sanitation/toilet facilities near recreational water sites	*Guidelines on sanitation and health,* WHO, https://apps.who.int/iris/bitstream/handle/10665/274939/9789241514705-eng.pdf?ua=1
Rip currents and dangerous surf	*Public education,* International Lifesaving Organization, https://www.ilsf.org/drowning-prevention/public-education/ *How to avoid getting caught in a rip current,* National Weather Service (USA), https://www.weather.gov/safety/ripcurrent
Seasickness	*What causes seasickness?,* National Ocean Service (USA), https://oceanservice.noaa.gov/facts/seasickness.html Takov V, Tadi P (2020). Motion sickness. In: StatPearls. Treasure Island, Florida: StatPearls Publishing, https://pubmed.ncbi.nlm.nih.gov/30969528/ Golding JF (2016). Motion sickness. Handb Clin Neurol. 137:371–90. doi:10.1016/B978-0-444-63437-5.00027-3.
Therapeutic uses of water (thalassotherapy, spas)	*Recommendations for hydrotherapy tanks,* Centers for Disease Control and Prevention (USA), www.cdc.gov/healthywater/swimming/aquatics-professionals/hydrotherapy-tank-pool-operation.html

[a] This list is indicative and not exhaustive.

1.1.1   Types of recreational water

In these guidelines, coastal and freshwater recreational water environments are defined as any coastal, estuarine or freshwater area where any type of recreational use of the water is made by a significant number of users. Sporadic yet significant recreational use may also occur in water bodies not usually considered recreational sites; for example, sporting events may occur in rivers or even canals (Russo et al., 2020). Management of these types of events can still be governed and informed through the RWSP framework (Chapter 2).

1.1.2   Types of use

Many different types of recreational, athletic and leisure activities occur in recreational water environments. These include both activities that involve water contact and activities that take place in the sand or near the water's edge. These guidelines apply to all types of use entailing direct water contact, inhalation of sea spray and beach use.

Competition for suitable waters and the popularity of recreation may create conflicts between activities. For example, recreational use of drinking-water reservoirs can result in contamination of drinking-water sources by faeces, litter, oil and fuel. Dog walking and horse riding on beaches can result in faecal contamination of the beach, and potential transmission of zoonotic pathogens (e.g. *Toxocara* roundworms in dog faeces, dermatophytes in dog and horse hair) from the animals. Water resources management for hydropower and dams may prohibit recreational uses or lead to hazards associated with seasonal pollution due to the management of sediments. These conflicts can be resolved by supervision, regulation, codes of good practice and voluntary agreements. Approaches to developing control measures and management approaches for these types of conflicts can be designed as part of an RWSP (Chapter 2).

1.1.3   Types of user

Users of coastal and freshwater recreational water environments include local residents; seasonal or sporadic users, such as tourists; and specialist sporting users, including competitive swimmers, surfers, anglers, canoeists, boaters and scuba divers.

The water quality guideline values recommended are for the general population. Hazards for particularly susceptible individuals and groups are also discussed.

Users can differ in their susceptibility to potential hazards. Children, for example, may be at greater risk because of their general reluctance to observe formal rules to ensure safety and hygiene. They are also likely to play for longer in recreational waters and are more likely to intentionally or accidentally swallow water (Schets, Schijven & de Roda Husman, 2011; DeFlorio-Barker et al., 2018). The elderly and people with disabilities may have lower strength, agility and stamina, which might limit their ability to recover from problems encountered in recreational water environments. Older and immunocompromised individuals may also be more susceptible to pathogenic organisms and therefore at higher risk of adverse health effects from microbial contamination of water. On the other hand, the elderly are likely to swallow less water during swimming, and may be more likely to heed rules and posted warnings about water quality and adverse conditions. Immunocompromised individuals should seek medical advice on their individual ability to tolerate exposure to surface recreational waters.

Traumatic events such as near drowning, when large volumes of water are aspirated, can also increase susceptibility to water quality hazards and result in rare adverse health outcomes such as severe pneumonia (Ender & Dolan, 1997). Extensive exposure to recreational waters by more susceptible populations should be considered in the management of recreational waters and as part of an RWSP.

1.1.4 Degree of water contact

Routes of exposure to infectious and toxic agents in water depend on the degree of water contact (Russo et al., 2020). The degrees of water contact encountered in coastal and freshwater recreational environments may be classified as follows.

- No contact – recreational activity in which there is normally no contact with water or where water is secondary to enjoyment of the activity (such as sunbathing on a beach with exposure to beach sand and inhalation of sea spray; refer to Chapter 7).
- Incidental contact – recreational activity in which only the limbs are regularly wetted and greater contact (including swallowing water) is unusual (e.g. boating, fishing, wading).
- Whole-body contact – recreational 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.

These categories do not necessarily capture exposure to all potential hazards in the recreational water environment. For example, even no-contact activities can result in inhalation of sea spray containing algal toxins and exposure to potential hazards associated with sand.

Generally, exposure of skin and mucous membranes during recreational water activities is the most common route of exposure to hazards. The probability of ingestion of water is greater for whole-body contact activities. Inhalation can be important where there is a significant amount of spray, such as in waterskiing and jet-skiing. The skill of the individual in water recreation is also important in determining the extent of involuntary exposure, particularly water ingestion. Children ingest more water than adults during recreation, as a result of more vigorous activity and longer time spent in the water. Studies have also suggested that males tend to ingest more water during recreational swimming than females (Schets, Schijven & de Roda Husman, 2011; Dufour et al., 2017; DeFlorio-Barker et al., 2018).

1.2 Recreational water safety framework

These guidelines inform the development of regional and national approaches to manage recreational water quality and reduce health risks, based on a water safety framework (Fig. 1.1) to support setting of national health-based targets for water quality and public health surveillance (Chapter 2).

These guidelines place preventive risk management through RWSPs at the centre of the water safety framework in accordance with the harmonized Stockholm framework for risk assessment and management adopted for WHO guidelines on water and sanitation (Bartram, Fewtrell & Stenström, 2001). This leads to a comprehensive and proactive approach for local decision-making to assure water safety based on the severity and frequency of health risks. RWSPs emphasize common sense and practical preventive measures, and reduce reliance on water quality testing. Detailed guidance on development of RWSPs is provided in Chapter 3, and supporting technical information for each type of hazard is in Chapters 4–9.

A risk management approach can often lead to the adoption of standards that can be measured, implemented and enforced – for example, dealing with water quality, dissemination of information, education of children and adults, and the obligation to prepare and disseminate comparative studies of the safety of locations for recreational water use. In developing strategies to protect public health, competent government authorities should consider the general education of both adults and children, and the efforts and initiatives of nongovernmental organizations (NGOs) and industry operators in this area.

Clearly, a broad-based policy approach will be required that may include legislation, positive and negative incentives to alter behaviour, and monitoring of conditions. Such an approach will require intersectoral coordination and cooperation at national and local levels. Successful implementation will require development of suitable skills and expertise, and elaboration of a coherent policy and legislative framework.

Fig. 1.1
Outline of the guidelines according to a recreational water safety framework
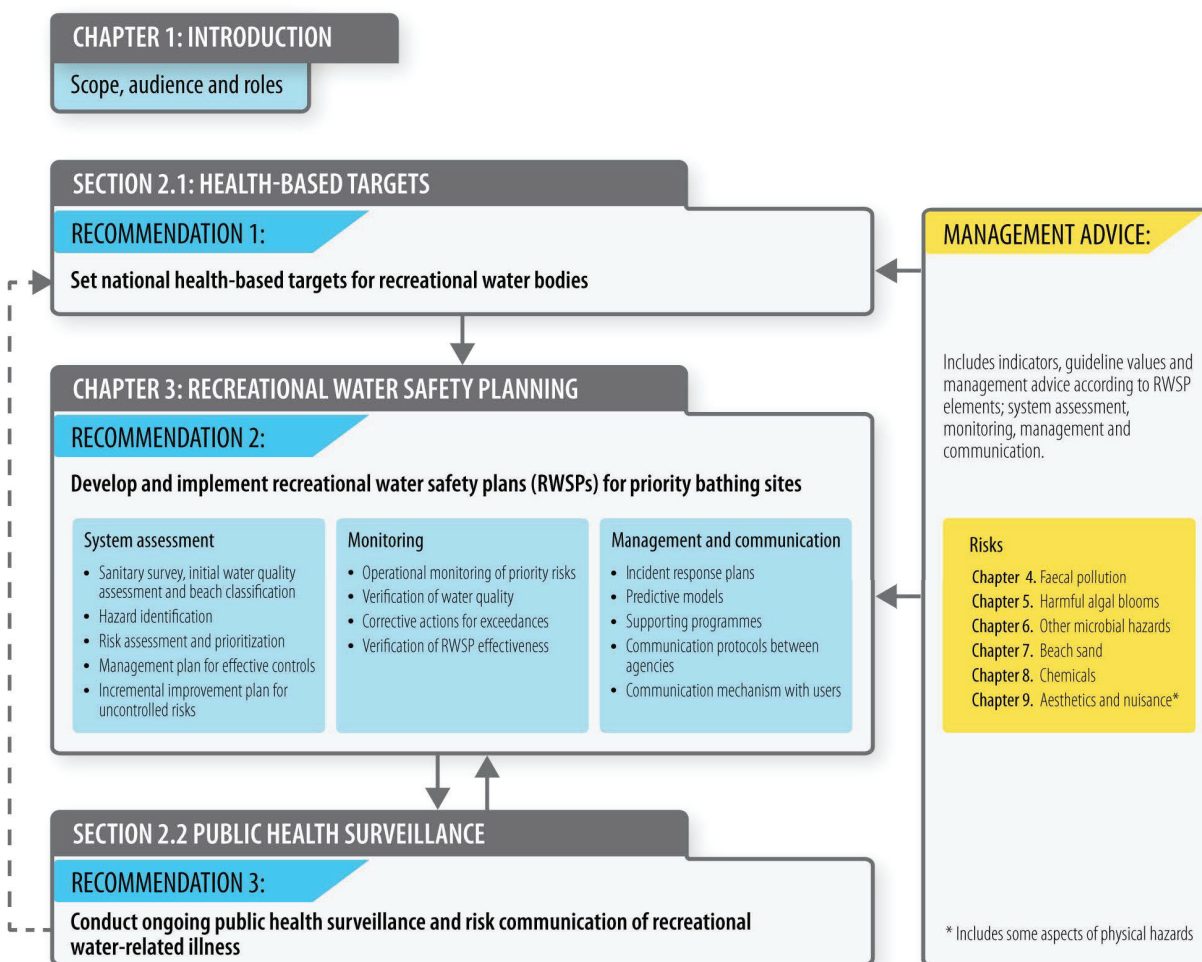
1.3 Audience and roles

1.3.1 Target audience

These guidelines are primarily targeted at entities with responsibility for ensuring recreational water safety at several levels.

- National and local agencies working in recreational water use – such as health, environmental and natural resource management bodies – have a responsibility to promote and ensure a safe environment.
- Owners or service providers of recreational water areas may have a legal obligation to exercise due diligence relating to the safety of water or beaches.

In addition, the guidelines contain information relevant to other stakeholders, including:

- NGOs and special interest groups with an important role to play in advocacy, communication and education; and
- recreational water users seeking information in addition to readily available public communications advising of health risks associated with recreational water quality.

1.3.2   Roles and responsibilities

Mutually supportive actions are needed at local, national and regional levels to reduce risks encountered during recreational water use.

Many interdisciplinary experts and stakeholders are involved in the assessment, use and protection of recreational waters. If not already established, clear roles and responsibilities should be defined, and stakeholders' efforts should be harnessed through an integrated planning framework. Fig. 1.2 illustrates the variety of stakeholders, and their roles in assessing and using recreational waters, and taking remedial action to limit health hazards.

Fig. 1.2
Stakeholders in recreational water environments
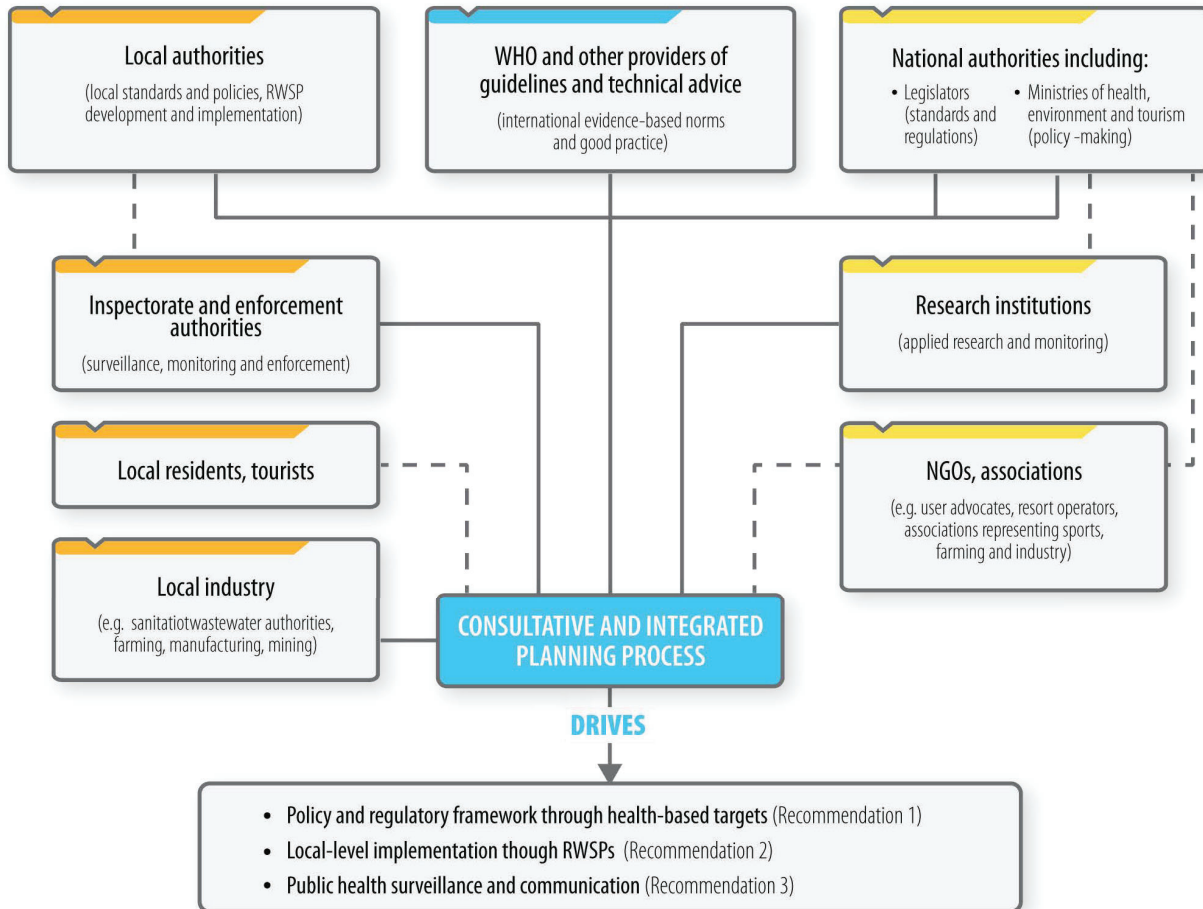
Agencies responsible for public health and/or environmental regulation will often take a leading and coordinating role in the application of recreational water guidelines. The coordinating authority should ensure the active participation of the other key stakeholders shown in Fig. 1.2. A wide variety of legislation and other regulation may contribute to ensuring and improving the safety of the recreational water environment. The potential actors and functions involved in improving safety are outlined in Table 1.2.

Table 1.2
Examples of actors and functions for management of recreational water quality

Authority or activity	Comments
Local authority or entity with responsibility for the recreational water location	May be responsible for: • safety of recreational water areas, as part of a duty of care or due diligence; and • establishing and implementing RWSPs (in consultation with other stakeholders, including agencies responsible for safety and health).
National authority responsible for public health or environmental regulation	May be responsible for: • leading policy to promote or make obligatory RWSPs by those with responsibility for recreational water locations; • maintaining and updating national standards (e.g. recreational water quality standards), including sampling regimes and methods; analytical methods; data analysis, interpretation and reporting; interlaboratory comparisons and reporting; • maintaining lists of national sites for recreational water use; and • surveillance of illness in the community.
Local authority responsible for public health or environmental regulation	Responsible for: • advising local facility operators/service providers and municipalities on public health aspects of the activities and resources under their supervision; • advising when to intervene if there is a threat to public health at a recreational water location (e.g. advising against use for a defined period or until safe conditions are re-established); and • communicating with users.
Authority responsible for safety	Often responsible for: • surveillance; and • developing and implementing voluntary codes of good practice. There may be more than one authority responsible for safety, and some may be nongovernmental.
Local tourism body	Although usually lacking a legislative/regulatory role, may provide information to the public on local or regional water quality or conditions.
Certification agencies	• Verify that devices, methods and techniques (e.g. analytical methods) meet a given level of quality and safety based on agreed standards. • Verify the RWSP, or elements of the RWSP (e.g. accuracy or predictive models).
Users of recreational water or facility	Exercise informed choice and take personal responsibility (e.g. by avoiding swimming after heavy rain or near drainage ditches).
Laboratories (water quality testing and research)	In most cases, water quality testing and research should be delivered by an externally accredited laboratory.
Academia	Close monitoring of the science literature and peer-reviewed evidence base, produced mainly by academia, should be an important aim of man-agers of bathing waters and related academics worldwide.
Other actors	These may include managers/operators of site-specific activities influenc-ing the frequency of use of recreational water environments, such as coast guards, and managers/operators of boat channels, drinking-water catch-ments and wastewater treatment plants.

1.4 Cross-cutting and emerging issues

1.4.1 Antimicrobial resistance

Antimicrobial resistance is an increasingly serious threat to global public health. Infections with bacteria and fungi that express antimicrobial resistance genes can be difficult or even impossible to treat. Antimicrobial resistance genes can transfer rapidly among bacteria and their bacteriophages in aquatic environments. Antimicrobial agents, detergents, disinfectants and residues from industrial processes may be present in recreational waters, leading to evolution and spread of resistance. Major sources of antimicrobial-resistant microorganisms include wastewater and sludges from municipal treatment plants, hospitals, agricultural runoff, and pharmaceutical manufacturing sites. Antibiotic-resistant strains of heterotrophic bacteria and of *Enterococcus* and *Escherichia coli* – bacteria that indicate faecal contamination – have been identified in recreational waters and beach sands (Huijbers et al., 2015; Leonard et al., 2015; Jorgenson et al., 2017). Surfers, who are frequent water users, have been found to be more than 3 times as likely as non-swimmers to carry resistant *E. coli* in their digestive systems (Leonard et al., 2018a).

The potential health impacts associated with antimicrobial-resistant organisms in recreational waters and beach sands are currently not well understood, and more research is needed to provide a better understanding of these hazards (Sanseverino et al., 2018).

1.4.2 Climate change

The increasing impact of global climate change on recreational water environments and water quality is not well understood. However, climate change is expected to increase the frequency of severe weather events (e.g. extreme precipitation, floods, hurricanes, droughts) and cause rising sea levels. These conditions can damage sewerage infrastructure and overwhelm wastewater treatment plants (typically sited close to sea level), resulting in treatment bypasses, particularly in combined sewer and stormwater systems. They can also flood on-site sanitation systems such as septic tanks and pit toilets. All of these events can cause discharges of inadequately treated human excreta into surface waters and nearby recreational areas. In some water bodies, extreme climate events could cause increased blooms of harmful algae (cyanobacteria) and other water-based pathogens during periods of low flow and warm weather (refer to Chapter 5). Major storm events could increase runoff of domestic, industrial and agricultural waste from non-point sources into surface waters (refer to Chapter 4). A warming climate, in combination with increased levels of nutrient runoff, may also make conditions in some areas more favourable for naturally occurring opportunistic waterborne pathogens (e.g. *Vibrio* species) (Weiskerger et al., 2019).

Effects of climate change may also lead to positive consequences for health. For example, limited evidence suggests that summer rainstorms, which can reduce water quality at northern European and Mediterranean beaches (Spain and the United Kingdom), will be less likely in the period to 2100 under climate change scenarios (Figueras et al., 2011), leading to improvements in water quality during the summer bathing season.

Climate change impacts on recreational water will certainly vary locally, depending on the hydrological characteristics of a water body, and potential local scenarios should be considered as part of an RWSP (refer to Chapter 3).

1.4.3 Microplastics

Microplastics are plastics less than 5 mm in diameter that are either manufactured for use in cosmetics, facial cleansers and abrasives, or formed as a result of degradation of larger plastic items. Microplastics can enter water sources through wastewater treatment plant discharges, landfill leachate and sewage sludge, as well as through physical and chemical degradation of plastic wastes and litter. Chemical risks from microplastics are discussed in Chapter 8. Aesthetic and nuisance aspects of macroplastic litter are discussed in Chapter 9.

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2 Health-based targets and surveillance

Although a variety of stakeholders are engaged in ensuring recreational water safety, health authorities have specific roles to play in determining national health-based targets and conducting health outcome surveillance. Health-based targets underpin implementation of recreational water safety plans (RWSPs) at priority sites (refer to Chapter 3). Health outcome surveillance can verify health impacts, support communication of water quality improvements under RWSPs, and generate evidence to inform updates to national health-based targets, as necessary. Recreational waters have been shown to present a measurable and significant risk to the health of water users that is worthy of control using water quality monitoring. For example, Graccia et al. (2018) collated data for the period 2000–2014 for 35 states of the United States of America and Guam among users of untreated surface waters (marine and fresh water), and reported 140 disease outbreaks, with 4958 cases of disease and two deaths caused by pathogens, toxins or chemicals. In the 95 outbreaks having a confirmed infectious etiology, 92% were caused by enteric pathogens; 22% of these were caused by norovirus.

2.1 Health-based targets

Recommendation 1: Set national health-based targets for recreational water bodies

Subrecommendations

1.1 Express targets as **microbial water quality standards** for sources of faecal contamination based on the guideline values in Table 2.1.[1]

1.2 Develop additional water quality standards for cyanotoxins or biovolume indicators from harmful algal blooms based on guideline values in Fig. 5.1.

1.3 Consider additional standards based on provisional guideline values for beach sand and chemicals, operational monitoring limits for other microbial hazards, and aesthetic and nuisance aspects if justified by national or local risk assessment and resource availability for monitoring and control measures.

Health-based targets are measurable health, water quality or performance objectives that are established based on a judgement of safety and on risk assessments of waterborne hazards. There are two distinct types of health-based targets relevant for recreational waters:
- health outcome targets (e.g. tolerable burdens of disease, cases of disease); and
- water quality targets (e.g. guideline values for microbial indicators, sources of faecal contamination).

Recommendation 1.1 specifies microbial water quality targets for feacal pollution because most countries do not have high-quality local epidemiological studies from which to derive adapted national health outcome targets. Some information on the underlying epidemiology and the approach for setting health outcome targets is given in section 2.1.1.

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[1] Where high-quality, locally relevant epidemiological studies are available, national authorities may adapt Table 2.1 to develop nationally relevant health-based targets, as described in section 2.1.2.

Health-based targets underpin the development of RWSPs (refer to Chapter 3) and verification of successful RWSP implementation. Health-based targets can be used to support incremental improvement by charting milestones in progress towards water safety and public health goals. This requires periodic review and updating of priorities, norms and standards. Health-based targets should assist in determining specific control measures, such as treatment processes for sources of faecal pollution, and guide public health surveillance and risk communication (refer to section 2.2).

For recreational water quality, the principal health-based targets relate to the adverse health effects associated with faecal pollution (Chapter 4) and harmful algal/cyanobacterial blooms (Chapter 5). Other hazards that may be locally or seasonally important include other microbial hazards (Chapter 6), contaminants in beach sand (Chapter 7), certain chemicals (Chapter 8), and hazards relating to aesthetics and nuisance (Chapter 9).

Details on derivation of health outcome targets for faecal–oral disease and microbial water quality targets (Recommendation 1.1) are detailed below.

2.1.1 Health outcome targets

Should a jurisdiction choose to develop health outcome–based targets, a considerable body of epidemiological information is available that may be adapted using high-quality locally relevant epidemiological studies, where available, and a national-level judgement of tolerable risk for the exposed population.

Numerous studies have shown a causal relationship between gastrointestinal symptoms and recreational water quality, as measured by levels of faecal indicator organisms (FIOs). Gastrointestinal symptoms are the most frequent health outcome for which significant dose-related associations have been reported (Wiedenmann et al., 2006). Randomized controlled trials conducted in marine waters in the United Kingdom (Kay et al., 1994; Fleisher et al., 1996) provide the most convincing data, and the most accurate measures of exposure, for water quality and illness. These trials are therefore the key studies for the derivation of guideline values for coastal and fresh recreational waters (refer to section 2.1.2). However, these results primarily apply to healthy adults using sewage-affected marine waters in temperate climates. Most studies reviewed by Prüss (1998) suggested that symptom rates were higher in younger age groups, and the United Kingdom studies may therefore systematically underestimate risks to children (Wade et al., 2008; Leonard et al., 2018).

Epidemiological studies are preferred as the basis for setting health outcome–based targets since they can eliminate sources of bias and error in assessment of human health impact. However, epidemiological studies are limited to a single, or a few closely related, diseases and carefully defined cohorts, and hence generally do not measure the full range of variation in population responses or environmental scenarios. Most recreational bathing studies have focused on temperate, not tropical, water environments, and the relationships between FIOs and pathogen survival may differ between these two environments (Harwood et al., 2014; Wade et al., 2018).

In resource-constrained settings, epidemiological studies may be challenging. Quantitative microbial risk assessment (QMRA) can be used to indirectly estimate the risk to human health by predicting infection or illness rates, given densities of particular pathogens in recreational waters, assumed rates of ingestion and appropriate dose–response models for the exposed population. QMRA estimates and epidemiological investigations have given comparable results for potential impacts of such events (Viau, Lee & Boehm, 2011; Soller et al., 2017), giving credence to the use of QMRA. QMRA can also explore risks below epidemiologically detectable levels or under circumstances that are not suited to epidemiological examination. However, caution is required in interpreting the results of QMRA because the risk of infection or illness from exposure to pathogenic microorganisms is subject to many uncertainties. Consequently, QMRA has greatest utility in resource-constrained settings for risk management (refer to section 4.4), where relative changes in estimated risks under various scenarios can be explored.

In the absence of high-quality, locally relevant epidemiological studies, national authorities are advised to develop microbial water quality targets derived from Kay et al. (1994) and Fleisher et al. (1996), as summarized in section 2.1.2 and Table 2.1.

2.1.2 Water quality standards

Guidance on setting national microbial water quality standards for the primary risk of faecal pollution (Recommendation 1.1) is detailed below. Indicators and guideline values for harmful algal blooms (Chapter 5), beach sand (Chapter 7) and chemical risks (Chapter 8) are included in each of the supporting chapters and summarized in the executive summary. For microbial hazards with insufficient information to develop specific guideline values (Chapter 6), operational monitoring options can be used in the context of an RWSP. Guideline values for aesthetic and nuisance aspects are presented in qualitative rather than quantitative terms since they reflect societal and cultural norms. Similarly, the quality of water that has special religious significance is also not quantified.

The guideline values presented are not mandatory limits; rather, they are measures of the safety of a recreational water environment. Derivation of guideline values and their conversion to national standards therefore require an element of valuation to address the frequency, nature and severity of associated health effects, since there is no clear cut-off value at which health effects are excluded. Societal norms play an important role in this valuation process, and the conversion of guidelines into national policy, legislation and standards should therefore take account of environmental, social, cultural and economic factors.

The existence of a guideline value or national standard does not imply that environmental quality should be allowed to degrade to this level. Indeed, a continuous effort should be made to ensure that recreational water environments are of the highest attainable quality and managed in a proactive manner. Many of the hazards associated with recreational use of the water environment are relatively short term. Short-term deviations above guideline values or conditions are therefore important to health, and measures should be in place to ensure and demonstrate that recreational water environments are continuously safe during periods of actual or potential use.

When a guideline value is exceeded, this should be a signal to:
- investigate the cause of the failure and the likelihood of future failure;
- liaise with the authority responsible for public health to determine whether immediate action should be taken to reduce exposure to the hazard; and
- determine whether measures should be put in place to prevent or reduce exposure under similar conditions in the future (refer to Chapter 3).

Predictive models, coupled with timely public communications, can prevent exposure by alerting water users in real time to likely exceedances (refer to section 4.2.3).

Guideline values for microbial water quality

Quantitative epidemiological studies (Kay et al., 1994) in marine water enable estimation of the degree of health protection (or, conversely, the burden of disease) associated with a range of water quality criteria. Derived guideline values for both marine and fresh water were first presented in the World Health Organization (WHO) *Guidelines for safe recreational water environments* (WHO, 2003), based on a tolerable burden of <1–5% gastrointestinal disease for voluntary recreational activities.

A subsequent study in fresh water (Wiedenmann et al., 2006) was used as a basis for slightly less stringent guideline values for fresh water in the later 2006 European Union Bathing Water Directive (EU, 2006), in which marine standards are generally applied to brackish or estuarine waters. Kay et al. (1994) found that enterococci best predicted gastrointestinal illness in recreational water users, whereas Wiedenmann et al. (2006) suggested that no-observed-adverse-effect levels, with respect to gastroenteritis, were evident for *Escherichia coli*, intestinal enterococci, somatic coliphages and *Clostridium perfringens*.

In these WHO *Guidelines on recreational water quality: volume 1 – coastal and fresh waters,* the marine water guideline values have again also been applied to fresh waters. This is based on a precautionary approach to fresh water, where effluent dilution and dispersal of untreated intermittent storm drainage is often constrained

after discharges to rivers and lakes. Further, WHO recommends intestinal enterococci only, rather than intestinal enterococci and/or *E. coli,* since no statistical relationship has been established for *E. coli* that can support a dose–response guideline value. Some jurisdictions, such as the European Union, use *E. coli* in fresh water with a 100 cfu/100 mL threshold of risk, based on findings of Wiedenmann et al. (2006). However, the study sites in Wiedenmann et al. (2006) are less characteristic of waters globally, and use of two FIOs can introduce avoidable complexity in analysis and interpretation of results at the operational level.

As further empirical epidemiological data become available, it may be possible to use *E. coli,* microbial source tracking markers and viral pathogens (Gitter et al., 2020; Schoen et al., 2020) or their indicators (e.g. phages), protozoa or helminths to assess health risk in recreational waters.

The current recommended approach defines a range of water quality categories for classifying individual locations. The use of multiple categories provides incentive for progressive improvement by achieving higher water quality standards that are more protective of public health.

Coastal water

The guideline values for microbial water quality given in Table 2.1 are derived from the key studies (Kay et al., 2004) corresponding to Recommendation 1.1. The guideline value threshold for no-observed-adverse-effect level or lowest-observed-adverse-effect level for gastrointestinal illness and acute febrile respiratory illness is 200 cfu/100 mL, corresponding to the upper range for Category B in Table 2.1.

Table 2.1
Guideline values for microbial quality of coastal and freshwater recreational waters

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

A–D: microbial water quality assessment categories (refer to section 4.3) used in the classification procedure; AFRI: acute febrile respiratory illness; GI: gastrointestinal; LOAEL: lowest-observed-adverse-effect level; NOAEL: no-observed-adverse-effect level.

The values are expressed in terms of the 95th percentile – that is, the value of intestinal enterococci per 100 mL below which 95% of environmental samples would be expected to occur. They represent readily understood levels of risk based on the exposure conditions of the key studies. The values may need to be adapted to take account of different local conditions and new epidemiological studies. They are recommended for use in the classification scheme for recreational water environments discussed in section 4.3.

Fresh water

Recommended guideline values for fresh water are the same as the values for marine water in Table 2.1. Gastrointestinal illness occurs at a higher rate in seawater swimmers than in freshwater swimmers at a given level of faecal indicator bacteria (WHO, 2009). This difference may be due to the more rapid die-off of indicator bacteria than pathogens (especially inactivation of viruses) in seawater compared with fresh water (WHO, 2009). This would result in more pathogens in seawater than in fresh water for the same culture-derived density of FIOs.

Application of the guideline values derived for seawater to fresh water from culturable FIOs would therefore be likely to result in a lower illness rate in freshwater users, providing a conservative (i.e. more protective) guideline in the absence of suitable epidemiological data for fresh waters. However, a number of national and international authorities have different standards for seawater and freshwater sites (e.g. European Union, since 2006), based on the randomized controlled trials of Wiedenmann et al. (2006) for recreational fresh waters.

Adaptation of guideline values to national and local circumstances

The guideline values in Table 4.1 were derived from studies involving healthy adult recreational water users swimming in sewage-affected marine waters in a temperate climate. They may not apply in tropical or brackish waters, or to children, the elderly or people who are immunocompromised, who may have lower immunity and might require a greater degree of protection. If there are significant water user groups in an area, or human excreta–borne pathogen conditions differ substantially from those in temperate waters, local authorities may need to adapt the guideline values.

Risks are also likely to be greater in areas with higher carriage rates or prevalence of diseases that could be transmitted through recreational water contact, and stricter standards may be judged appropriate by local authorities if they can also be followed up with appropriate management and control actions.
If a region is an international tourist area or only used for special events, the susceptibility of visiting populations to locally endemic disease (e.g. hepatitis A) and the risk that visitors might introduce unfamiliar pathogens to the resident population need to be considered. Special events where samples have been taken to make decisions are further discussed in section 4.3.3.

Because pathogens and FIOs are inactivated at different rates, any one FIO is, at best, only an approximate index of the efficacy of pathogen removal in water (Davies-Colley, Donnison & Speed, 2000; Sinton et al., 2002; Maraccini et al., 2016; Boehm, Graham & Jennings, 2018; Jennings et al., 2018; Nelson et al., 2018; Box 4.3). This suggests that factors influencing FIO die-off should be taken into consideration when applying the guideline values in Table 4.1, depending on local circumstances. This is particularly the case where sewage is disinfected before release because disinfection may markedly increase the pathogen to indicator ratio, as described by QMRA studies (Schoen, Soller & Ashbolt, 2011).

2.2   Public health surveillance

Recommendation 3: Conduct ongoing surveillance and risk communication of recreational water–related illness

Subrecommendations

3.1 Collect, analyse and interpret **health-related data** on suspected or confirmed illness in humans and/or animals, and systematically document outbreaks associated with recreational waters.

3.2 Provide the public with timely **information about the status of health risks**, and provide water users with advisory warnings before, during and after a public health incident, in conjunction with RWSPs.

Public health surveillance for recreational water bodies involves collecting, analysing and interpreting health-related data on suspected or confirmed illness in humans and/or animals associated with exposure to contaminants in recreational waters. High-quality health-related data may also inform revision and adaptation of health-based targets.

In addition to health-related data, public health surveillance includes producing summary reports about advisories and closings for beaches and waters subject to a national or regional programme for beach water quality monitoring and public notification. Risk communications are derived in combination with water quality monitoring and managed under an RWSP, as described in Chapter 3. Fig. 2.1 shows how public health surveillance activities link with elements of RWSPs.

Fig. 2.1
Public health surveillance and risk communication process for recreational waters
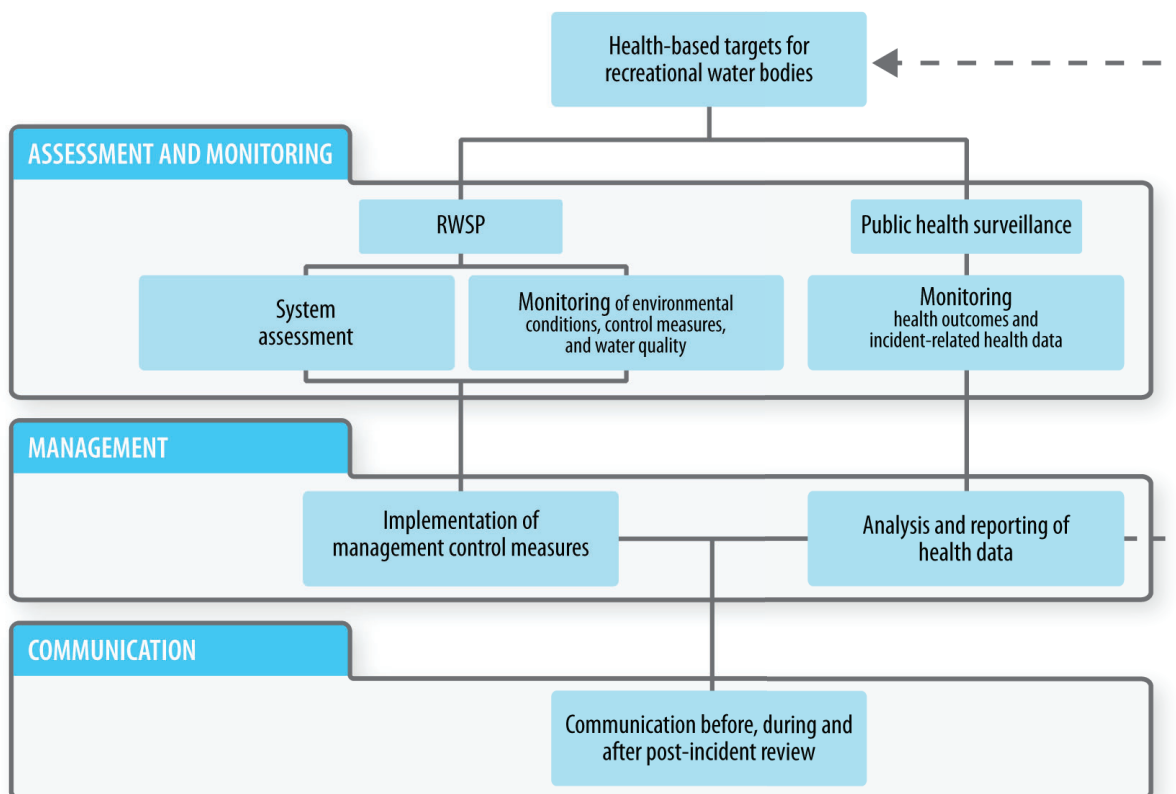
Depending on national systems, different organizations can have key roles and responsibilities for assessing water quality, collecting and managing public health information, and communicating risks. It is important that these organizations are identified and work together at national or regional levels (refer to section 1.3.2).

Public health and environmental authorities are usually the main responsible bodies for surveillance and risk communication. These can be at a mix of levels: national, regional or local government. They might include international or national sports bodies, or specific event managers. Nongovernmental organizations, local communities and citizen science programmes can also make useful contributions and provide engagement opportunities.

2.2.1 Health outcome surveillance

Systematic documentation of 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 waters. However, despite the valuable insights outbreak surveillance can provide, it is limited by the retrospective and voluntary nature of reporting. Counts of outbreaks and cases are likely to underestimate actual disease incidence, as a result of variations in public health capacity and reporting requirements. Outbreaks may often go unreported for mild cases of illness when the exposed population is geographically dispersed and when tourists leave the area, as is the case for recreational exposures at beaches and lakes. 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 etiology. For these reasons, large water sports events can be used as sentinel events to combine verification water quality monitoring under RWSPs and public health surveillance. However, sports event participants may not be representative of normal recreational water users.

Examples 2.1–2.3 provide examples of surveillance for illnesses resulting from recreational water exposure.

Example 2.1. Outbreak identification and incident response following an open-water swim event at Strathclyde Loch, Scotland

Following a competitive open-water swim event in July 2012, held at Strathclyde Loch near Glasgow, Scotland (a water sports venue that has hosted rowing, open-water swim, and national and international triathlon events), a large number of participants reported gastrointestinal illness. Of 71 swimmers, 60 were affected. Those affected reported illness next day to their medical services at various locations around the country (nine regions). Ten secondary cases were reported with onset dates 4–6 days later.

The illnesses were noted as arising from the same location by clustering and commonality, which were recognized within the national reporting system NHS24, part of the National Health Service (NHS). The NHS quickly informed the regional senior public health consultant, who took charge of the incident. This management control lasted for 8 weeks. The recreational water body was closed for water contact sports using the relevant legislation. The outbreak was subsequently described as having a severe attack rate (85%), and the etiology was confirmed as norovirus. (NHS, 2013)

In Scotland, any cluster or outbreak of gastrointestinal illness is investigated by the local NHS board and managed in line with national guidance on management of public health incidents. This involves convening a multi-agency incident management team. If the outbreak is linked to recreational water use, the management team includes the relevant Local Authority Environmental Health team and the Scottish Environment Protection Agency (SEPA).

An immediate consequence of the incident was that a planned 2013 British triathlon was cancelled. A future international event (2014 Commonwealth Games triathlon) went ahead as planned and was successful, but required costly control measures, interventions and pollution abatement.

The incident had some positive outcomes.
- An updated water management procedure was developed by the relevant authorities (the local authority owner, with input from the statutory public health consultant and environmental regulator), and a new daily water quality assessment (ongoing) was introduced using a rainfall trigger model.
- The 24-hour national surveillance system was effective in this case – a relationship cluster was identified, and the surveillance system worked.
- There was good cooperation and communication between the event organizer, the local authority, the site management and SEPA. Communication responses were shared.
- The health protection team responded before the start of the main summer holiday period (associated with greater recreational use of the facility).

Example 2.2. Leptospirosis – athlete participation in Eco-Challenge event, Malaysian Borneo

- Adventure travel is becoming more popular, and is the fastest growing segment of the leisure travel industry, with a growth rate of 10% per year since 1985 (Adventure Travel Society, pers. comm.). These activities may predispose participants to infection with unusual organisms through exposures to lakes, rivers, caves and canyons, as well as insect vectors. These illnesses may be unfamiliar to practitioners in the travellers' home countries, and symptoms may go unrecognized.

- Leptospirosis, a bacterial zoonotic infection, is more frequently found in tropical climates, and its variable early symptoms may be difficult to diagnose clinically.

- In the period 7–11 September 2000, the Idaho Department of Health, the Los Angeles County Department of Health Services and the GeoSentinel Network (an international surveillance network of travel clinics) notified the Centers for Disease Control and Prevention of at least 20 cases of febrile illness. The illness was characterized by the acute onset of high fever, chills, headache and myalgia; major laboratory test abnormalities and important pulmonary or central nervous system involvement were absent. All ill people had participated in the Eco-Challenge–Sabah 2000 multisport endurance race, held in Malaysian Borneo from 21 August to 1 September 2000; 304 athletes from 26 countries and 29 USA states competed in the 10-day endurance event. Segments of the event included jungle trekking, prolonged swimming and kayaking (in both fresh and ocean water), caving, climbing and mountain biking. Symptoms and exposure history, as well as initial laboratory testing, suggested that the illness was leptospirosis.

- Athletes were investigated to determine illness etiology and implement public health measures (Sejvar et al., 2003). Of 304 athletes, 189 were contacted. Eighty (42%) athletes met the case definition. Twenty-nine (36%) case patients were hospitalized; none died. It was concluded that improved efforts are needed to inform adventure travel participants of unique infections such as leptospirosis associated with water exposure.

- Self-reporting of health issues following exposure to pathogens in recreational waters can sometimes be quite specific. It can have obvious additional uses in providing increased data and information that could be used by responsible agencies and academics for risk management.

Example 2.3. Swimmer's itch and sea lice

Cercarial dermatitis, colloquially known as swimmer's itch, is a rash contracted in natural fresh water bodies, when people are exposed to skin-penetrating, larval flatworm parasites of the family Schistosomatidae, which emerge from aquatic snails. Swimmer's itch is a globally distributed allergic condition. Very little is known about local dynamics of transmission (refer to Chapter 6 for further detail).

More than 3800 cases of swimmer's itch were captured across Canada by a self-reporting surveillance system (Gordy, Cobb & Hanington, 2018). Swimmer's itch cases were reported from every province except Prince Edward Island. Species surveys in Alberta revealed seven new parasite and host records, with the potential for swimmer's itch to occur throughout most of the province based on host distributions. A review and comparison with the literature highlighted several knowledge gaps surrounding schistosome species, host species, and their distributions and contributions towards swimmer's itch.

In marine waters, seabather's eruption (also known as sea lice) is a similar condition with a different cause. Seabather's eruption is usually a benign syndrome that normally resolves without intervention, although severe symptoms can occur that are treated with antihistamines and steroids. Research suggests the larvae of a jellyfish, Linuche unguiculata, as the cause of outbreaks when jellyfish larvae are transported to shore by ocean currents (Tomchik et al., 1993).

2.2.2 Public health risk communication

Information for the public on the safety of recreational water bodies comprises:
- information on the general classification of recreational water locations (refer to section 4.4); and
- short-term information that reflects day-to-day conditions (e.g. on-the-day warnings and advisories generated using predictive models; refer to section 4.2.3).

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

Some locations have consistently poor water quality due to the proximity of human excreta discharges or other local hazards such as agricultural runoff. In these cases, appropriate communication will include long-term measures to discourage recreational use of the site, such as fencing; signposting; or moving the location of car parks, bus stops and toilets until pollution sources have been remediated.

Public health authorities should participate in risk communication before, during and after incidents according to the roles defined in the RWSP (refer to section 3.4). In addition, public health authorities are advised to verify the data underlying risk communication messages and test communication approaches with users to maximize user understanding and adherence to behaviour change measures and messages.

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3 Recreational water safety planning

Recommendation 2: Develop and implement recreational water safety plans (RWSPs) for priority bathing sites

Subrecommendations (also refer to Box 3.4 checklist for developing RWSPs)

2.1 Identify the lead entity and **assemble a team to develop the RWSP.**
- Identify the lead entity and key stakeholders, and form a coordination committee that includes relevant stakeholder representatives with clear roles and responsibilities.

2.2 Undertake a **system assessment** for each existing priority recreational water site (or group of sites within the same catchment) and before developing new sites.
- Describe the recreational water environment – by combining a sanitary survey of adjacent land and water drainage with an initial microbial quality assessment to assign a beach classifications (refer to sections 4.1–4.3).
- Identify hazards and hazardous events, considering seasonality and predicted local climate change scenarios.
- Assess and prioritize the risks.
- Identify existing control measures, assess risks and prioritize risks that are insufficiently controlled.
- Establish plans, with sustainable funding, for managing currently effective control measures.
- Establish improvement plans, with sustainable funding, for incrementally implementing control measures where priority risks are insufficiently controlled.

2.3 Conduct and maintain **system monitoring.**
- Establish and implement an operational monitoring regime for priority control measures in the catchment to give rapid warning when operational limits are exceeded.
- Establish and implement corrective actions for exceedances of operational limits.
- Conduct ongoing verification monitoring of water quality.
- Establish procedures to verify effectiveness of the RWSP.

2.4 Establish coordinated **management and communication** strategies to support effective pollution control and public communications.
- Document management procedures for normal and incident conditions, including incident response plans.
- Where feasible, develop predictive models to support timely communication to water users.
- Develop supporting programmes – for example, training, research and development, standard operating procedures, quality control activities, procedures for visual inspections, sample collection and equipment calibration.
- Establish communication protocols between responsible organizations and agencies.
- Establish mechanisms for communication with users and managers of the site.

2.5 **Review and update** RWSPs.
- Meet periodically and after incidents to review performance of plans, including operational monitoring and water quality results, an updated sanitary survey and beach classification, the occurrence of incidents, communication and complaints; if necessary, update the risk assessment.

Recreational water safety plans (RWSPs) provide a holistic and practical approach to assessing and managing risks associated with recreational uses of water. The design and functions of RWSPs are guided by health-based targets and effectiveness, assessed using ongoing surveillance (refer to Chapter 2).

The use of RWSPs is consistent with the harmonized Stockholm framework for risk assessment and management adopted by the World Health Organization for the water and sanitation sector (Bartram, Fewtrell & Stenström, 2001). This framework drew from experiences in product safety and quality assurance (Deere & Davison, 1998, 1999), and has been adapted for recreational waters (Ashbolt & Bruno, 2003).

RWSPs organize, collect and structure information about recreational water sites, to support sound and practical management of recreational activities. They focus on understanding water environments and users – including hazardous sources and events potentially causing water pollution, potential risks to public health, and sensible management approaches and surveillance. They also lead to improved documentation.

RWSPs provide clear direction to those responsible for managing recreational water bodies; this is particularly important when multiple agencies are involved. Importantly, RWSPs provide an organized approach to minimize the chance of failure through oversight or lapse of management. They include contingency plans to respond to system failures or unforeseen events that may affect water safety, such as heavy rainfall or flood events. RWSPs are an ongoing and iterative process, since the conditions that affect a site are dynamic.

Existence and implementation of RWSPs should provide public confidence that recreational water bodies are being managed appropriately.

A checklist for developing an RWSP is in Box 3.4 at the end of this chapter.

3.1 RWSP structure and development

RSWPs comprise three elements: system assessment, monitoring, and management and communication. These components incorporate a number of activities (Table 3.1).

Table 3.1
Components of recreational water safety planning

Component	Activity
Preliminary	• Identify the lead entity and assemble the RWSP team.
System assessment	• Describe the recreational water environment (using a sanitary survey, and historical water quality results or classification). • Identify hazards and hazardous events (e.g. untreated or partially treated wastewater contamination, epidemiological data). • Assess the risks. • Identify existing control measures (e.g. offshore wastewater outfalls). • Identify risks that are insufficiently controlled. • Prioritize uncontrolled risks.

Monitoring	• Define operational monitoring.
	  – Establish a monitoring regime to give rapid warning when operational limits are exceeded.
	  – Where possible, establish corrective actions for exceedances of operational limits.
	• Identify verification monitoring.
	• Establish procedures to verify effectiveness of the RWSP.

Management and communication	• Document management procedures for normal and incident conditions. • Develop supporting programmes. • Establish communication protocols between responsible organizations and agencies, and mechanisms for communication with users of the site.

The lead entity will coordinate development, implementation and maintenance of the RWSP. Lead entities might be recreational water facility operators/service providers, or national, regional or local health authorities. In some jurisdictions, environmental protection agencies take a lead role in monitoring and managing recreational water safety. It is important to designate a point of contact (such as a recreational site manager) for driving development of the RWSP, and ensuring that essential management and operational tasks are performed in accordance with the RWSP. The site manager will typically be a representative of the lead entity.

The lead entity should assemble the RWSP team, which will steer the overall process. This team should represent all stakeholders – for example, representatives of public health agencies, environmental protection agencies, local public health professionals, land-care and water resource management agencies, local authorities, local communities (including volunteer groups), recreational water user groups, the local tourism industry, anti-litter groups, the local water and sewerage industry, agriculture and industry, other stakeholders such as dam managers, and aquaculture facilities. It should include experts in hazard and risk analysis. The roles and responsibilities of each of these stakeholders, in the context of recreational water area management, should be identified.

Collectively, the interdisciplinary, multisector team should have a thorough understanding of the recreational water area and include necessary levels of technical expertise (e.g. in microbiology, biology, chemistry, hydrology, hydrogeology, catchment management, natural resource management). Experts could be consulted on specific aspects (e.g. harmful algal blooms [HABs], toxicology). Members of the team should be included or consulted in future reviews of established RWSPs. The team should be formally joined (e.g. through a letter of intent) since the team will need to share all or parts of the RWSP steps.

Example 3.1 presents a case study illustrating a successful multi-agency approach to managing recreational water quality. The case study illustrates the importance of active communication with water users and the general public.

Example 3.1. Case study on multi-stakeholder management

The Fylde coast in north-west England used to have poor-quality beaches. In 2012, faced with the realization that stricter water quality regulations (EU, 2006) were likely to lead to more than 50% of the region's bathing waters being classed as "poor", the Turning Tides partnership was formed to tackle water quality issues and to create bathing waters that the region could be proud of, are valued by communities and support a vibrant economy.

Components identified as causing poor water quality included sewage treatment plants, combined sewer overflows, poorly functioning private on-site systems such as septic tanks, misconnections, urban runoff, agriculture, birds and dogs. The partnership brought together a multi-stakeholder group that included six local authorities, directors of public health, the regional water and sewerage company (United Utilities), the environmental regulator (Environment Agency), an agricultural organization (National Farmers Union) and an environmental charity (Keep Britain Tidy). The partnership is jointly funded by the Environment Agency and United Utilities, and is operated through Keep Britain Tidy.

Actions taken include:
• meetings of senior stakeholders (three times per year);
• development of an overall action plan;
• development of action plans for each designated bathing water site;
• recruitment of a dedicated Campaign and Communication Manager to drive the work of the partnership, and to ensure that actions and work programmes were delivered;
• investment to improve existing assets and create new ones;
• outward-facing communications to stakeholders and the public; and
• development of a public engagement campaign – LOVEmyBEACH – which aims to change people's behaviour through targeted campaigns on nonflushable wastes, dog fouling, private sewerage works and plastic litter.

By 2016, the region had reached 100% compliance, and the north-west coast is the cleanest and safest it has been in decades. The area is also certified with the Blue Flag system, which independently verifies that the beach meets its standards. With these large improvements, the partnership had to decide whether to conclude its work or work towards even better water quality, as well as ensuring that local communities and visitors achieve maximum benefit from the improvements. Although water quality remains at the heart of the work of the partnership, unlocking these community benefits is now also a focus. The group is actively highlighting the possibilities and providing opportunities for better physical health and well-being from beach use in the area.

Source: EU (2006).

3.2   System assessment

The aims of system assessment are to:
- describe the recreational water environment
- identify hazards, and events likely to introduce hazards (i.e. hazardous events, as defined in Box 3.2)
- assess the public health risks
- identify existing control measures
- identify risks that are insufficiently controlled
- prioritize insufficiently controlled risks.

Where a number of similar recreational waters occur in a defined geographical area (e.g. separate beaches on an extended coastline, separate recreational sites on a river), a common risk assessment process might be possible.

Box 3.2. Hazard and risk definitions

- 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 or increased presence of a hazard (i.e. what can happen and how).
- Risk is the likelihood of identified hazards causing harm in exposed populations (including subgroups such as young children and vulnerable populations) in a specified time frame, including the magnitude of the harm.

3.2.1   Description of recreational water environments

The description of recreational water environments should incorporate all parts of the recreational water body, including adjacent land and water environments (drainage catchments), that can be sources of hazards. It is important to take a realistic and practical approach to identifying potential sources of hazards. For example, in long river systems, dilution and attenuation can minimize the downstream impacts of hazards.

A sanitary survey or inspection is the best way to describe the environment. The survey should aim to identify:
- the physical characteristics of the site (e.g. type of water body and beach or shoreline, water flows, tidal action, depth of water);
- existing and planned recreational activities (e.g. swimming, surfing, fishing, use by motorized vessels, access by pet dogs and horses); and
- all sources of microbial, chemical and physical hazards, including sources of nutrients leading to increased risks of cyanobacterial blooms.

Information may have already been collected through informal or formal sanitary surveys and inspections. Available information, including maps and reports, should be collected on land use, wastewater treatment plants and discharge points, areas served (and not served) by sewerage systems, areas served by septic systems/latrines, stormwater pipes and overflows, runoff, riverine flows and discharges, estuarine environments, locations of marinas and other berthing sites, ports, and locations of industrial and agricultural activities. Physical, meteorological and geographical data from previous surveys should be confirmed by field visits and should be used to map the area of influence on recreational sites.

Historical water quality information may also be available, such as:
- data on the occurrence of organisms such as enterococci, *Escherichia coli,* cyanobacteria and other potentially harmful algal blooms or pathogenic microbes;
- data on nutrients, temperature, turbidity, pH and chemical quality;
- previous observations of visible algal blooms and reports of health impacts associated with recreational water use;

- results from investigations (e.g. of the impacts of heavy rainfall or other events on microbiological quality); the outcomes of such investigations should be assessed to determine whether they provide a basis for predictive models (see section 3.4.2); and
- faecal source tracking marker results, where available.

The quality and reliability of historical data should be assessed – for example, whether testing was undertaken in an accredited laboratory.

Historical and contemporary sanitary surveys should be combined to produce a comprehensive description of the recreational water environment (see Table 3.1).

Table 3.2
Types of information identified by sanitary surveys

Characteristic	Detail
Physical characteristics of the immediate site	• Type of water body (e.g. sea, ocean, estuary, natural or constructed lake, dam, river) • 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 catchments • 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 • Presence of homeless populations • Markets, festivals, temporary events
Recreational activities	• Types of activity and extent of exposure (e.g. swimming, fishing, surfing, windsurfing, rowing, triathlons, kayaking, sailing, waterskiing, paddle boarding) • Local use of motorized vessels (e.g. boats, jet skis) • Numbers of people, including densities of water users, with seasonal and weekday/weekend variations and population variation of users (e.g. local vs incoming tourists and event users) • Distribution of activities (e.g. greater activity from rock ledges/outcrops) • Duration of the recreational water use season
Local sources of animal waste	• Access of dogs, horses, wild animals, and grazing animals such as sheep and cattle to recreational waters, beaches and foreshores • Presence of significant bird populations or breeding colonies • Aquaculture activities
Agricultural impacts	• Runoff from agricultural land with animal grazing or use of manures • Runoff containing fertilizers and pesticides • Erosion or animal access to shorelines creating flow paths for runoff
Wastewater outfalls, combined sewer overflows and municipal stormwater discharges	• Type of sewage treatment, and nutrient concentrations in discharge • Volumes, periods of flow and turbidities (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) • Histories 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 motorized vessels (e.g. boats, jet skis)

Table 3.2 continued

Characteristic	Detail
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 landfills 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 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
Fish cleaning and cutting	• 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 • Programmes for litter or solid waste disposal
Legislative requirements	• Nature of the legislation (e.g. general public health regulations, specific recreational water regulations) • Recreational water quality standards and health advisory levels • Responsible agencies

Fig. 3.1 illustrates the principal inputs into recreational water bodies that should be included in a sanitary inspection form.
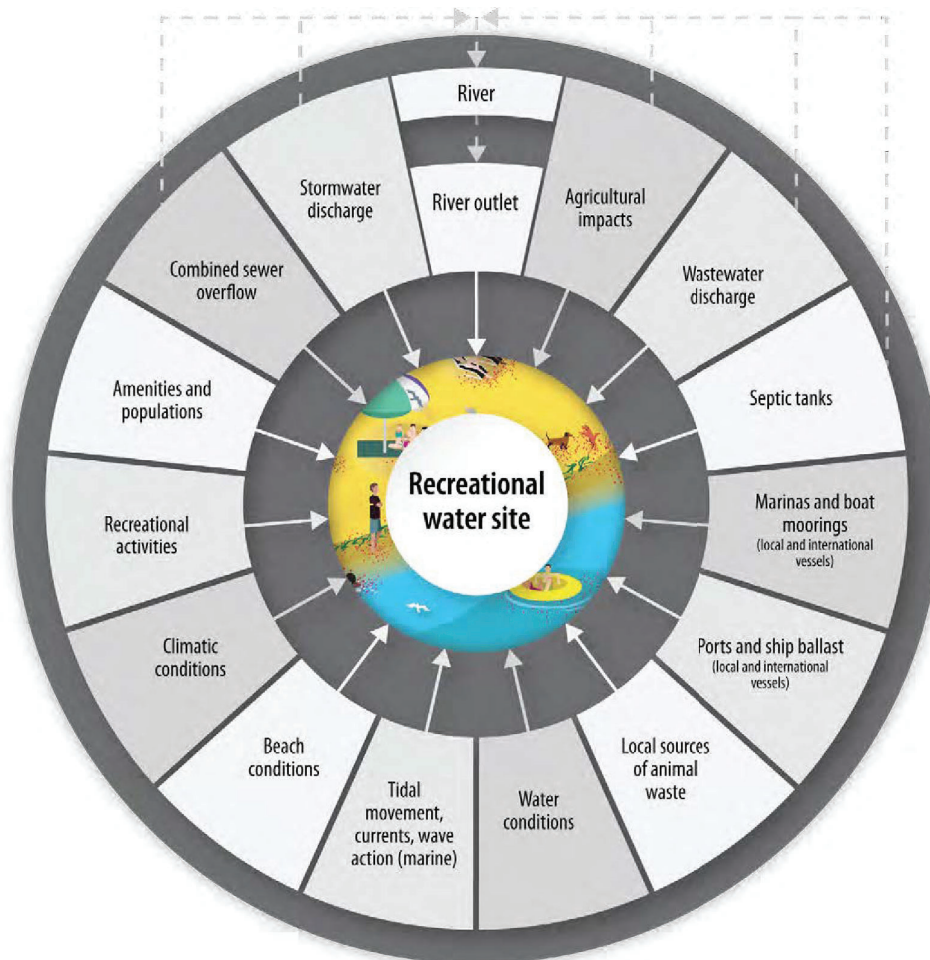
3.2.2 Hazard identification

Relevant historical events, including incidents and emergencies, and any available epidemiological health data (e.g. recurrent dermatitis in people associated with recreational water use) should be considered as part of the process of identifying hazards and hazardous events that might affect recreational water bodies. The frequency, extent and likelihood of exposure are important inputs to risk assessment. For example, a study conducted in a temperate climate reported that the average frequency of exposure to recreational waters for both children and adults was 7–8 events per year (Schets, Schijven & de Roda Husman, 2011). In warmer climates, frequencies are expected to be higher; an Australian upper estimate of 150 events per year seems reasonable (NHMRC, 2019). Future events, such as the potential impacts of climate change (e.g. increased magnitude and frequency of storms and droughts), should also be considered.

Faecal microbial hazards

The most common hazards in recreational waters are microbial pathogens introduced by faecal contamination from humans and animals. Sources of faecal contamination can include:
- discharges from wastewater treatment plants, disposal of faecal sludge from trucks, sewer breaks and overflows, septic tank overflows to near-shore groundwater or open drains, and urban stormwater including overflows;
- feacal waste disposal from boats – boats from outside the local area may introduce new pathogens (e.g. cholera);

- excreta from livestock animals, birds and dogs at the water use site or transported by runoff;
- direct contamination from recreational water users, which is particularly hazardous at high densities of users; and
- local beach toilet facilities.

Depending on the type of recreational water, information that may be useful for assessing the impact of discharges includes:
- strength and volumes of river flows, tides, currents and wave action, which can all influence dilution and dispersion;
- rainfall (duration and quantity);
- wind (speed and direction); and
- coastal physiography.

The risk of faecal contamination should be determined by combining the outcomes of sanitary surveys with assessments of microbiological quality through measurements of faecal indicator organisms (refer to Chapter 4).

Harmful algal blooms

HABs can be formed by prokaryotic cyanobacteria, and eukaryotic diatoms and dinoflagellates (refer to Chapter 5). Each of these includes marine and freshwater species. Only cyanobacteria are known to cause public health impacts in fresh water.

Relevant physical features and water quality characteristics that can influence the likelihood, extent and location of HABs include:
- the nature and depth of a water body (e.g. river, lake, reservoir);
- water flows and retention times, including seasonal variations;
- potential thermal stratification;
- water temperature;
- turbidity/clarity; and
- nutrient concentrations, activities and inputs (e.g. sewage discharges and septic tank effluent, agriculture, riverine discharges) that can cause nutrient loading.

Historical data and reports could include data on occurrence of HABs, satellite or aerial images, reports of previous blooms and scums, and reports of impacts on humans or animals.

Other microbial hazards

Other microorganisms of potential health concern (refer to Chapter 6) may be naturally occurring (e.g. noncholera *Vibrio* species, *Naegleria fowleri*) or introduced by sources other than faecal contamination (e.g. Leptospira from rodent urine, *Staphylococcus aureus* from body shedding by recreational water users, schistosomes from a bird host). Some naturally occurring pathogens are ubiquitous and will be present in most waters (e.g. *Pseudomonas aeruginosa*) but at low or nonpathogenic levels. The likelihood of these being present will be influenced by local risk factors (e.g. temperature).

Disease surveillance may provide indications of the potential presence of these nonfaecal pathogens in recreational waters.

Beach sand

Microorganisms can be introduced to beach sand (refer to Chapter 7) through shedding by recreational water users, animals, stormwater and other types of contaminated water runoff. Inadequate disposal of litter or solid waste can also contribute to microbial contamination of beach sands.

Factors that can influence persistence and growth include discharges of wastewater, riverine discharges containing wastewater, stormwater, runoff from agricultural land, animals (including birds), lack of toilet facilities and the long-term presence of homeless populations.

Persistent beach wrack and seaweed may promote survival or growth of microorganisms in sand. Physical and geomorphological factors may also influence survival and dispersion of microbial pathogens in sand. These include wave and tidal action, and mineralogy (e.g. fine sand versus gravel beaches).

Chemical hazards

Some water bodies, such as quarries and abandoned mining pits, may contain permanently high concentrations of the mineral that was being extracted or chemicals used in extraction processes. These water bodies can have very high pH (>10) or very low pH (<3), depending on the nature of the mine or quarry.

In other water bodies, the most likely sources of chemical hazards (other than cyanobacterial toxins) are untreated or treated industrial discharges and spills or accidental discharges. These are more likely in recreational waters adjacent to industrial areas. Historical discharges onto land or into groundwater may also be a potential source of persistent chemical hazards. Contamination by fuels and oils may occur where motorized craft are used extensively (refer to Chapter 8 for more detail).

Chemical pollution episodes may be due to runoff phenomena (pesticides, chemicals, fertilizers), oil spills, illegal dumping of pesticides or solid wastes, movements of sediments caused by management of dams, or industrial incidents.

3.2.3 Risk assessment

The aim of assessing risks is to identify the likelihood and magnitude of occurrence of the hazard or hazardous events, and the severity of consequences from exposure to the hazard. The potential impacts on public health are the most important consideration, but impacts on aesthetic quality of recreational waters are also important. The aim is to identify the most significant risks so that priorities can be established for management by RWSPs.
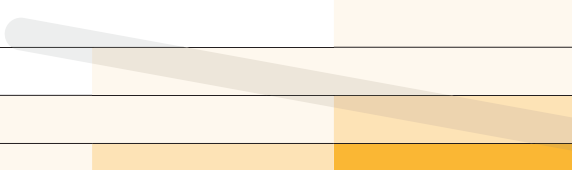
Events that are commonly identified as being significant include:
- sewage spills from burst mains or major pump station overflows;
- failure of sewage treatment plants, leading to discharge of large volumes of untreated or poorly treated sewage;
- diffuse pollution from agricultural runoff and on-site sanitation systems, such as near-shore septic tanks
- major storm events, leading to discharge of large volumes of poor-quality water and debris; and
- substantial HABs.

Typically, a matrix of the type shown in Table 3.3 is used to identify and prioritize significant risks. Significant risks are likely to vary between different recreational water areas.

Table 3.3
Simple matrix for ranking risks

Likelihood	Severity or consequence			
	Insignificant	Minor	Moderate	Major
Rare (or very low)	Low			
Unlikely (or low)				
Likely (or moderate)				
Almost certain (or high)				High

3.2.4 Control measures

Reliable risk management strategies should be implemented, and these form the core of the RWSP (Deere et al., 2001). Existing control measures that deal with significant hazards and hazardous events should be identified, and their effectiveness determined. If improvement is required, additional controls should be identified and documented in an improvement plan. Priorities for implementation of controls should be determined by the significance of inadequately controlled risks.

Control measures should be validated to ensure that they achieve the targeted risk reduction. Validation can use existing data and information – for example, from other recreational water managers with experience in applying a particular control measure.

Table 3.4 provides examples of control measures and associated operational monitoring (discussed in section 3.3). Some control measures, and associated operational procedures and operational monitoring will be the responsibility of partner agencies (e.g. wastewater treatment plants). Monitoring through observation of recreational areas (e.g. beach cleanliness, presence of visible algal blooms) is likely to be the responsibility of recreational area managers.

In some circumstances, behavioural control measures can be applied – for example, advising users that a recreational water body is closed for use for 2–3 days after storm events.

These control measures need to be supported by good communication and education of recreational water users about applying the measures.

Table 3.4
Examples of control measures and related operational monitoring

Hazards	Control measure	Operational monitoring
Human faecal waste	Treat human excreta in centralized treatment plants or well-functioning on-site sanitation systems, such as septic tanks with faecal sludge management services.	Monitor treatment processes (e.g. biochemical oxygen demand, suspended solids in treated wastewater, disinfectant residuals/doses). Conduct household sanitary inspection of septic tanks and audit performance of faecal sludge services.
	Minimize sewage overflows during storm events (e.g. by phasing out combined sewer overflows, and finding and remedying household stormwater connections to sewer).	Monitor flows in sewer mains (e.g. through pump stations) and overflows via event duration monitors. Monitor stormwater connections to sewers through inspection programmes.
	Regulate on-site treatment (septic systems) and associated maintenance programmes. Apply buffer zones from water body shorelines.	Audit performance of regulated maintenance programmes.
	Introduce response protocols to minimize impacts of sewage overflows on recreational areas.	Monitor compliance with established protocols.
	Apply land-based use of treated sewage, sludge and stormwater to reduce discharges.	Monitor volumes used and discharged.
	Provide toilet facilities at recreation water use sites to reduce risk of open defecation.	Monitor the need for maintenance of toilet facilities.
	Consider limits on visitor numbers or recreational water user density to reduce the risk of person-to-person transmission and pathogen inputs due to shedding from users.	Monitor levels and nature of use of the site, and user behaviour using methods such as on-site visual observations, electronic camera surveillance and vehicle counters.
	Install (or lengthen) offshore discharges to reduce impacts of sewage discharges.	Undertake routine integrity checks of discharge pipelines.

Table 3.4 continued

Hazards	Control measure	Operational monitoring
Animal faecal waste (farm livestock)	Restrict access of animals to recreational water bodies, and rivers that discharge into recreational water bodies (e.g. fencing, riparian zones).	Undertake routine inspections of integrity of riparian zones and fences.
	Control stocking densities.	Monitor stocking rates.
	Minimize runoff from agricultural land.	Undertake routine inspections.
Animal faecal waste (horses and dogs on beach or foreshore)	Restrict access.	Monitor access.
Animal faecal waste (e.g. rodents, feral birds, seagulls)	Introduce solid waste collection and removal process.	Monitor cleanliness of the beach/shoreline and size of bird populations.
Agricultural manures, chemicals, fertilizers, pesticides	Apply good management practices to minimize overuse of chemicals and mitigate flows to recreational water body.	Monitor application of good management practices.
Litter and debris	Install interception schemes on stormwater drains.	Monitor collection of debris and cleanliness of recreational water area.
Industrial chemicals	Regulate industrial discharges (apply effective trade waste controls).	Monitor control of discharges, including treatment applied to discharges.
	Remediate historically contaminated sites (e.g. remove or stabilize contaminated soils, remove old heaps and tailings).	Monitor soil and underlying groundwater.
Harmful algal blooms (cyanobacteria)	Reduce nitrogen and phosphorus inputs by implementing sufficient removal in wastewater treatment and/or controlling runoff from agricultural land.	Monitor nitrogen and phosphorus in treated wastewater. Monitor application of good management practices in use of fertilizers and runoff from agricultural land.
	Induce artificial mixing in lakes and impoundments.	Monitor operation of mixing device. Monitor temperature and dissolved oxygen profiles.
	Maintain sufficient flows in rivers.	Monitor flows.
	Reduce detention times in lakes and impoundments.	Monitor flows through the water body.

3.3 Monitoring

The focus of recreational water safety management should be on common sense and practical preventive measures, rather than on testing of water quality. Monitoring (e.g. observational measures and water quality testing) has a place, but only to support sound management practices. Development and application of RWSPs reduces reliance on water quality testing.

There are three types and purposes of monitoring in the context of recreational waters:
- initial microbial water quality assessment to establish the characteristics of the recreational water body and support risk classifications (refer to section 3.3.1);
- operational monitoring of control measures to give timely warning of exceedances beyond normal conditions (ongoing short-term assessment; refer to section 3.3.2); and
- verification to determine whether RWSPs are functioning correctly to support designated recreational activities (longer-term assessment; refer to section 3.3.3).

It is essential that monitoring is carefully planned with specific aims and, before samples are collected, a clear awareness of potential responses to the results. Those responsible for interpreting the results should understand both the intent and the meaning of results.

Effective monitoring relies on establishing the following.
- Who is responsible for monitoring?
- What parameters will be monitored?
- How will monitoring be performed?
- When will monitoring take place (timing and frequency)?
- Where will monitoring be performed (locations)?
- Who will do the analysis (with consideration of quality assurance/quality control and accreditation or certification)?
- Who will receive, assess and store the monitoring data?
- How will data be reported?

Planning of monitoring programmes should take account of:
- socioeconomic, laboratory and institutional capacities and capabilities
  - those involved in collecting samples and assessing results need to be appropriately trained;
  - wherever possible, laboratories accredited to undertake specified testing should be used; if accredited laboratories are not available, evidence of quality assurance/quality control programmes should be established;
  - wherever possible, sample collection should also be accredited, or comply with international standards for sampling;
- staff capacity available;
- equipment and material availability;
- transport and safety requirements; and
- regulatory requirements.

Guidance on designing monitoring programmes is available from Welker et al. (TCiW 2021) and Bartram & Rees (2000). General requirements for sampling, preservation, handling, transport and storage of water samples, as well as quality assurance/quality control, can be found in the international standards ISO 5667[1] (parts 1, 3, 4, 6, 9 and 14) and ISO 19458[2] for microbiological analysis.

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[1] Water quality – Sampling.

[2] Water quality – Sampling for microbiological analysis.

3.3.1 Initial microbial water quality assessment

Recreational water bodies are characterized and classified to determine their suitability for recreational use, based on susceptibility to faecal contamination, development of HABs and proliferation of specific free-living microbial pathogens.

Initial microbial water quality assessment is the way to gain knowledge of recreational water quality, including its trends and variations, as a pillar for careful selection of methods for protection of the recreational water body or area. A good understanding of contamination sources and pathways (i.e. an assessment of the vulnerability of the water body) is essential to prevent and control water quality deterioration due to weather events, human activity, accidental discharges or other events. Short-term changes are of particular importance to the microbial quality of source water, and monitoring plans for microbiological indicators need to be appropriate to track and understand the origins of faecal contamination of recreational water.

Water quality data will sometimes be available for established recreational water bodies, allowing initial classifications to be made. In other cases, water quality data may be incomplete or not available. In addition, residential developments or construction of tourist facilities can increase accessibility to previously unused recreational water bodies. Where data are not available, monitoring will be needed for an initial or provisional classification. This might include monitoring for:
- *E. coli* or intestinal enterococci, for microbial classification based on faecal pollution (refer to Chapter 4);
- temperature and dissolved oxygen profiles in lakes, to assess the potential for stratification;
- nutrients such as nitrogen and phosphorus;
- turbidity;
- pH; and
- water flows and detention times, as indicators of the potential for a water body to support growth of HABs.

Initial microbial water quality assessment may include testing to measure the impact of predictable events such as storms or heavy rainfall that can cause short-term deterioration in water quality, leading to conditional classifications (e.g. good for recreational use except for 2–3 days after rain).

3.3.2 Operational monitoring

Operational monitoring involves observation, and simple and rapid water tests or laboratory analytical measurements to assess whether control measures are functioning effectively on an ongoing basis.

Operational monitoring typically focuses on simple observations, such as:
- observing cleanliness of recreational waters following rain events;
- inspecting fences designed to keep livestock away from watercourses;
- monitoring sewage treatment processes, flow rates, and frequency and duration of sewer overflows;
- collecting grab samples and using field kits for parameters that are simple to measure in situ (e.g. salinity/conductivity, turbidity, pH, temperature, dissolved oxygen);
- undertaking automated testing for some parameters (e.g. rainfall, water flow rates and turbidities in stormwater channels or rivers) – this monitoring may be undertaken for other purposes such as water quality prediction (e.g. by water resource and environment agencies);
- observing cleanliness of beaches and shorelines to assess performance of solid waste removal programmes; and
- assessing compliance with behavioural control measures, such as following advice to avoid use of recreational areas during certain periods (e.g. for 2–3 days after storm events).

Further examples are included in Table 3.4 in section 3.2.4.

If resources are available, online water quality monitoring could be considered for parameters such as turbidity, chlorophyll, total organic carbon and dissolved organic carbon, and total suspended solids. A water spectral

fingerprint would give an indication of water quality change that might affect faecal indicator organisms used to manage recreational waters. If resources, data or monitoring capacity are limited, recreational water managers could consider using citizen volunteers to conduct visual inspections and take photos (e.g. for appearance of HABs), in addition to departmental or agency staff.

Operational monitoring should separate acceptable from unacceptable performance based on meeting predefined and documented operational limits and targets. Where possible, timely and effective corrective actions should be taken in response to exceedances – for example, implementing solid waste removal if beach cleanliness is unsatisfactory. It is important to identify how the return to acceptable performance will be determined following remedial actions.

Where corrective actions cannot be applied rapidly enough (e.g. following sewage overflows during storm events or in the event of HABs), recreational areas may need to be temporarily closed.

3.3.3   Verification

The most common form of verification is measurement of concentrations of intestinal enterococci and/or *E. coli* per 100 mL, as indicators of faecal contamination, to confirm that the RWSP is operating effectively and that faecal pollution classifications for recreational water bodies are stable or improving (refer to Chapter 4). Water prone to development of HABs should be monitored for HABs (refer to Chapter 5).

Where chemical quality is questionable (refer to Chapter 8), targeted monitoring can be included in verification. Linking water quality verification to surveillance of public health outcomes can be challenging because mild cases of illness often go unreported and the exposed population may be geographically dispersed (e.g. tourists). For this reason, large water sports events can be used as sentinel events to combine verification water quality monitoring under RWSPs and public health surveillance (refer to Chapter 2). However, sports event participants may not be representative of normal recreational water users.

Procedures should be established to audit that RWSPs are being implemented as intended and are working effectively.

3.4   Management and communication

Most management procedures described in RWSPs will relate to activities and functions that are undertaken during normal operating conditions. However, it is important that RWSPs also describe procedures and actions that will be implemented to respond to incidents (defined as a loss of control) and emergencies when recreational water quality is either under threat (e.g. initial observations of a cyanobacterial bloom at vigilance levels; refer to Chapter 5) or compromised (e.g. cyanobacterial bloom triggering Alert Level 2).

Because management of recreational water environments will typically involve multiple agencies and organizations, it is essential that roles, accountabilities and responsibilities are identified in RWSPs. Effective protocols should also be established for communication with the media and direct communications with the public (e.g. via signs and mobile phone applications). This is particularly important during incidents.

Management procedures undertaken when recreational water bodies are operating under normal conditions or during incidents should be documented and shared with all stakeholders and personnel involved in managing recreational water bodies.

3.4.1 Incident response plans

A range of predictable incidents will usually be identified during hazard identification and risk assessment. These predictable scenarios should be dealt with in an incident response plan (IRP). Examples of predictable incidents are:

- poor performance of treatment processes at a wastewater treatment plant, leading to discharge of inadequately treated water into a recreational water body;
- spills due to sewerage system bursts;
- large flows of stormwater associated with storm events, even when they are quite far from the recreational water area;
- onshore or offshore chemical spills; and
- occurrence of HABs.

In some IRPs, exceedance of an initial target or limit can provide an early warning signal that requires further investigations. A procedure for dealing with unpredictable incidents should also be developed. IRPs outline the procedures and provide the tools needed for effective responses and the protection of public health during contamination events and in response to reports or outbreaks of illness. Individual events can require tailored responses. These can be influenced by the type of hazard or hazardous event, the nature of the recreational water environment, available resources and the interaction with partner agencies.

The key aims of effective IRPs are:

- preparedness;
- clarity of purpose;
- coordinated actions;
- implementation of rapid and effective responses; and
- timely and clear communication among agencies and with recreational water users (refer to section 3.4.4).

Attempting to develop incident responses with no preparation can add confusion and exacerbate or prolong incidents. Suggested content of IRPs is summarized in Box 3.3.

Box 3.3. Content of incident response plans

- Protocols for dealing with reasonably predictable incidents and unforeseen events.
- Identification of a water incident coordinator and mechanisms for establishing incident management teams (membership could vary depending on the type of incident).
- Descriptions of incident conditions and criteria for measurable indicators/parameters that would trigger responses, such as additional sampling, issuing of warnings or closing of areas – for example:
  – heavy rainfall (amount of rain, upper limits on river flows);
  – sewage or sludge spills, or failures in wastewater treatment (e.g. enterococci/*E. coli* counts); and
  – HABs (visible blooms including red tides and scums, cyanobacterial biovolumes, toxin concentrations).
- Accountabilities of, and contact details for, key personnel, including secondary contacts.
- Communication lines with those involved.
- Timelines.
- Remedial actions that can be taken to reduce impacts (e.g. aeration of inland water bodies in the event of an HAB).
- Availability of resources, including necessary tools and equipment (e.g. sampling equipment), and accredited or certified laboratories.
- Responsibilities for closing and reopening recreational use areas.
- Procedures for announcing and communicating closures in a timely manner.
- Criteria for rescinding warnings and reopening areas.
- Mechanisms for increased public health surveillance (refer to Chapter 2).
- Communication with the public – about both the risk and appropriate actions to take or avoid.

Implementation of IRPs, including application of responses, will typically involve multiple agencies. Expectations of agencies and supporting partners before, during and after the incident should be specified. The agencies involved will depend on the nature of the incident. They might include:

- recreational water managers;
- the ministry of health (or public health) and its regional and/or local offices;
- environmental protection authorities;
- local government;
- emergency management agencies;
- water suppliers (if the water body is also used as a source of drinking-water);
- wastewater utilities;
- poison information centres;
- water resource agencies;
- agriculture agencies;
- media;
- tourism offices and local businesses;
- other actors, such as dam basin managers and water management associations; and
- citizens and local communities (e.g. citizen science and reporting mechanisms such as Bloomwatch[1]).

Personnel involved in implementing IRPs should have appropriate skills and knowledge to enable effective management of incidents. They should understand the intent and actions described in IRPs. Their roles should be outlined clearly and regularly updated, together with contact information and relevant details for each member, including employing agency, position, role in the incident (e.g. primary contact, alternative contact, communication or media specialist), contact details and secondary contact (in case the primary contact cannot be reached). The lead entity should also identify the resources, infrastructure and staff to effectively respond to the event.

Plans should be regularly reviewed and practised.

3.4.2   Predictive models and rapid tests

Predictive models can be used at recreational water sites to deliver timely (e.g. daily) microbial water quality forecasts, which can be made available to the public (refer to Chapter 4). Predictive models work particularly well for waters that are directly subject to weather-related or other local environmental factors that correlate with short-term pollution or elevated microbial contamination (refer to example 4.1).

Rapid monitoring has been proposed as an alternative to predictive modelling. The aim is to develop a method or package of methods that provide results rapidly, enabling same-day decisions to be taken about water safety.

3.4.3   Supporting programmes

Activities other than control measures that are used to ensure recreational water quality are called supporting programmes. These can include programmes and procedures describing how tasks should be undertaken (e.g. standard operating procedures). Examples are:

- research activities for specific investigation programmes (e.g. monitoring of antimicrobial resistance and viruses);
- visual inspection of recreational areas;
- sample collection, preservation and transport;
- calibration of field monitoring equipment;
- interpretation, recording and reporting of results;
- modelling (e.g. hydrodynamic and water quality models, site-specific climate change projections, erosion scenarios);
- training of personnel involved in implementation of RWSPs on events that can influence water quality;

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[1] https://cyanos.org/bloomwatch/

- training of personnel on implementation of IRPs; and
- protocols for liaising with stakeholders, including other agencies with management responsibilities and user groups.

Supporting programmes should be designed to improve control of recreational water quality, fill gaps in knowledge and facilitate implementation of RWSPs.

3.4.4 Communication

Effective communication before, during and after an incident within responsible organizations and agencies, and between stakeholders, including local businesses, households and water users, is required to support the development of RWSPs and is crucial to ensure implementation. Reports by water users can play an important role in identifying and communicating risks.

Before an incident

The lead entity should determine the personnel to be part of the task force responsible for developing communication materials and for issuing information. The responsible person may be the person in charge of the response or a public media coordinator, or someone with a related position or role.

The communications task force will develop a contact list – for example, households, businesses and consumers, media, visitor centres, recreational parks and veterinarians (i.e. representatives of those potentially contributing to pollution, those affected, and those involved in the incident response).

Methods of communication will differ, depending on the most effective communication pathway for each audience. A contact list and/or decision tree (showing communication steps) should be developed with the personnel who oversee communications.

Generic communication materials are best developed before any contamination incident to prevent incidents (e.g. communications with businesses and homeowners on sewer damage or cross-connections) and to guide managers of recreational sites to communicate with the public as appropriate in the event of an incident (e.g. recreational site closure). These materials should be kept up to date in such a way that they can be readily adapted to any specific situations and offer water users a method of reporting poor water quality.

Communication materials may include:
- notices in water and waste customer communications
- beach postings
- generic warning symbols
- frequently asked questions and answers
- media statements
- fact sheets
- other background materials.

Pathways for distribution include:
- media releases and briefings
- email and text message alerts
- broadcasting
- mass distribution through social media via (e.g. Facebook, Instagram, Twitter, texts)
- posting on beaches
- posting on websites and other digital platforms
- listservs by email
- phone messages
- flyers

- community meetings
- any other locally relevant means of communication.

When adapting communication materials to a specific situation, the communications task force should make sure that the message is consistent across all partners involved in the response. Consultation with experts may be helpful:
- to provide understanding of potential health impacts and exposure routes, and for determining the most effective control measures and appropriate actions; and
- to integrate the experts in joint communication with the public so that any disparities in the messages given can be avoided.

Public information needs to be given in formats that the public can read and understand. The information may need to be tailored to specific populations, such as people:
- with different language backgrounds;
- with hearing or vision impairments;
- with specific medical needs; and
- at certain stages of life that may make them more sensitive to water quality issues, such as babies, young children, and pregnant and nursing mothers.

The communication messages may also need to be tailored to work across different digital platforms (e.g. webpages, smartphones).

During an incident

If a deterioration in water quality is detected or predicted, the communications task force should be called together for an emergency meeting (also refer section 3.4.1). The first stage of communication will be internal communication, coordinated by the responsible public authority and the water manager, to confirm that the resources needed for the response are available, and that a quick, accurate and effective response will take place once the exposure risk is confirmed.

The task force will determine the appropriate content, format and frequency of risk communication. For public communication, the task force will adapt the previously developed templates, such as media and press releases or beach signage, to the specific situation. These materials should give specific information about:
- the current event (including information about its severity in relation to guidance values)
- the location of the incident
- when the incident started
- how people and animals may be affected
- precautionary measures, such as avoiding contact with contaminated water
- steps taken to respond to and control the incident
- which agency oversees the response
- name and phone number of a contact person.

Considering multiple outlets of communication media may be important to reach the greatest number of people in a timely manner.

After an incident

Once the contamination event is over or under sufficient control, the communications task force should notify the public and other related partners that the incident is resolved and that the water is safe for recreational use. The task force could use the same communication outlets to contact the same partners that were notified of the incident. Communication should include information about the final decision, control measures applied, monitoring results, follow-up steps that will be taken, longer-term prevention approaches and related outreach materials.

A post-incident comprehensive assessment can be used to identify the adequacy of the response, and assess the effectiveness of the risk communication activities during and after the incident. A debrief with all the agencies involved after the incident helps to identify:
- problems and flaws during the incident, and areas that need improvement; and
- actions that contributed to a successful response and should be repeated in future contamination events.

The task force could also assess the effectiveness of the risk communication during the incident – for example, through a customer survey after the incident or questions to complainants on how well the type of material provided met information needs and how the respondent learned about the incident. The results of the debrief and customer survey should be used to update or modify the RWSP and IRP, if appropriate.

3.4.5   Documentation
All aspects of RWSPs should be documented, including:
- the lead agency and members of the RWSP team(s)
- the responsibilities of stakeholders
- performance and outcomes of system assessments, including
  - description of the recreational water area, including water catchments
  - sanitary surveys
  - hazard identification and risk assessment
  - existing control measures
  - identified improvement plans
- operation of control measures, operational monitoring and corrective actions
- verification of management effectiveness
- IRPs
- supporting programmes
- communication protocols.

Documents should be written with target audiences in mind. For example, documents describing operational procedures should be clear, unambiguous and understandable by personnel responsible for implementing the procedures. These personnel should be consulted before the documents are finalized, to ensure that these aims have been met.

RWSPs should be shared with all stakeholders. All personnel involved in managing recreational water bodies should have access to RWSPs and should be provided with documented procedures for activities that they undertake. After initial implementation of the RWSP, these personnel should be consulted about the functionality of documented procedures and where, if needed, improvements could be made.

3.5   Review of RWSPs

The RWSP team(s) should meet regularly (e.g. once per year) to review performance of plans and procedures, and operation of recreational water sites. The team should assess operational monitoring and water quality results, recreational area classifications (e.g. faecal pollution, cyanobacterial risks), occurrence of incidents, changes in inputs to recreational areas (e.g. modifications or upgrades of stormwater systems, improvements to on-site or centralized sewerage systems) and communication, including complaints from users. The team should also review and update hazards and risk assessments, if needed. The RWSP team should regularly (e.g. once every 2 years) review the overall content of the RWSP, including incident protocols.

RWSPs can quickly become out of date as a result of:
- changes in land use, including development of residential areas or tourist facilities;
- development of marinas;

- changes in recreational water use, including types of use and numbers of users;
- changes in allocation of responsibilities among stakeholders or changes in stakeholder agencies; and
- major events such as storms.

Reviews are essential to keep RWSPs up to date. Reviews also maintain the confidence and support of stakeholders involved in managing and operating recreational water bodies.

RWSPs should also be reviewed following every emergency or significant incident, particularly any incidents that lead to closure of recreational areas. The review should examine the cause of the incident, how it was detected, the immediate and long-term consequences, the effectiveness of the response (including what worked well and what did not) and possible areas for improvement, including changes to the IRP and the RWSP. For example, the IRP may need to be changed if problems were encountered in collection, transport to laboratories or timely analysis of samples. RWSPs will need to be changed if an incident is caused by an emerging hazard or a hazard that had not been identified in the system description.

Reviews of IRPs and RWSPs should focus on building competencies and recognizing the positives in implementing improvements from lessons learned.

✓ Box 3.4. Checklist for development of RWSPs

This checklist provides an indicative guide for development of RWSPs. It is not intended to be prescriptive, and it can be adapted to suit specific circumstances.

1. **Identify the lead agency**
   - ❏ Identify the agency that will be responsible for management of the recreational water body.
   - ❏ Initiate development of the RWSP.

2. **Assemble the RWSP team**
   - ❏ Identify and include representatives of all stakeholders who can influence water quality (e.g. public health agencies, environmental protection agencies, water resource agencies, local authorities, representatives of agriculture wastewater treatment and industry).
   - ❏ Identify and include representatives from all stakeholders with an interest in using the recreational water body in the local community, including volunteer groups, recreational water user groups and the local tourism industry.
   - ❏ Identify and include independent experts with appropriate skills (e.g. experts in risk assessment).
   - ❏ Ensure that, collectively, the RWSP team has a thorough understanding of the recreational water area and includes necessary technical expertise (e.g. microbiology, biology, chemistry, hydrology, natural resource management).
   - ❏ Record and maintain contact details of the RWSP team.

3. **System description**
   - ❏ Describe the recreational water area using a sanitary survey, including adjacent land and water areas that can be a source of hazards and potentially influence recreational water quality.
   - ❏ Assemble, and assess the quality of, available information, including historical water quality data and investigations.
   - ❏ Prepare maps of the recreational water area and conceptual flow diagrams of potential influences on water safety (e.g. stormwater and wastewater discharges, river outlets).
   - ❏ Conduct site visits to confirm the accuracy and completeness of descriptions.
   - ❏ Identify recreational water activities and intensity of site use.
   - ❏ Identify relevant water quality standards or targets, recreational water classification schemes and legislative/regulatory requirements.

4. **Hazard identification, control measures and risk assessment**
   - ❏ Identify hazards and hazardous events with potential impacts on recreational water quality.
   - ❏ Ensure that normal and unusual events, and both historical and potential future events (e.g. climate change) are considered.

❏ Identify existing control measures.
❏ Determine how risk assessments will be performed.
❏ Perform risk assessment, including consideration of existing control measures.
❏ Identify and validate control measures that could be implemented to reduce inadequately controlled risks.
❏ Establish and prioritize improvement plans.

5. Monitoring
❏ Plan mechanics of monitoring programmes: who is responsible, what will be monitored, how it will be done, timing and frequency, locations, who will do the sampling and analysis, who will receive and assess results, how data will be reported and stored.
❏ Ensure that monitoring programmes incorporate accredited laboratories or appropriate quality assurance and quality control (e.g. in collection and analysis of samples).

6. Initial microbial water quality assessment and recreational water classification
❏ Determine whether sufficient data are available to classify the recreational water based on susceptibility to faecal and chemical contamination, development of HABs or free-living microbial pathogens.
❏ Determine whether data are available to allow conditional classification of recreational water bodies (e.g. good for recreational use except for 2–3 days after rain).
❏ Determine monitoring required to classify a recreational water body (refer to Chapters 4 and 5).

7. Operational monitoring
❏ Identify operational monitoring requirements for priority control measures.
❏ Establish operational targets and limits that separate acceptable from unacceptable performance for each control measure.
❏ Identify corrective actions to respond to unacceptable performance.
❏ Establish criteria that need to be met to prove that acceptable performance of control measures has been regained.

8. Verification
❏ Identify a monitoring programme for indicators of faecal contamination and, where appropriate, HABs and ecotoxicity to verify performance of the RWSP and to confirm that established recreational water classifications are stable or improving.

9. Incident response plans (IRPs)
❏ Establish IRPs, including a framework for implementing responses, criteria for defining predictable incidents, reporting requirements including timelines, and criteria for issuing and rescinding recreational water closures.
❏ Identify a water incident coordinator and mechanisms for establishing incident management teams (IMTs).
❏ Identify responsibilities of IMT members.
❏ Establish communication protocols, including, where necessary, for notifying recreational water users.

10. Predictive models and rapid tests
❏ Determine whether predictive models can be used to forecast periods of poor water quality.
❏ Identify rapid monitoring programmes that could be used to determine same-day recreational water quality.

11. Supporting programmes
❏ Identify supporting programmes to improve control of recreational water bodies, fill gaps in knowledge and facilitate operation of RWSPs.

12. Communication
❏ Ensure that protocols are in place to support effective communication between stakeholders and with users, including in the event of incidents and emergencies.
❏ Develop communication plans and programmes to promote involvement and awareness of recreational water users.

13. Documentation
❏ Document all aspects of RWSPs, including the lead agency and members of the RWSP team; responsibilities of all stakeholders; system assessments, including system descriptions, hazard identification and risk assessment, existing control measures and improvement plans; operational procedures, monitoring programmes and corrective actions; IRPs; supporting programmes; and communication protocols.

14. Review
❏ Establish mechanisms and timing for regular review of performance of RWSPs and the overall content of RWSPs.
❏ Review the RWSP and IRP after significant incidents and emergencies to identify necessary changes.

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4 Faecal pollution

Faecal pollution introduces disease-causing microorganisms into recreational water that are largely derived from human sewage or excreta from warm-blooded animals. Guidance on setting of national health-based targets for faecal pollution is covered in Chapter 2. This chapter addresses:

- faecal pollution aspects in recreational water safety plans (RWSPs; Chapter 3 – Recommendation 2) with the following key elements
- system assessment, primarily through sanitary surveys (section 4.1.2)
- microbial water quality monitoring (section 4.2)
- combining sanitation survey and water quality results to classify beaches (section 4.3)
- ongoing operational and verification monitoring and communication that can be done in real time using predictive models (sections 4.2.2 and 4.2.3)
- management of risks though pollution abatement (section 4.4); and
- research needs (section 4.5).

The approach is summarized in Fig. 4.1.

Fig. 4.1
Flowchart for assessing recreational water environments
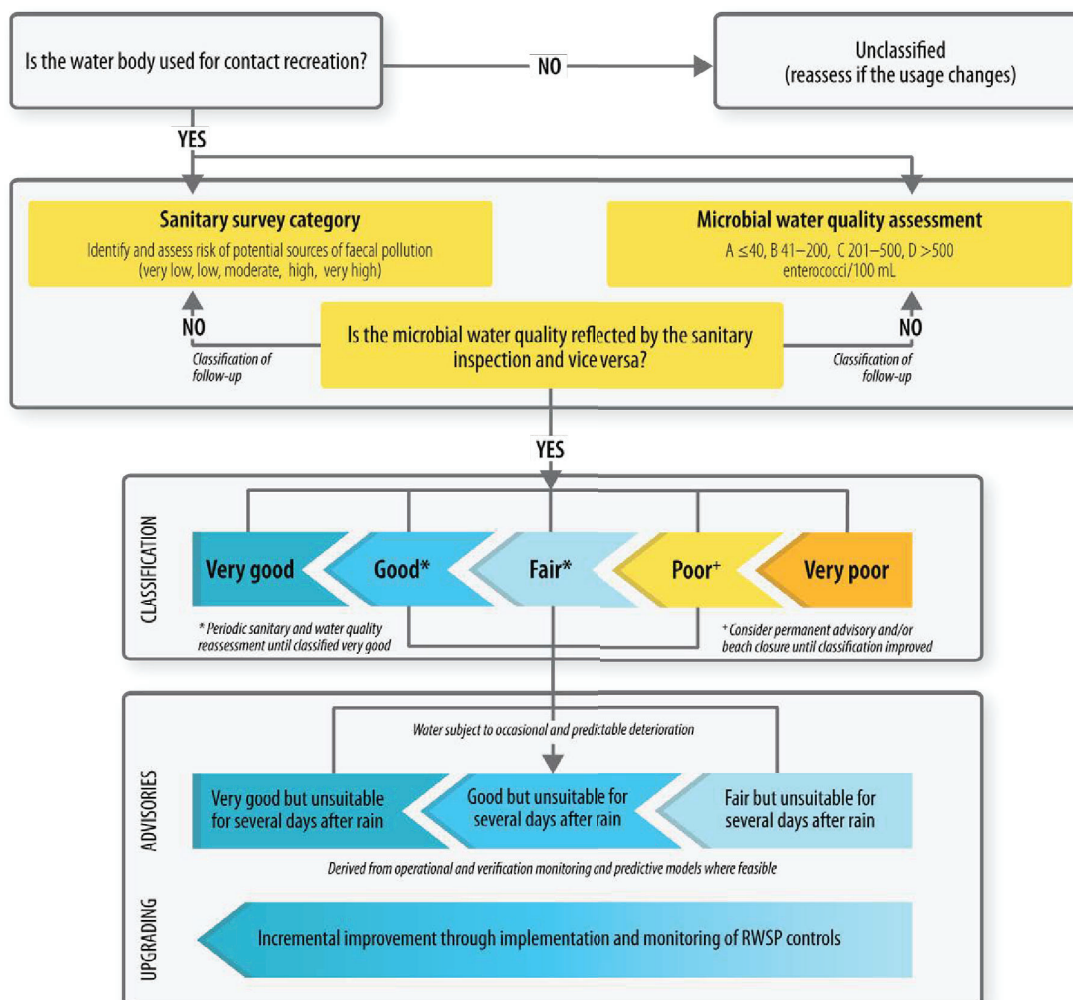
4.1   System assessment

System assessment involves identifying sources and levels of faecal pollution (human and animal) as part of RWSPs.

4.1.1   Health effects of faecal pollution

Expected pathogen numbers when thousands of people contribute to raw excreta flows are given in Table 4.1, together with the health effects of these pathogens.

The likelihood of a pathogen causing infection or disease depends on:
- the specific strain of the pathogen;
- the dose – for viral and parasitic protozoan infections, the infectious dose might be very few infectious units (Simmons et al., 2019);
- the form in which the pathogen is encountered;
- the conditions of exposure; and
- the host's susceptibility and immune status.

Table 4.1
Numbers of faecal pathogens and indicator organisms in raw sewage

Pathogen/indicator organism	Disease or role	Microbes/L
Viruses		
Adenoviruses	Respiratory disease, gastroenteri-tis	10^2–10^9 GC
Astrovirus	Gastroenteritis	10^3–10^7 GC
Hepatitis A virus	Hepatitis	Undetected to 10^9 GC
Hepatitis E virus	Hepatitis	Undetected to 10^5 GC
Norovirus (and other caliciviruses)	Diarrhoea, vomiting	10^2–10^9 GC
Enterovirus	Poliomyelitis, mild febrile illness, myocarditis, meningitis	Undetected to 10^4 (cell culture)
Rotavirus	Diarrhoea, vomiting	10^2–10^8 GC
F+ coliphages	Indicator organism	10^5–10^7 PFU
Somatic coliphages	Indicator organism	10^6–10^8 PFU
Bacteria		
Campylobacter spp.	Gastroenteritis	10^3–10^6 MPN 10^6 GC
Escherichia coli	Indicator organism (except specific pathogenic strains[a])	10^7–10^8 CFU or MPN
Intestinal enterococci	Indicator organism	10^6–10^7 CFU or MPN
Salmonella spp.	Gastroenteritis	Up to 10^5 MPN
Shigella spp.	Bacillary dysentery	10^2–10^8 MPN
Vibrios such as *Vibrio cholerae*, *V. parahaemolyticus* and *V. vulnificus*	Gastroenteritis	<10–10^5 MPN
Parasitic protozoa[c]		
Cryptosporidium spp.	Diarrhoea	10–10^4 oocysts
Entamoeba histolytica	Amoebic dysentery	Undetected to 100 cysts
Giardia duodenalis	Diarrhoea	10–10^5 cysts
Helminths[b]		
Ascaris spp.	Ascariasis	5–450 ova
Ancylostoma spp. and *Necator* sp.	Anaemia	5–190 ova
Trichuris spp.	Diarrhoea	10–40 ova

CFU: colony forming unit; GC: gene copies; 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: Rusiñol & Girones (2017); WHO (2018); García-Aljaro et al. (2019); https://www.who.int/news-room/fact-sheets.

4.1.2   Sanitary inspection survey

The inspection process to determine faecal pollution impacts to inform beach classification is called a sanitary survey. Comprehensive sanitary surveys can also identify other pollution sources and risks such as nutrient sources that may promote proliferation of harmful algal blooms, sources of chemical contamination and sources of other microbial hazards as part of the RWSP (refer to section 2.2.1). Sanitary surveys, together with microbial water quality analysis (section 4.1.3), leads to the beach classification (section 4.3). Although the sanitary survey may take many forms (e.g. NHMRC, 2008; USEPA, 2013; EEA, 2020), the goal is to ascertain likely faecal sources to help select beach sampling sites and outline management actions.

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. In studies of the impact of faecal pollution on the health of recreational water users, several faecal indicator organisms (FIOs; refer to section 4.1.3.1) have been used to index water quality. These FIOs are not considered the causative agents of illness but appear to behave similarly to some faecal pathogens, and may be related to illnesses in a dose-responsive manner (Prüss, 1998; Wade et al., 2010).

Guidance on items to include in sanitary survey forms is provided in Table 3.2 and Fig. 3.1 (section 3.2.1).

Human inputs

The most important sources of human faecal contamination of recreational water environments for public health purposes are typically:
- sewage and faecal sludge disposed of in the recreational water area via pipes, open drains and trucks;
- riverine discharges and combined sewer overflows (CSOs), where the river is receiving water from sanitation systems (e.g. sewage discharges, liquid effluent from septic tanks) and either is used directly for recreation, or discharges near or into a coastal or freshwater area used for recreation;
- contamination from recreational water users (including, in decreasing order of human health risk, faecal shedding, vomitus and urine) – particularly hazardous at high density of users; and
- runoff from surrounding land where open defecation and/or flooding of pits and septic tanks is prevalent.

The risks may vary with local circumstances. For example, sewage and septic tank 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.

Although several contamination sources may be significant, a recreational water environment may be most readily classified using the single most significant source of pollution. Management actions, however, should consider all the contamination sources. The classification is based on a qualitative assessment of the risk of exposure under normal conditions, considering the operation of sewage and faecal sludge treatment plants, on-site septic tanks and faecal sludge management services, and hydrometeorological and oceanographic conditions.

Sheltered coastal areas and shallow lakes may accumulate fine sediments that may be associated with high faecal microbial loads – these might be resuspended by water users or rainfall events. The health risks associated with resuspended sediments are poorly understood, but the potential risk should be noted during sanitary surveys.

Animal inputs

Animal sources are generally less important to human health risk than human excreta flows. However, in some instances, animals (e.g. gulls, waterfowl) can have a significant impact on faecal indicator bacteria used to measure microbial water quality and could result in management actions that are unnecessary in terms of public health (Smith, Snyder & Owen, 2020). Pollution of recreational waters with animal excreta can sometimes lead

to human health risks, because some zoonotic pathogens (e.g. *Cryptosporidium parvum; Campylobacter* spp.; pathogenic *Escherichia coli,* such as *E. coli* O157:H7) can be transmitted in animal faeces, particularly from intensive livestock raising near waterways (Soller et al., 2015). Thus, 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.

4.1.3 Determining recreational water quality

Guideline values for recreational water quality (section 2.1.2) are based on standard methods (e.g. International Organization for Standardization – ISO[1] and American Society for Testing and Materials - ASTM[2]) carried out by an accredited laboratory to assess the concentration of intestinal enterococci; however, a number of other organisms and gene targets may also be used. Although laboratory accreditation for non-culture-based, quantitative polymerase chain reaction (qPCR) to assay enterococci or E. coli may be less well developed and/ or available, DNA extract may also be used to assist in determining the presence of sewage or other important sources of faecal pollution.

Faecal indicators

The most commonly used FIOs are intestinal enterococci and *E. coli*, typically used to assess marine and fresh recreational waters, respectively.

Different methods used to assess FIO levels may target a slightly different subset of FIOs. Hence, it is critical to have a standard method or methods for analysis to be performed by an 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 epidemiology studies addressing marine and fresh waters and shown to reflect, in a dose–response manner, gastrointestinal illness in recreational water users (Wade et al., 2010).

Enterococci

The intestinal enterococci species most predominant in faecally polluted aquatic environments are *Enterococcus faecalis, E. faecium* and *E. durans*. In fresh water, *E. faecium* may prevail over *E. faecalis,* whereas in seawater the opposite is normal (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), and therefore may not indicate recent faecal contamination (Byappanahalli et al., 2012; Tiwari, Kauppinen & Pitkänen, 2019).

Escherichia 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; Table 4.1). 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). Environmentally naturalized *E. coli* populations also exist (Luo et al., 2011), as do treatment-resistant biotypes very similar to urinary-pathogenic *E. coli* (Zhi et al., 2020).

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[1] Relevant ISO standards include ISO 7899-1, ISO 7899-2, ISO 9308-2, ISO 9308-3, ISO 14189.

[2] Relevant ASTM standards include ASTM D6503.

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 reoviruses (Betancourt, Gerba & Abd-Elmaksoud, 2018), but 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, Rose & Gin, 2016).

Several bacteriophages have been suggested as candidate indicators (McMinn, Ashbolt & Korajkic, 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 waters, although generally in low numbers (Contreras-Coll et al., 2002; USEPA, 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 FIOs in response to specific local conditions. For example, the bacterium *Clostridium perfringens* has been used as an additional FIO in Hawaii. In tropical climates, enterococci are naturally present in soils, whereas the presence of *C. perfringens* indicates human excreta (Vierheilg et al., 2013).

Faecal source attribution

When unacceptable levels of FIOs are detected in a water body and sewage is not expected, it is important to ascertain the faecal source(s) contributing FIOs. A suite of methods can be used, including chemical approaches and microbial source tracking (MST) techniques (Harwood, 2014). 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). More than 40 MST targets have been used. Some of the most common, and their associated hosts, for investigating recreational water quality are described in Li et al. (2019).

4.2   Monitoring

The aim of RWSPs (refer to Chapter 2) is to reduce the amount of costly monitoring and to proactively manage the safety of recreational water users. Monitoring corresponding to Recommendation 2.3 in RWSPs has three aspects:
- initial monitoring to characterize the recreational water body using the health-based targets and the beach classification described in section 4.3 (refer to section 4.2.1);
- ongoing verification monitoring that provides a check on meeting health-based targets (refer to section 4.2.2); and
- operational monitoring, to enable quick response and reduce overall monitoring costs (refer to section 4.2.3).

4.2.1   Initial microbiological water quality assessment

Initial water quality assessment supports beach classification (section 4.3) and involves five stages (for further details, refer to Bartram & Rees, 2000).
- Stage 1 – initial sampling to determine if significant spatial variation exists along the recreational site.
  - Sampling at spatially separated sampling sites should be carried out at 50–100 metre intervals along the bathing area foreshore during the initial assessment on different days. Timing of samples should consider the likely period of maximum contamination from local sewage and septic tank discharges, and maximum shedding by recreational water users (e.g. the afternoon or day of peak numbers of water users).

- Stage 2 – assessment of spatial data based on data from stage 1.
  - If spatial variation occurs, see stage 4; if no spatial variation occurs, see stage 3.
- Stage 3 – intensive sampling and assessment of results.
  - If there is no evidence of spatial variation, the initial classification (refer to section 4.3) is determined from the results of the sanitary inspection category and microbial water quality assessment (Table 4.3). It is suggested that microbial water quality for recreational waters is classified into four categories (A–D) using the 95th percentile (refer to section 4.2.2) of intestinal enterococci distribution, as shown in Table 4.3.
- Stage 4 – definition, separate assessment and management of affected areas if spatial variation is evident at stage 2.
- Stage 5 – confirmatory monitoring in the following year, using a reduced sampling regime and a repeat of the sanitary inspection. If the subsequent classification (Table 4.3) is "very good" or "very poor", less frequent monitoring can be justified (Table 4.2).

The sampling programme should be representative of the range of conditions (e.g. dry, wet) and spatial patterns (e.g. close to stormwater drains) in the recreational water environment while it is being used. When determining the recreational water classification, all routinely collected samples on days when the recreational water area was open to the public should be used. For example, it is not appropriate to resample the bathing water following a high count measured when the beach was open and no advisory notice had been posted, and then to use the resample result but not the original result. However, where an advisory notice has been posted, the sample taken during the period of the posted advisory would be omitted from the percentile calculations. On the other hand, samples may be taken following an adverse event or an unexpectedly high result from a routine sample. The additional samples may be used to investigate the full impact of the event on the bathing water or to further characterize the area and the impacts of adverse events.

It is important that sufficient samples are collected to enable an appropriate estimation of the FIO densities to which recreational water users are exposed. The number of results available can be increased significantly – with no additional cost – by pooling data from multiple years. This practice is justified unless there is reason to believe that local (pollution) conditions have changed. 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.[1]

Overall, bathing waters with consistent classifications will require fewer samples, and bathing waters with changing classifications will require more samples. In some circumstances, fewer samples may be required – for instance, where the water quality is consistently very poor and swimming is not recommended. However, 60 samples should be the minimum considered for an analysis of the effects of an insufficient number of values for credible derivation of water quality standards for recreational waters.

4.2.2   Ongoing verification monitoring

Many agencies have chosen to base criteria for recreational water compliance on either percentage compliance levels – typically 95% compliance (i.e. 95% of the sample measurements taken must lie below a specific value to meet the standard) – or geometric mean values of water quality data collected in the water use zone. Both statistics have significant drawbacks. For example, the geometric mean provides limited information on the high values at the top end of the statistical distribution that are of greatest public health concern. The 95% compliance system, on the other hand, does reflect much of the top-end variability in the distribution of water quality data and is more easily understood. However, the 95th percentile is affected by greater statistical uncertainty than the geometric mean; this is therefore a less reliable measure of water quality, and care is required if it is to be applied in management of water quality5 (WHO, 2009).

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[1]   The standard error of any percentile calculation is inversely proportional to the square root of the number of data points included in the calculation, and also increases with the variance in the underlying data and the distance of the percentile from the median. This means that any beach classifications made on the basis of small numbers of microbiological test results are liable to considerable uncertainty – for example, a classification based on 10 or 20 samples will result in >20% and >14% misclassification, respectively. If compliance is estimated from 100 samples, as may be accrued over five bathing seasons with 20 samples per season, the probability of misclassification is less than 1%. Thus, estimating compliance on too few samples is unlikely to protect public health (because it will allow too many beaches to pass) or protect the interests of beach managers (because it will fail too many good-quality beaches).

There is no best way to calculate percentiles. It is important to know which method is being used, as each will give a different result.

Datasets that include numerous values below the limit of detection can be difficult to manage and produce non-normally distributed data. When use of such data is unavoidable, the Hazen method is a robust method for calculating the 95th percentile (Hunter, 2002; WHO, 2009). In this method, the data are ranked in ascending order, and the percentile is calculated by interpolation between the two data points on either side of the calculated rank.

In the subsequent analyses, however, appropriate dilutions should be used to ensure that nondetectable events (termed censored data) are rare or completely avoided.

Verification parameters and frequency of assessment

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 survey has occurred over several years;
- the sanitary inspection category is "very low" or "low"; and
- the initial microbial water quality assessment is stable and based on at least 100 samples.

For areas where the sanitary inspection resulted in a "very high" categorization for susceptibility to faecal contamination (where swimming would be strongly discouraged), a similar situation applies.

For intermediate-quality recreational water environments (i.e. "moderate" and "high"), an annual verification sampling programme involving more frequent sampling is recommended, as shown in Table 4.2.

Table 4.2
Recommended verification monitoring schedule

Risk category identified by sanitary survey	Microbial sampling	Sanitary survey
Very low	Minimum of 5 samples per year	Annual
Low	Minimum of 5 samples per year	Annual
Moderate	Annual low-level sampling 4 sample locations × 5 occasions during swimming season Annual verification of management effectiveness Additional sampling if abnormal results are obtained	Annual
High	Annual low-level sampling 4 sample locations × 5 occasions during swimming season Annual verification of management effectiveness Additional sampling if FIO results do not fit with sanitary survey expectation	Annual
Very high	Minimum of 5 samples per year	Annual

Where a change is made in the FIOs or microbiological method used, limited data may be available in the initial years of implementation. To overcome this, historical records may be used by applying correction factors appropriate to local conditions. These factors would normally be driven by comparative studies of the results of local analyses. Another strategy is to collect both old and new data on FIOs during the transition period. Although this increases costs, it provides a break-in period.

4.2.3 Operational monitoring and communication using predictive models

Operational monitoring may use a range of parameters, including nonmicrobiological ones – for example:

- warnings on release of poorly treated sewage or faecal sludge from a utility or service provider;
- rainfall that may influence runoff or release excreta from flooded septic tanks and sewers;
- unloading by faecal sludge trucks in coastal zones;
- changes in wind speed or direction and water temperature that may change the dispersal of sewage, septic tank effluent and stormwater from outfalls; and
- operational data collected by individuals associated with a recreational site, surveillance drones and citizen science.

The range of sources of operational data means that roles and responsibilities need to be defined in the RWSP (refer to Chapter 2) for operational monitoring associated with faecal pollution.

Timely response to changing recreational water quality has been a major concern in the appropriate management of the safety of 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 (refer to Chapter 3). 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 Example 4.1).

Example 4.1. The Safeswim predictive model for Auckland, New Zealand

In 2017, Auckland City launched the Safeswim website and mobile application as a joint initiative between the Auckland Council, Watercare (the city water and wastewater utility), Surf Lifesaving Northern Region and the Auckland Regional Public Health Service. This initiative was partly funded by a targeted council rates increase for water quality improvement.

Safeswim encourages users to "jump online before you jump in", directing users to the nearest of more than 100 classified beaches in the region. The system allows users to decide when and where they swim by indicating safety using a red and green coding system. A small number of beaches are permanently closed or unclassified.

Safeswim uses a predictive model built using real-time rainfall and tide data, together with a historical time series of water quality testing results for intestinal enterococci and E. coli. The model provides real-time estimates of the likelihood of an exceedance and classifies beaches as red when the risk of illness by ingestion exceeds 5%.

All Safeswim's water quality models are overseen by an independent panel of public health experts, which meets quarterly to evaluate performance and provide direction. An independent audit of Safeswim completed by Audit New Zealand in 2020 found that a random sample of Safeswim's water quality predictions was 89% accurate.

Generally, water quality, especially on the north shore, is good for 95–97% of days. However, exceedances are more common in areas of the city with CSOs where rainfall of more than 15 mm occurs in a 24-hour period, particularly after extended dry periods. In areas with permanently closed beaches, exceedance can occur in dry weather or with as little as 3–4 mm of rain.

The system is a marked improvement over the previous system, which had a 48-hour delay between sample collection and public reporting of results. Transparent public reporting has also increased public awareness and scrutiny about the causes of water pollution, and willingness to pay via targeted council rates for improvement. This has increased the capacity of local authorities to address the primary sources of pollution.

A range of improvement projects are under way, including a large central sewer interceptor (designed in preparation for future growth and impacts of climate change) that will divert overflows away from the harbour to the main wastewater treatment plant. The interceptor is due for completion in 2028. In the meantime, water quality is continually being improved through detection of damaged pipes, and misconnections of sewer and stormwater; restoration of natural treatment in streams and wetlands; and sewer and pump station upgrades. These are all combined with streetscape improvement, where possible.

Source: https://www.safeswim.org.nz/

Predictive models should be validated and checked against real conditions – they may not be suitable for some beach types, and changes within beach catchments are likely to require updating of regression-based (i.e. empirical) models. In operational standards such as the European Union Bathing Water Directive (EU, 2006), accurate predictive modelling can significantly improve regulatory compliance if a regulatory sample with high concentration of FIOs caused by, for example, high antecedent rainfall is discounted (i.e. not used) for regulatory calculations of the regulatory upper percentile values. This approach is based on the Annapolis Protocol (WHO, 1999).

Assessing and acting on single and/or high analytical results

Responsible agencies should ensure that they are fully apprised of any sanitary survey information for the site and any past records of water quality, and that they have undertaken a recent visual inspection. Three main conditions might lead beach management agencies to consider posting an advisory notice of likely adverse water quality.

- Climatic conditions, such as high rainfall, lead to elevation of FIOs in recreational waters. The microbial source may be agricultural runoff and/or urban surface water. 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 causes gross pollution of the bathing water. Often, the first evidence of such an event will be visual reports of gross pollution, indicated by high turbidity and associated sanitary wastes from sewer overflow, and/or overflow debris from rivers and drains discharging to the bathing water. A protective advisory notice informing the public of potentially adverse water quality should be posted on first observation of the evidence. Microbiological testing to confirm adverse water quality (high microbial concentrations) could provide a yardstick of a return to more normal water quality for the affected 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. 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.

4.3   Beach classification based on sanitary survey and water quality

Recreational water is classified by combining the sanitary inspection category (section 4.1.2) with the microbial water quality assessment category (section 4.1.3), using a matrix such as that shown in Table 4.3 and summarized in Fig. 4.1.

The classification emphasizes faecal contamination from humans. FIOs may significantly overestimate risks if they have sources other than human excreta (Schoen, Soller & Ashbolt, 2011).

The assessment framework (Fig. 4.1) enables local management to respond to sporadic or limited areas of pollution, 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 4.4). This form of classification (as opposed to a pass/fail approach) therefore 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. It helps to identify the principal management and monitoring actions that are likely to be appropriate.

Table 4.3
Example of a classification matrix for faecal pollution of recreational water environments

Sanitary inspection category (susceptibility to faecal pollution)	Microbial water quality assessment category (95th percentile intestinal enterococci/100 mL)				
	A ≤40	**B** 41–200	**C** 201–500	**D** >500	**Exceptional circumstances**[a]
Very low	Very good	Very good	Follow-up[b]	Follow-up[b]	
Low	Very good	Good	Fair	Follow-up[b]	
Moderate	Good[c]	Good	Fair	Poor	Action
High	Good[c]	Fair[c]	Poor	Very poor	
Very high	Follow-up[c]	Fair[c]	Poor	Very poor	
Exceptional circumstances[a]	Action				

[a] Exceptional circumstances (section 4.3.5) relate to known periods of higher risk, such as an outbreak of a pathogen that may be waterborne, or sewer rupture in the recreational water catchment. Under such circumstances, the classification matrix may not fairly represent risk or safety.

[b] Implies nonhuman source of faecal indicators (e.g. livestock); this should be verified (section 4.2.2).

[c] Indicates possible sporadic contamination (often driven by events such as rainfall). This is most commonly associated with CSO. These results should be investigated further. Initial follow-up should include verification of sanitary inspection category and ensuring that samples recorded include event periods. Analytical results should be confirmed, and possible analytical errors reviewed (section 4.2.2).

Note: In certain circumstances, there may be a risk of transmission of pathogens associated with more severe health effects through recreational water use. The human health risk depends on specific (often local) circumstances. Public health authorities should be engaged in the identification and interpretation of such conditions (section 4.3.5).

Note: Where users can be effectively discouraged from entering the water following occasional and predictable quality deteriorations (e.g. after rain), the area may be upgraded to reflect the water quality that users are exposed to. This requires accompanying explanatory material and timely warning through advisory signage or online communication, to give potential water users informed choice before they decide to enter the water (Fig. 4.1).

4.3.1 Initial classification

The outcome of the sanitary inspection and the microbial water quality assessment, based on Table 4.3 and Fig. 4.1, is a five-level classification for recreational water environments: very good, good, fair, poor and very poor. In addition, there is a follow-up category or requirement where there is discrepancy between the results of the microbial water quality assessment and the sanitary survey.

If the assessment shows that higher microbial contamination levels are limited to only a part of the recreational water environment, separate assessment and management are required for these areas.

Where there are multiple sources of contamination, the single most significant source is used to determine the susceptibility to faecal influence.

4.3.2 Follow-up of initial classification

Where the sanitary inspection and water quality data inspection result in a potentially incongruent categorization in Table 4.3, further assessment will be required. This could include re-examining the sanitary survey (i.e. identifying further potential faecal sources in the catchment and assessing their risk) and additional analysis of 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 survey;
- the sampling points are not representative of the influence of sewage, septic tank effluents and faecal sludge;

- important CSOs 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; and
- 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 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, MST markers) may be appropriate. Confirmation that contamination has negligible nonhuman (e.g. bovine, avian) sources (Soller et al., 2015) may allow reclassification (refer to section 4.3.4) to a more favourable grading. Care is needed here because nonhuman pollution may still be a source of important pathogens (refer to section 4.1.2.2).

Similarly, where microbial water quality assessment indicates a very low risk that is not supported by the sanitary survey, consideration should be given to the sampling design, the analytical methodology used and the possibility that the sanitary survey may be incomplete.

A worked example is provided in Example 4.2 to illustrate beach classification.

Example 4.2. Beach classification worked example

Historical microbial data for the site were available; thus, the most recent 5 years of data (in this case, more than 20 samples per year) were used to provide the initial microbial water quality assessment (refer to footnote 9 on sample number and risk of misclassification).

1. Sanitary inspection category (following criteria described in section 4.1.2.1)

a) Sewage discharges (if present)

Outfalls	Present? (Y/N)	If present:		
		Type of treatment	Type of outfall/disposal	Risk category
Sewage outfalls	Y	Primary	Effective	Low
CSOs	N			
Faecal sludge disposal	N			
Stormwater	Y		Direct	Very high

b) Riverine discharges (if present)

Present? (Y/N)	If present:		
	Size of population from which sewage or septic tank effluent originates	Type of treatment	River flow during bathing season (high, medium, low)
N			

c) Water user shedding

Water user density in bathing season (high, low)	Dilution (low if beach has restricted water flow – lakes, lagoons, enclosed inlets; otherwise high)
High	High

Are there toilet facilities on the beach (Y/N)?	Y

Example 4.2. continued

d) Physical characteristics of the beach; provide a scale sketch map showing location of sampling points and swimming areas.
   The beach is 800 m long. There are several stormwater drains discharging to the beach.

e) Overall category of sanitary inspection
   Very high susceptibility to faecal influence.

2. Initial microbial water quality assessment

a) Describe the current monitoring programme for assessing microbial water quality.

   Sample volume = at least 250 mL (for 100 mL analysed volume)
   Tested for *E. coli* and intestinal enterococci
   Sampling schedule: approximately every 6 days
   Sampling points: 1

b) Summarize data file(s) covering at least 5 years of monitoring (or 100 samples) for faecal indicator organisms (100 raw numbers
   are needed in order to calculate 95th percentiles). Preferably, these should be the most recent data available.
   $N = 100$
   95th percentile = 276 intestinal enterococci/100 mL

3. Combined sanitary and microbial water quality assessment, and overall classification

Sanitary inspection category: Very high susceptibility to faecal pollution
Microbial inspection category: C
Overall classification: This beach is rated as "poor".

Sanitary inspection category (susceptibility to faecal pollution)	Microbial water quality assessment category (95th percentile intestinal enterococci/100 mL)				
	A ≤40	B 41–200	C 201–500	D >500	Exceptional circumstances
Very low	Very good	Very good	Follow-up	Follow-up	Action
Low	Very good	Good	Fair	Follow-up	
Moderate	Good	Good	Fair	Poor	
High	Good	Fair	Poor	Very poor	
Very high	Follow-up	Fair	Poor	Very poor	
Exceptional circumstances	Action				

Notes: Refer to Table 4.3.

Reassessment of beach classification following management of exposures

The initial classification based on the sanitary inspection category (very high susceptibility to faecal pollution) and initial microbial water quality assessment (C) was "poor".

However, this classification appeared to be driven principally by the presence of occasional stormwater overflows. Subsequent investigation found that the stormwater overflow events were predictable. Signage was introduced to warn water users not to swim during rain and for up to 2 days following heavy rain. The beach was posted whenever heavy rain had occurred.

Exclusion of the stormwater overflow changes the sanitary inspection category from "very high" to "low" susceptibility to faecal pollution, which results in a provisional upgrading to "fair (but unsuitable for 2 days after heavy rain)".

Monitoring of the recreational water over a bathing season revealed that water users complied with the notices not to bathe. Water quality sampling showed that, after 2 days following heavy rain, the microbial quality returned to normal levels. Reanalysis of microbial water quality data using the water quality to which users were exposed found a 95th percentile of 185, resulting in a final classification of "good (but unsuitable for 2 days after heavy rain)".

The local authority intends to remove the source of stormwater overflow. They expect that the advisory can then be removed, and the beach can be classified as "good".

4.3.3   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 Fig. 4.1 is incomplete.

Three scenarios may be envisaged.

- No data are available on the microbial water quality of the water body or its susceptibility to faecal influence (such as new developments).
- The data available from the microbial water quality assessment and/or the sanitary inspection are incomplete.
- There is reason to believe that the existing classification no longer accords with changed circumstances, but insufficient data are available to complete the classification.

In these circumstances, it may be necessary to issue a provisional classification (refer to Example 4.3). When such a step is taken, it should be made clear that the advice is provisional and subject to change. A provisional

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Example 4.3. Actions for provisional beach classification

No historical data or assessment

Examples of recreational water environments for which no sanitary inspection information and no water quality data are available are a newly used beach or a part of a long beach that becomes popular. Steps to take are as follows.

- Identify the extent of the water body or beachfront requiring classification. Urgent microbial water quality assessment will be required. If sampling and analytical capacities are insufficient, the most intensively used recreational water area should be selected for initial study.
- At the first opportunity, and during the bathing season, take a minimum of 8–12 samples across the selected transect, ideally at about 50 m intervals (depending on the length of the beach and possible discharges from stormwater or other outfalls), but, in any case, not more than 200 m apart.
- Conduct a limited sanitary survey to identify possible pollution sources in the immediate vicinity of the area that will require further evaluation. While waiting for laboratory results, the sanitary survey should be completed as far as possible. Arrangements should be made to obtain maps, plans, information on the sewerage system and other information that may be needed for a proper interpretation of the findings.
- Review the initial laboratory results as soon as they become available. If the results are extremely good or extremely bad, it may already be obvious that the water body may be provisionally placed in microbial water quality assessment categories A or D. For example, if at any time during the collection of classification data it becomes obvious that, once all 100 samples have been collected, the 95th percentile will exceed a particular classification boundary, the recreational water should be provisionally classified at the appropriate level.
- If the results are less clear-cut, a second round of sampling will be needed; use of MST markers may be beneficial. This should be conducted as soon as possible, providing it is during the bathing season.
- Based on the sanitary survey and the microbial water quality assessment data available after the second round of sampling, make an early assessment. If necessary, a time-limited provisional classification of the recreational water environment should be made and acted upon. At the same time, a commitment should be made to proceed with all necessary steps to permit full classification of the area in accordance with Fig. 4.1 and Table 4.3 as soon as possible.

Incomplete data

Where the data available are insufficient, the steps are as follows (also see footnote 9).

- For either or both of the microbial water quality assessment or the sanitary survey, review the data carefully to see whether it is possible to reach any provisional conclusions. This may be relatively easy at the extreme ends of the classification spectrum – for example, if there is a major sewage or feacal sludge discharge point in the immediate vicinity of the recreational water area, or a set of analytical results with a strong trend towards very high or very low values.
- If it is not possible to make a provisional classification, use the review to identify key deficiencies in the data and therefore the additional information that is most critically needed.
- In the absence of past intestinal enterococci data, consider using historical records relating to another FIO.
- Consider undertaking a complete data gathering process (as in Fig. 4.1).
- If beach classification is urgently needed, the procedure outlined above for a recreational water environment for which there are no data may be adapted accordingly.

Inappropriate existing classification

Where there is reason to believe that the existing classification no longer accords with changed circumstances, the steps are as follows.

- Collect sufficient data before reassessing the beach classification, or carefully review the existing data to see whether any provisional conclusions can be reached.
- If this review shows an incongruity between the sanitary survey data and the microbial water quality assessment data, take steps (as set out in section 4.3.2) to understand this.
- If both the sanitary survey data and the microbial water quality data point to a similar change in beach classification, draw a provisional conclusion, and take steps to obtain sufficient data for proper classification.

classification should be time limited, and there should be a commitment to obtaining the necessary data to follow the steps described in Fig. 4.1 to provide definite classification as soon as possible.

4.3.4 Upgrading classifications

As water contamination may be triggered by specific and predictable conditions (e.g. rainfall), local management actions (e.g. advisories) can be used to reduce or prevent exposure at such times. If these actions are effective, the recreational water classification may be upgraded to a more favourable level. A reclassification should, however, initially be provisional and time limited. It may be confirmed if the efficacy of management interventions is subsequently verified during the following bathing season. If the reclassification is not confirmed, the water environment will automatically revert to the original classification. This is illustrated by the last part of the worked example in Example 4.2.

4.3.5 Exceptional circumstances

Although these guidelines do not provide general guidance (e.g. guideline values) about risks during exceptional circumstances – such as sewer breaks, extreme floods and rainfall events with a return period of more than 5 years – the ability to identify and manage these types of circumstances is important. Initial identification of a problem may arise from (human) disease surveillance, authorities responsible for wastewater treatment, and management or veterinary authorities. Public health authorities should be engaged in defining water quality standards or appropriate triggers relevant to specific circumstances. This will normally require the responsibility and authority to act in response to such circumstances (refer to Chapter 3). Implementing appropriate actions will require intersectoral action, often including local government, facility operators, user groups and so on.

4.4 Management and communication

This section describes abatement and remediation measures for managing water quality improvement and ensuring the safety of recreational water users.

4.4.1 Direct point-source pollution abatement

Effective outfalls with sufficient length and diffuser discharge depth are designed to ensure a low probability of sewage-contaminated water reaching the recreational water environment. Long outfalls can be an effective means of protecting public health by separating recreational water users from contact with sewage. Pretreatment with milli-screens is the minimum treatment level.

For nearshore discharges of large urban communities, where effluent may meet recreational waters, tertiary treatment with disinfection will provide the greatest health benefits and a sanitary inspection category of "very low" susceptibility to faecal influence. However, public health risks will depend on the operation and reliability of the plant and the effectiveness of disinfection.

4.4.2 Intermittent pollution abatement

Runoff via drainage ditches and so on is predominantly event-driven pollution that may affect recreational water areas for relatively short periods after rain. CSOs – where effluent combines with rainfall – are built into many sewerage systems. Similarly, many in-site sanitation systems, such as pit latrines and septic tanks, 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 septic tank effluent present a direct health risk, and contact with the overflow should be avoided.

The best option is to have separate collection systems for human excreta and rain/stormwater. Although treatment is an option for CSOs, often the treatment plant cannot cope with the quantity of sewage, or the effectiveness of the treatment is lowered as a result of a change in the load of the sewage.

Other pollution abatement options for CSOs include:
- retention tanks that discharge during periods when recreational water is not being used – these are costly and may be impractical for large urban areas;
- transport of sewage to locations distant from recreational areas via piped collection systems or effective outfalls; and
- disinfection (ozone, chlorine, peracetic acid or ultraviolet light), which may not be effective against all hazards.

These pollution abatement alternatives usually require major capital expenditures and may not be readily justifiable, especially in low- and middle-income countries. An alternative is management programmes that minimize recreational water use during event-driven pollution incidents (refer to section 4.4.1).

Programmes to scare gulls and waterfowl away from recreational sites, or remove seaweed or other detritus that may attract them, have been effective in reducing FIO levels (Converse et al., 2012).

4.4.3 Catchment pollution abatement

Significant pollution sources that may present a challenge to pollution abatement include:
- upstream diffuse pollution (e.g. poorly functioning septic tanks, local breaks in sewerage pipes);
- point-source discharges (e.g. illegal faecal sludge disposal sites);
- animal-derived faecal pollution, especially in livestock-raising catchments; and
- pathogen accumulation in stream sediments and remobilization via riverine discharges to coastal recreational areas.

Major sources of pollution should be identified and a catchment-wide pollution abatement programme 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.

4.4.4 Enforcement of regulatory compliance

Enforcement of regulatory compliance has limitations as the principal tool for protecting and improving microbial quality of recreational waters, although the threat of closure may be a powerful driver for improvement.

Where a recreational water use location fails a regulatory standard, it may be difficult to define responsibility for this failure – in many locations, several sources will contribute to the overall pollution.

It may be appropriate to base regulatory compliance on the obligation to act. Thus, there could be a requirement to immediately consult the public health authority and to inform the public, as appropriate, when conditions are detected that are potentially hazardous to health and uncharacteristic of the location. There could also be a general requirement to strive to ensure the safest achievable bathing conditions by taking measures to improve classification of the recreational water, including pollution control.

4.5   Research needs

Empirical data from the United Kingdom and the USA suggest very high within-day variability (i.e. 2–4 $\log_{10}$ orders every day in the bathing season) in regulatory FIO concentrations (Fleisher, 1985; Wyer et al., 2018). This pattern has been evident at seven marine beaches sampled to date 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 is therefore being questioned, and this has implications for design of predictive modelling protocols. It is important to test the hypothesis that this apparently chaotic pattern is present in other settings worldwide.

Although still relevant, the epidemiological studies underpinning recommended water quality guideline values are old, and limited in terms of 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 the subpopulation 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 recommended guideline values. Epidemiological studies are also needed to associate the levels of *Clostridium perfringens* (as an FIO for tropical waters) and various MST (molecular) markers with ailments after bathing in recreational areas. Although the research is compelling with regard to the value of MST markers, standardization of MST targets and methods have not reached the same maturity. Hence, research is needed on implementation aligned with progress made on portable qPCR machines and application of sequencing machines (e.g. Oxford MiniIon) for field use (Symonds et al., 2016; Liang, Goh & Gin, 2017; Zhang et al., 2019; Gitter et al., 2020).

In addition, statistical approaches to censored data are needed to resolve the inability to compare methods when waters are too clean.

Further research is also needed to understand the sanitary significance of environmental proliferation of FIOs, particularly in submerged vegetation compared with pollution derived from human and animal faeces, and its consequences for monitoring and interpretation of results.

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5 Harmful algal blooms

Harmful algal blooms (HABs) do not multiply in the human body like pathogens, but some species contain secondary metabolites that are toxic to humans and animals. The function of these substances for the cells themselves is poorly understood. Some are potent toxins, so that the HABs that produce them have similar toxicity to mushrooms such as the white death cap, which contains amatoxin. HAB organisms are unicellular, often occurring planktonically and thus in quite a dilute state. Their toxins reach hazardous concentrations where cells accumulate to high density – for example, in scums on lake surfaces, in mussels and shellfish that filter plankton out of seawater, or where they grow in dense mats or clumps on submerged surfaces.

HAB organisms occur naturally. However, around the globe, human activities (e.g. agricultural runoff, inadequate wastewater treatment, road runoff) have led to excessive fertilization (eutrophication) of many water bodies, including coastal areas of the sea (van Dolah, 2000). This can lead to excessive proliferation of algae and cyanobacteria in water, termed blooms, which can have a considerable impact on the marine and freshwater environments. Blooms result in turbidity, discolouration of the water and sometimes scum formation; they may also cause aesthetic problems (such as smell). Where the water exchange rate is low, their decay can consume oxygen, causing low concentrations (hypoxic conditions), which result in plant and animal die-off.

Although HABs occur both in freshwater and marine settings, the organisms producing them are different: in freshwater and some brackish water bodies, species of cyanobacteria cause HABs, whereas, in marine waters, HABs are typically caused by species of dinoflagellates and diatoms. In both fresh and marine water bodies, the HABs growing on sediments and surfaces are cyanobacteria. In fresh water, they grow either directly as mats on the sediment or on the surface of submerged macrophytes.[1] In contrast, in marine subtropical and tropical coastal areas, large filaments of cyanobacteria 10–30 cm in length (sometimes termed mermaids' hair) grow in mats or clumps on the sediment down to depths of 30 m. Specific toxins from these filaments can cause severe skin blistering, oedema and deep skin lesions lasting up to 12 days (Osborne, TCiW 2021). Because of these differences, both risk assessment and effective management interventions differ substantially between freshwater and marine recreational sites. Section 5.1 focuses on approaches for assessing and managing risks from HABs in freshwater and brackish water bodies. Although some of these approaches can be adapted for marine HABs as well, section 5.2 adds aspects that are specific to marine HABs.

5.1 Toxic cyanobacteria in freshwater and brackish water bodies

Cyanobacteria are organisms with many characteristics of bacteria and some of algae. Like bacteria, their cells have no nucleus. However, like algae, they contain a green pigment (chlorophyll *a*) with which they can perform photosynthesis. They also contain another blue pigment (phycocyanin), which is mostly visible when cells in scums die and lyse, releasing the pigment into the water – this sometimes appears as if turquoise-coloured paint has been spilled. 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 or bright green. Cyanobacteria can contain several different types of potent toxins – the cyanotoxins. However, not all cyanobacterial blooms are toxic. As well, a bloom consisting of one species (e.g. *Microcystis aeruginosa*) can be composed of genetically different clones or genotypes (strains), some of which contain the genes for toxin production and some of which do not. Toxic and nontoxic strains can be distinguished only by molecular or chemical analyses, not visually.

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[1] Submerged macrophytes are underwater plants.

The World Health Organization (WHO) guidebook *Toxic cyanobacteria in water* (TCiW; Chorus & Welker, 2021) gives a comprehensive overview of the information and expertise needed to assess the risk of cyanotoxin occurrence, including for recreational water use, and for developing effective risk management strategies. The information below is largely summarized from specific chapters of this book, unless cited otherwise. The WHO background documents for four groups of cyanotoxins (microcystins, cylindrospermopsins, anatoxin-a and saxitoxins) give detailed information on the derivation of WHO guideline values, including for recreational exposure (WHO 2020a, b, c, d, e).

5.1.1 Cyanotoxins

Table 5.1 gives an overview of the groups of currently known cyanotoxins and the most frequently occurring genera of cyanobacteria with species that produce them.

Table 5.1
Guideline values for cyanotoxins relevant to human health

Toxin and type of chemical	Mechanism of toxicity and WHO guideline value $(GV)_{recreation}$[a]	Genera[b] that commonly produce the toxins	Comments
Microcystins (MCs) Cyclic heptapeptides with specific amino acid (ADDA) Many congeners (>250) A small number occur commonly	Inhibit protein phosphatases; act predominantly on the liver WHO $GV_{recreation}$ = 24 µg/L	*Microcystis* *Planktothrix* *Anabaena* (some now classified as *Dolichospermum*) *Nostoc*	The cyanotoxins most frequently found at hazardous concentrations. Numerous animal deaths. Occur largely cell bound, thus accumulating in scums; concentrations dissolved in water are usually low. Occur widely in fresh water and sometimes in brackish areas.
Nodularins (NODs) Cyclic heptapeptides with specific amino acid (ADDA)	Inhibit protein phosphatases; act predominantly on the liver No WHO $GV_{recreation}$	*Nodularia* *Nostoc*	Like MCs, but occur predominantly in brackish water (*Nodularia* extensively in the Baltic Sea) and sometimes on surfaces.
Cylindrospermopsins (CYNs) Alkaloids with tricyclic guanidino moiety and uracyl	Cytotoxic; act predominantly on the liver, kidneys, erythrocytes WHO $GV_{recreation}$ = 6 µg/L	*Raphidiopsis* (formerly *Cylindrospermopsis*) *Anabaena* (some now classified as *Dolichospermum*) *Aphanizomenon* *Chrysosporum* *Oscillatoria* *Umezakia*	Frequent in some regions. 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.
Anatoxin-a (ATXs) Amine alkaloid	Neurotoxic, pre- and post-synaptic depolarization WHO $HBV_{recreation}$ = 60 µg/Lc	*Anabaena* (some now classified as *Dolichospermum*) *Aphanizomenon* (some now classified as *Cuspidothrix*, some as *Chrysosporum*) *Raphidiopsis* (formerly *Cylindrospermopsis*) *Oscillatoria* *Planktothrix* *Phormidium* *Tychonema* *Lyngbya* (some now classified as *Microcoleus*, some as *Moorea*)	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.

Table 5.1 continued

Toxin and type of chemical	Mechanism of toxicity and WHO guideline value (GV)recreation[a]	Genera[b] that commonly produce the toxins	Comments
Saxitoxins (STXs) Also termed paralytic shellfish poisons, known from toxic marine algae accumulated in shellfish Alkaloids Many analogues	Neurotoxic; block Na+ channels in neuronal cells, and Ca++ and K+ channels in cardiac cells WHO GVrecreation = 30 µg/L	*Anabaena* (some now classified as *Dolichospermum*) *Planktothrix* *Aphanizomenon* (some now classified as *Cuspidothrix*, some as *Chrysosporum*) *Raphidiopsis* (formerly *Cylindrospermopsis*) *Lyngbya* (some now classified as *Microcoleus*, some as *Moorea*) *Oxynema* (formerly *Phormidium*)	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.
Anatoxin-a(S) Organophosphate	Neurotoxic; inhibits acetylcholinesterase No WHO GVrecreation	*Anabaena* (some now classified as *Dolichospermum*)	Occurrence sparsely documented.

GV: guideline value; HBV: health-based value.
[a] Source: WHO 2020.
[b] Many genera were recently reorganized and are still undergoing reorganization; new names rarely correspond fully with old names.
[c] For ATXs, toxicological data were insufficient for deriving a guideline value, but allow deriving an upper bounding value below which health impacts are highly unlikely – that is, a health-based value.

Notes: Refer to TCiW, Chapter 2, for further details on toxin production. Genera subject to reclassification are given with current and former genus; in some cases, new genera encompass only some of the species belonging to the former genus (refer to TCiW, Vidal et al., 2021, for details of new classification).

5.1.2 Health effects

Recreational exposure to cyanotoxins is possible through:
- uptake of cells and toxins ingested with water – generally unintentional through reflex swallowing (although for small children it may occur during play); large amounts can be swallowed during recreational accidents;
- aspiration – water entering the nasopharynx and subsequently being swallowed;
- inhalation – when spray is formed, and droplets contain cells (e.g. during jet skiing) or when dried scums present on the beach are raised as dust; and
- skin and mucous membrane contact, including contact with scum, dislodged material from benthic mats or vegetation with attached cyanobacteria floating in swimming areas or accumulated on beaches.

Human fatalities are known only from exposure to cyanotoxins via haemodialysis. Although a small number of severe health effects have been plausibly attributed to recreational exposure, many of the health effects that have been associated with recreational exposure to cyanobacteria are mild and self-limiting, such as irritation of the skin, mucous membranes and gastrointestinal tract; hay fever–like symptoms; nausea; and fever (refer to TCiW, Chorus & Testai, 2021). In some cases, more severe symptoms such as fever, nausea, abdominal pain and muscle weakness are reported. 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. As for most harmful substances in water, cause–effect relationships between toxins and symptoms are challenging to establish from case reports and epidemiological data because exposure is usually poorly characterized and the presence of the causative hazard may not have been recognized. This is partly due to lack of awareness of cyanotoxins, and to the delay between exposure and symptoms (symptoms such as liver damage cause no pain until damage is substantial). Chorus & Testai (TCiW, 2021) give case examples attributed to cyanotoxins, as well as an overview of epidemiological surveys, and discuss the quality of the evidence currently available from these.

The main human health concern is ingestion or nasal uptake of the toxins that cyanobacterial scums may contain (Table 5.1). Although no human deaths have been unequivocally attributed to recreational exposure, numerous deaths of livestock, pets and wild animals have been caused by consumption of water containing toxic cyanobacteria (Backer et al., 2013; Trevino-Garrison et al., 2015; Testai et al., 2016). This gives rise to concern regarding accidental ingestion of water containing cyanotoxins during recreational activities.

Dislodged benthic mats of cyanobacteria or of underwater vegetation with epiphytic toxic cyanobacteria may contain high levels of cyanotoxins, and the death of pet dogs that have ingested such material triggers concern. However, humans are highly unlikely to ingest such material. Use of recreational water may be safe if users avoid direct contact with, and keep some distance from, such material (for more information, refer to TCiW, Chorus & Testai, 2021).

To support assessing the risk of health hazards from recreational exposure to cyanotoxins, WHO has derived the guideline values given in Table 5.1 (refer to WHO, 2020a, b, c, d, e, for the full derivation of these guideline values).

5.1.3   Risk assessment and management

Environmental conditions in a water body that determine its potential for cyanobacterial bloom formation include the availability of the resources that cyanobacteria and algae (together termed phytoplankton) need to proliferate (i.e. nutrients and light), as well as hydrophysical conditions that determine their access to the resources (i.e. the rate of water exchange and vertical mixing of the water). These conditions determine the amount of biomass that phytoplankton can attain in a water body. They also shape the conditions for competition between species, leading to the dominance of certain species of cyanobacteria or eukaryotic algae. High nutrient concentrations that allow the development of a high density of phytoplankton cells render the water turbid, reducing the average amount of light available for each cell. This may enhance cyanobacterial dominance because, under low-light conditions, the growth rates of some cyanobacterial species are higher than those of many other phytoplankton organisms. Thus, once some species have reached a high amount of biomass, causing pronounced turbidity, they create an environment in which they can continue to outcompete other phytoplankton (TCiW, Burch, Brookes & Chorus, 2021). Note that this does not apply to cyanobacteria growing on submerged surfaces, including on macrophytes: they require clear water, and particularly on sunny days their intensive photosynthesis can produce substantial amounts of gas bubbles that dislodge lumps of material that then floats and can accumulate along shorelines.

Phytoplankton ecology in each water body is complex. It is therefore recommended to involve limnological expertise when assessing the risk of occurrence of cyanobacterial blooms. Two chapters in TCiW give guidance for this: Ibelings et al. (2021), on phytoplankton ecology, and Burch, Brookes & Chorus (2021), on assessing water body conditions and management.

Among the nutrients determining the amount of biomass that can form, total phosphorus (TP) has a key role in many water bodies: blooms of significance to recreational exposure usually require TP concentrations above 20–50 μg/L. Very large water bodies may show exceptions: although TP concentrations below 20 μg/L will not support a high biomass per unit water volume, buoyant cyanobacteria at low cell density can rise to the surface in a large water body and establish a film, which can be 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. Where nutrient concentrations are low, such accumulations of cells rarely reach levels containing toxin concentrations above the guideline values given in Table 5.1.

As cyanobacterial growth rates are relatively slow, blooms do not form in rapidly flowing rivers. They are also unlikely in lakes or reservoirs with water retention times of less than a month. Water body mixing is well tolerated by many cyanobacteria, but deep and strong mixing can suppress the proliferation of scum-forming cyanobacteria. The conditions determining the potential for blooms tend to be more stable over time than the blooms themselves. Thus, 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, once a year, either at the beginning of the growing season or later in summer when peak blooms are expected (spring or late summer in temperate climates).

Understanding the conditions conducive to blooms is a highly valuable basis for risk assessment and management. It requires expertise in limnology, a good understanding of the activities in the catchment that may lead to nutrient inputs, and collaboration with the stakeholders of these activities. A recreational water safety planning team (refer to Chapter 2) provides an effective platform for this necessary collaboration. Where risk assessment shows that toxic cyanobacteria occur or are to be expected, the best approach, sustainable in the longer term, is to initiate management interventions to reduce the nutrient load and thus eutrophication. However, as discussed in section 5.1.3.2, success in reducing critical nutrient loads requires time – often several years to decades – until concentrations in the water body decline to levels that limit phytoplankton biomass sufficiently to where eukaryotic algae outcompete cyanobacteria. Until that target is stably reached, regular monitoring and short-term interventions can be important to discourage or prevent recreational activities that could potentially lead to hazardous exposure when blooms still occur.

Assessing exposure risks and short-term responses to prevent exposure

Particularly where numerous recreational sites are potentially affected by blooms, it may be important to develop a surveillance strategy that gives priority to sites most likely to be relevant to public health. Criteria for determining these priorities are:
- the likelihood of toxic blooms; and
- the pattern of use of the recreational water body, including users' willingness to comply with generic recommendations and to use their own judgement accordingly (Table 5.2).

Assessing the likelihood of toxic blooms can be based on:
- existing information about the occurrence and amounts of cyanobacteria, trophic state and hydrophysical conditions; and
- a targeted programme of site inspection, sampling and analyses. Such a programme does not need to include regular analyses of cyanotoxins, particularly where blooms are less likely. Cyanobacterial biomass or indicators of high biomass can serve as triggers for action, which may, if appropriate and possible, include toxin analyses.

Where information about the water body is insufficient for assessing exposure risks, an initial assessment of conditions in the water body is important. Guidance for this is given in section 5.1.4 and in more detail in Chapters 7–9 of TCiW.

The following list may be useful for assessing the likelihood of exposure to cyanotoxins through recreational and occupational use of a water body (adapted from TCiW, Chorus & Testai, 2021).
- Is information available to indicate the likelihood of bloom occurrence (e.g. from catchment characteristics and land use that affect nutrient loads, from trophic status, or from direct observations of cyanobacteria and/or water body characteristics; Table 5.2, 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 location of the site used for recreational activities?
- How intensively is the site used (refer to Table 5.2)? Is use by an individual occasional, or are the same people exposed frequently (e.g. almost daily)?
- Are site users likely to be receptive to information and to adapt their activities at the site accordingly? Or might more stringent enforcement of restrictions be important?
- 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 recognize blooms?

- Are water or beach quality information systems in place that can be adapted to include 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?

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. Such levels should be sufficiently protective but not set so low that they lead to undue restrictions on site use.

Table 5.2
Criteria to prioritize water bodies for cyanobacterial bloom monitoring

Part A: Conditions affecting or indicating the likelihood of high cyanobacterial biomass

Total phosphorus	Mixing conditions		Transparency	pH
>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 (e.g. *Planktothrix agardhii*) and other fine filamentous forms (e.g. *Limnothrix*)	Low; Secchi depth often <1 m	>7 (often >8 or possibly >9 due to high rates of photosynthesis caused by high biomass)
>20 to <50 µg/L	Stagnant, deeper than 10 m, stratified: potential for mass development of *Planktothrix rubescens*, which accumulates at the metalimnion		Moderate; Secchi depth ~1–3 m	≥7
>10 to <20 µg/L	Fast-flowing river	Lake or reservoir with water residence time <1 month	High; Secchi-depth ~3–7 m	6–7
<10 µg/L	Mountain stream or brook		Very high – clear water; Secchi depth often >7 m	<6
	Exception: cyanobacteria attached to surfaces			

Source: Adapted from TCiW, Burch, Brookes & Chorus (2021).

Part B: Recreational use patterns of water bodies prone to blooms, as criteria for monitoring and intervention

Appropriate intensity of monitoring and intervention	Water body use pattern	
	Almost daily exposure during the bloom season (e.g. at lakeside holiday homes and campsites)	Use of recreational sites by a large number of people
	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.	
	Sites used by only a small number of people and only occasionally or discontinuously	
	Site users who are receptive to information on blooms, how to recognize them and how to respond to them	Site 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 thus triggering targeted surveillance; refer to Example 5.1 in section 5.1.4.1)

Source: Adapted from TCiW, Chorus & Testai (2021).

Fig. 5.1
Alert level framework for monitoring and managing cyanobacteria in recreational water bodies

Pre-screening water-bodies for elevated risk of blooms and exposure to cyanotoxins:
- Total phosphorus concentrations >20 µg/L and/or experience of cyanobacterial occurrence,
- Intensive recreational activity.

(Section 5.2.3)

Alternative or complementary entry point for assessment at intervals of about 2 weeks.

Assessment by visual site inspection

Assessment supported by laboratory analysis

Fairly clear water, slightly turbid, greenish discolouration.

Secchi disc transparency < 1-2 m

YES → **VIGILANCE LEVEL** ← **YES**

Microscopy showing dominance of cyanobacteria with up to 1-4 mm3/L, or
Up to 3-12 µg/L chlorophyll-a with dominance of cyanobacteria.

Vigilance level

Vigilance level

Assess further characteristics determining its potential to support blooms or scums.
Assess for cyanobacteria known to be toxin producers *(Fig. 5.2)*.
If yes, intensify monitoring and/or inform site users about toxic cyanobacteria and how to recognize them. *(Fig. 5.3)*.
Inform relevant authorities.

NO

NO

Pronounced greenish turbidity; feet barely visible when standing in knee deep water *(Fig. 5.3)*.

Possibly minor thin green film or streaks on part of the surface *(Fig. 5.2)*.

Secchi disc transparency < 0.5-1 m.

YES → **ALERT LEVEL 1** ← **YES**

Cyanobacterial biovolume > 4-8 mm3/L, or
Up to 12-24 µg/L chlorophyll-a with dominance of cyanobacteria.
If toxins are analysed;
> 24 µg/l MCs
> 6 µg/L CYN
> 60 µg/L ATX
> 30 µg/L STX

Alert level 1

Alert level 1

Watch for scums.
Investigate further (if possible, conduct toxin analysis).
Inform site users to watch for scums and avoid activities that can lead to uptake through mouth or nose, particularly for children; if this cannot be controlled, keep children out of the water.
Inform relevant health authorities.

NO

NO

Visible thick cyanobacterial scum covering most of the water surface in areas used for recreation

Secchi disc transparency < 0.5-1 m.

YES → **ALERT LEVEL 2** ← **YES**

Cyanobacterial scum and;
> 24 µg/L MCs
> 6 µg/L CYN
> 60 µg/L ATX
> 30 µg/L STX

Immediate action to prevent contact with scums; possible temporary prohibition of swimming and other water contact activities.
Inform site users to stay out of the water and to avoid sports activities 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.

Source: Chorus & Testai (*Toxic cyanobacteria in water*, 2021).

A number of countries have defined trigger values for action restricting site use during blooms. 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. Biovolume (i.e. cells/L multiplied by mean cell volume of the species) provides a much better indication of biomass and thus of toxin concentration than mere cell counts. This approach also encompasses nonspecific health impacts associated with the presence of cyanobacterial cells but not with any specific known cyanotoxin.

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. 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, thus avoiding undue restrictions on site use. WHO has published guideline values for recreational exposure (WHO, 2020a, b, c, d, e) for microcystins, cylindrospermopsin, anatoxin-a and saxitoxins (refer to Table 5.1). These may be used for such calibration. 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 (refer to TCiW, Padisák et al., 2021, for methods) to understand the development of the bloom situation.

The alert level framework (ALF) given in Fig. 5.1 replaces the three-tiered table given in the 2003 guidelines (Table 8.1 in WHO, 2003). The ALF 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 use of the water body. It then provides two different approaches to monitoring: visual assessment only, and visual assessment supported by laboratory analysis. Visual monitoring alone may well suffice, because clear water will not contain cyanotoxins at concentrations relevant to health through recreational exposure. When using laboratory analysis, it is nonetheless important to interpret the laboratory data in conjunction with visual information (from site inspection, observation of scums and water transparency, and qualitative microscopy).

The ALF is based on assumptions that may not be applicable nationally or even locally. Therefore, it needs to be adapted to national or local conditions. Assumptions include body weight of recreational water users and the amount of water ingested. The WHO recreational guideline values are based on a worst-case situation of a 15 kg toddler swallowing 250 mL of water; in contrast, a 60 kg adult would reach a dose corresponding to the guideline value by ingesting 1 L of water with the toxin concentration of the respective guideline value.

The alert levels given for biovolume and chlorophyll *a* are quite conservative (i.e. protective), and periodically calibrating them against data obtained for the specific water body may well allow use of higher thresholds for triggering action to prevent exposure. Cylindrospermopsins may be an exception due to their high share of toxin dissolved in water – Box 5.1 in TCiW gives further details.

These alert levels do not take into account people who have dermal sensitivity or an allergic predisposition (e.g. atopy).

The following discussion of the alert levels and corresponding actions to take is adapted from TCiW (Chorus & Testai, 2021):

> **The vigilance level** addresses a situation with dominance of cyanobacteria in the phytoplankton, but at biomass levels too low to contain hazardous toxin levels, and thus with fairly clear water that might show slight turbidity with greenish discolouration; transparency determined with a Secchi disc will usually be in the range of 1–2 m. However, because of the potential for rapid increase or even scum formation, it is appropriate to intensify surveillance and inform site users about the potential for cyanobacteria to increase to higher levels.

Vigilance is particularly relevant for water bodies with TP concentrations well above 20 µg/L (provided nitrogen is not reliably limiting; for determining this, refer to TCiW, Chorus & 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. However, lakes and reservoirs with low nutrient concentrations and low phytoplankton density rarely show prolonged dominance of cyanobacteria; if they do, such scums tend to be short-lived, minor events.

Alert Level 1 addresses a situation in which cyanobacteria are clearly visible when inspecting the 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, with Secchi disc transparency in the range of 0.5–1 m or even less (Fig. 5.2). In such a situation, cyanotoxin concentrations can reach potentially hazardous levels even without scums, but typically they do not, and recreational use may be continued without exposure to cyanotoxins exceeding the recreational guideline value. This is particularly the case for scum-forming microcystin-producers such as *Microcystis* or *Anabaena*, which may be visible as slight streaks or small specks between which water is fairly clear. However, site users should be informed (see below).

Determining biomass and possibly toxin concentrations provides more precise information and is important in water bodies with a history of supporting the proliferation of non-scum-forming species of cyanobacteria. Informing site 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. Fig. 5.3 shows one option for a visual criterion for self-assessment of the situation.

Where data from visual inspection and quantifying cyanobacterial biomass can be supported by cyanotoxin analyses, this can avoid undue restrictions on recreational site use in situations where cyanobacterial biomass is high, but toxin content is low (below Alert Level 1).

At Alert Level 1, 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 is therefore recommended, and increased surveillance may therefore be appropriate, particularly for heavily used recreational sites, to rapidly detect if the situation escalates to Alert Level 2.

Alert Level 2 describes a situation with scums or very high cell density leading to substantial turbidity (Fig. 5.3). 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. Although in such a situation the recreational guideline values for cyanotoxins are not necessarily exceeded, this is quite likely. Cyanotoxin analysis can be used to confirm or downgrade the alert level status. As discussed above, 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.

Alert Level 2 situations call for immediate action to avoid scum contact and, in particular, oral uptake. Temporary banning of water use may be appropriate, and intensified monitoring may be important to either confirm or downgrade the alert level status, in order to not unnecessarily restrict use. Providing information to site users is important to achieve an understanding of the hazard and thus 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 sites while other sites largely remain unaffected, directing recreational use to another 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).

Fig. 5.2
Alert Level 1 conditions observed as streaks, specks and Secchi disk transparency
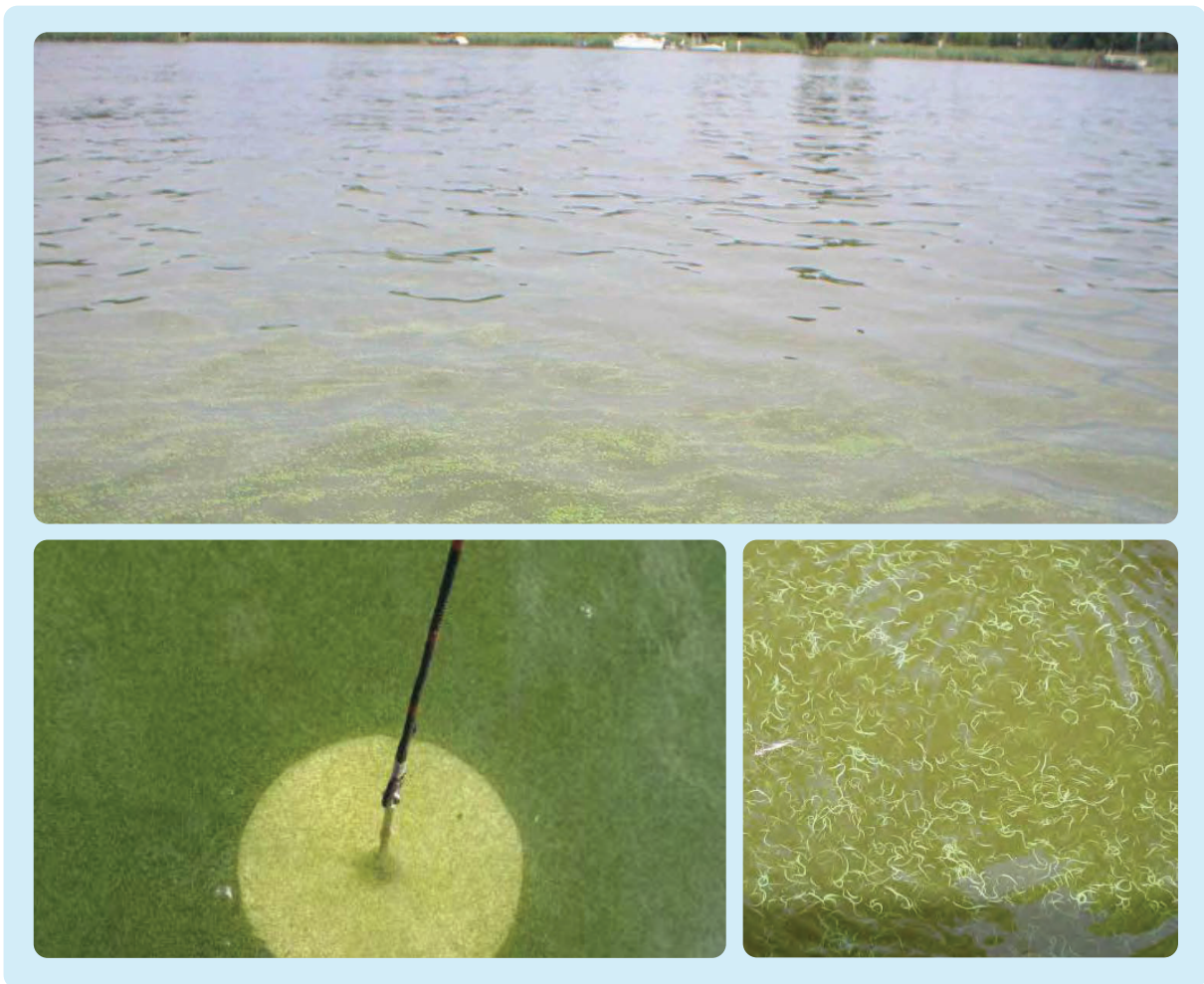
Fig. 5.3
Simple guidance for checking presence of potentially unsafe levels of non-scum-forming cyanobacteria

Alert levels for non-scum-forming cyanobacteria

Check for yourself:

- Carefully wade into the water up to your knees, without stirring up mud or sediment.
- Can you still see your toes?
- If not or only barely, swim elsewhere.

Alert level 1

Alert level 2
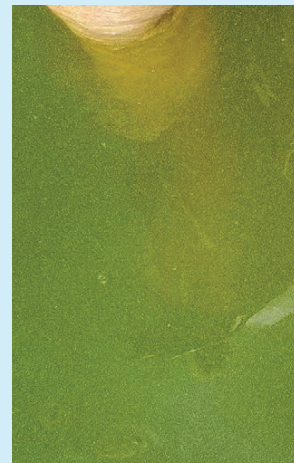
*Source:* TCiW, Chorus & Testai (2021).

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. Site 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 after a bloom, when recreational use is safe again, is important to avoid unduly discouraging healthy outdoor recreational activity, as well as warning fatigue. If warning signs remain posted even though the water is clear, it is likely that site users will tend to ignore them in the future.

This ALF approach does not allow assessment of risks from detached mats of benthic cyanobacteria or from toxic cyanobacteria attached to underwater vegetation. Such situations are typically not associated with elevated cyanotoxin concentrations in the open water. Significant stands of underwater vegetation or benthic mats of cyanobacteria grow and persist on the surface to which they attach, unless they detach and float. If these release any toxin, this is usually quickly diluted. Not all such material is toxic, and where access to cyanotoxin analyses 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. This should be connected to advising site users to avoid contact with the toxic material (clumps that are either floating in the water or beached along the shoreline). Guidance on monitoring benthic cyanobacteria and materials for informing site users has been developed in New Zealand (http://www.gw.govt.nz/freshwater-toxic-algae/; Wood, 2017).

Sustainable management of water bodies to remediate or prevent occurrence

The most sustainable approach for controlling cyanobacterial blooms is to reduce nutrient loads – often phosphorus – from the catchment to the water body (Fig. 5.4). Although blooms also depend somewhat on hydrophysical characteristics, particularly mixing depths and water exchange rates, potentially hazardous levels

Fig. 5.4
Identification of control measures to reduce catchment nutrient loads

Determine the target nutrient concentration in the water body to effectively control cyanobacteria

Estimate the critical nutrient load to reach this target load

Identify potential pathways and sources of nutrients

Assess the respective loads they contribute to the total load reaching the water body

Identify and implement measures to control nutrient loads, including climate change scenarios

Source: Chorus & Zessner (TCiW, 2021).

of cyanobacterial biomass are highly unlikely at TP concentrations below 20 µg/L, and in shallow water bodies possibly below 50 µg/L; thresholds for limitation by total nitrogen are about 7 times higher (refer to TCiW, Chorus & Zessner, 2021, for a more detailed discussion). Nutrient loads can be estimated from their sources and their pathways to the water body.

Chorus & Zessner (TCiW, 2021) give guidance for estimating critical loads that lead to elevated concentrations of nutrients in a water body. In summary, two major sources of nutrients are important.
- Human excreta from wastewater treatment plant outfalls and septic tank effluent. Human excreta carries the most substantial nutrient loads where it enters water bodies without treatment or passes through treatment plants with insufficient nutrient removal.
- Fertilizers, manure and slurry spread on land. Fertilizers reach water bodies mainly from agricultural land, but also from other areas with runoff to the water body, such as golf courses, lakeside lawns and gardens. Large animal husbandry operations are a source of nutrients, particularly feedlots that are close to watercourses.

Wastewater from industries and manufacturing enterprises can also contribute significant loads.

Identifying the nutrient load to a water body, and the sources and activities in the catchment that contribute can be challenging (refer to Rickert, Chorus & Schmoll, 2016, for more information and guidance). It is most straightforward for point sources (e.g. outlets of wastewater treatment plants or industries), where the amounts of water leaving the facility and the nutrient concentration in the water can be measured. Alternatively, nutrient loads can be estimated from known process parameters, such as the size of the population served by the sewage system and the average nutrient concentration emitted per person.

For diffuse sources, a basis for estimating the most important nutrient sources is to identify the activities in the catchment, and their size and way of operating – for example, the number of livestock animals held, the amount of fertilizer sold on local markets, and the number of households that may discharge untreated or insufficiently treated effluent directly to the water body.

For nutrients spread on land, their pathway to the water body can be important. For example, some of the nitrogen may volatilize to the atmosphere, and some of the phosphorus will be adsorbed to the soil. Soils that enter the water body as a result of erosion might carry high loads of phosphorus, and drainage can carry high loads of nitrate. Erosion and runoff are determined by the slope of the land, ploughing techniques, access of livestock directly to the shore and vegetation cover along the shoreline; buffer strips covered with thick vegetation can intercept some of the runoff and prevent access of livestock.

Catchment inspection and collation of information from, for example, permits for activities in the catchment are a good way to get started with assessing key sources of nutrient loads. Approaches can begin with the obvious and the feasible, and extend to quantifying loads using catchment modelling (refer to Rickert, Chorus & Schmoll, 2016; TCiW, Chorus & Zessner, 2021). Quantitative approaches that use catchment models require substantial amounts of data and expertise in hydrology.

After measures to control nutrient loads are implemented, the time it takes for the water body to respond with a sufficient reduction of nutrient concentrations strongly depends on the exchange rates with water containing low nutrient concentrations. Particularly in shallow lakes, with low water exchange rates, nutrients stored in the sediment may cause internal loading for a number of years before the lake becomes a sink for nutrients. If concentrations remain too high and blooms still occur, or if more immediate success is needed, it may be possible to implement measures that make conditions less favourable for cyanobacteria. Such management options are termed internal measures, and Table 5.3 gives an overview (refer to TCiW, Burch, Brookes & Chorus, 2021, for guidance). The choice of internal measures and their chances of success strongly depend on water body characteristics. Internal measures are most likely to be successful once concentrations of nutrients in the water feeding the water body are below the target concentration in the water body (e.g. for TP, below 20–50 µg/L), and they typically require ongoing monitoring and maintenance.

Table 5.3
Overview of measures to suppress cyanobacterial proliferation by influencing internal water body processes

Intervention target	Intervention type	Techniques
Suppress dominance of cyanobacteria, potentially in favour of other phytoplankton	Hydrophysical control of growth conditions	Mixing – artificial destratification Maintaining sufficient flow and thus a rapid change of hydrophysical conditions (i.e. avoiding or removing impoundments)
Suppress internal phosphorus load released from the sediment – only likely to be successful if sediments are a major P source relative to the external P load	Internal P control through sediment treatment or removal	Removing sediment Treating sediment with P-binding agents (e.g. lime, alum, modified clay, zeolite) Suppressing redox-sensitive P release by oxidization of the surface sediment (through hypolimnetic aeration or oxygenation)
Increase loss rates of phytoplankton, including cyanobacteria, or support their competitors	Biological control (biomanipulation)	Stocking carnivorous fish that reduce planktivorous fish, thus allowing zooplankton that feed on phytoplankton to increase For shallow water bodies, planting shoreline macrophytes; possibly also protecting them from physical disturbance (e.g. by wave action)
Induce rapid lysis of cyanobacterial cells or inhibit their proliferation	Chemical control	Applying algicides or algistats at the beginning of a bloom. Warning: the technique may cause large release of toxins if applied to a bloom that has already developed; it raises environmental concerns and is recommended only for single applications in emergency situations. Hydrogen peroxide is emerging as the most environmentally friendly chemical to use; it appears to act selectively on cyanobacteria.

Source: TCiW, Burch, Brookes & Chorus (2021).

Appropriate expertise (e.g. hydrology, ecology), as well as stakeholders for activities, should be included in the team planning measures – most effectively in the context of a recreational water safety plan. This may help to gain acceptance for measures that require investments and/or changes in the way that stakeholders operate their activities.

Climate change

The impact of climate change on the incidence of cyanobacterial blooms is far more complex than the frequently mentioned slightly higher growth rate of some cyanobacteria in warmer water compared with the growth rate of many species of eukaryotic algae. Climate change affects hydrophysical conditions and therefore nutrient concentrations, and these effects can far outweigh a direct temperature effect on growth rates. Conditions linked to climate change that can support an increase of cyanobacteria include more extreme precipitation (causing increased erosion and thus nutrient input), drought, more stable thermal stratification beginning earlier in the year, and higher carbon dioxide concentrations (Visser et al., 2016; Chapra et al., 2017). However, these conditions can also be less favourable for cyanobacteria. For example, more stable thermal stratification can prevent phosphorus released from the sediment from reaching the phytoplankton in the upper layer (Salmaso et al., 2018). 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 cyanobacteria strongly depends on the conditions of the specific water body (refer to TCiW – in particular, Ibelings at al., 2021 – for an in-depth discussion). Two generalizations are emerging.
- Although the effects of climate change are more uncertain for thermally stratified water bodies, for shallow ones, climate change is more likely to enhance bloom formation (Jeppesen et al., 2009).
- In oligotrophic to slightly eutrophic water bodies (i.e. with TP concentrations <20–50 µg/L, depending somewhat on hydrophysical conditions; refer to section 5.1.3.2), climate change is unlikely to promote blooms because nutrient concentrations are not high enough to support them (Gallina et al., 2013; Kraemer, Mehner & Adrian, 2017).

5.1.4 Monitoring

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 ALF
- 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 5.4).

Table 5.4
Examples of sampling strategies for particular monitoring objectives

Objective	Sampling sites	Sampling frequency	Analytical targets
Capacity of nutrient concentrations to sustain blooms of cyanobacteria	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 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
Spatial distribution of cyanobacteria or cyanotoxins	Multiple sites and multiple depths	Single or few sampling campaigns during bloom season	Phytoplankton, chlorophyll *a*, cyanotoxins
Protection of health during recreational activity	Sites used for recreation in presence of surface blooms or transparency less than 1–2 m (refer to Fig. 5.2)	As necessary, in response to visual inspection and recreational use (refer to Table 5.2)	Transparency, cyanobacterial biovolume, chlorophyll *a*, cyanotoxins

Source: Adapted from TCiW, Welker et al. (2021).

Developing a strategy for monitoring and planning the programme

For planning a monitoring strategy, it is important to understand the patterns of bloom occurrence in time and space. For example, patterns of vertical mixing of the water body may determine formation of cyanobacterial scums, and wind direction can determine where scums accumulate.

Many cyanobacteria 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. Thus, an understanding of phytoplankton composition is a useful basis for assessing the risk of blooms at recreational water sites.

When and where cyanobacteria dominate 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 cyanobacteria and – if information is available – seasonal patterns in its previous bloom history is therefore very useful when planning a monitoring programme.

Especially during bloom development, it may be more useful to take multiple samples (at different 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. As for any monitoring programme, appropriate planning of fieldwork includes establishing the necessary routines with the laboratories conducting the analyses, training staff, testing the scheme in a pilot phase, and storing and documenting data (refer to TCiW, Welker et al., 2021).

The intensity of monitoring will depend on the intensity of recreational use of the site (Table 5.2) and bloom occurrence. 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). This could involve local capacity of, for example, site operators or lifeguards. As discussed in section 5.1.3.1, in the context of the ALF, monitoring of toxin concentrations can be used to calibrate other parameters locally, showing how toxin concentrations relate to measures of biomass (biovolume, chlorophyll a or other indicators of cyanobacteria). As cyanobacterial biomass usually changes more quickly than its toxin content, toxin concentrations can be analysed less often (e.g. monthly), using the most recent toxin/biomass ratio between analyses.

For an initial assessment – particularly where cyanobacteria have been observed – it is useful to assess whether TP concentrations are above 20–50 µg/L and thus capable of sustaining blooms. Where TP 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 TP 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 site users, should also be documented. Documentation is important to underpin the reasons for any site closure, as well as for establishing a longer-term understanding of the water body's bloom patterns.

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 (refer to Chapters 7–9 of TCiW). To get started, the following information, where available, is useful:

- nutrient concentrations (especially TP 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 – of lumps of detached material accumulating in the water or on the beach;
- seasonal dynamics of phytoplankton occurrence and taxonomic composition (refer to section 5.4.2);
- satellite images showing phytoplankton (chlorophyll) 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; and
- reports of suspected or demonstrated bloom-related illness in humans and animals (refer to section 5.1.2).

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 (refer to Example 5.1).

> **Example 5.1. Algal blooms and citizen science**
>
> Numerous citizen science schemes, ranging widely in complexity, address cyanobacterial blooms around the world; they include:
> - recruiting volunteer private pilots who have GPS-enabled cameras mounted on the wing underside of their small aircraft for monitoring Lake Erie (www.nasa.gov);
> - making turbidity measurements with Secchi discs; and
> - taking a photograph and uploading the location of a bloom on a mobile phone app.
>
> In the USA, for example, there are numerous coordinated citizen science monitoring projects addressing cyanobacteria – for example, bloomWatch, cyanoScope and cyanoMonitoring (https://cyanos.org). People choose their level of involvement in these projects, from uploading photographs of blooms, taking water samples and using microscopy to identify cyanobacteria, to a more complete water quality assessment. In Argentina, the CIANOBs project introduces schoolchildren to recognizing and reporting blooms using a simple worksheet (Giannuzzi et al., 2011; D'Anglada, 2020).
>
> Looking out for blooms is a valuable addition to routine monitoring and can potentially speed up public health warnings. These schemes have also been used to generate field data for research purposes, leading to scientific publications (Castilla et al., 2015; Cunha et al., 2017). Besides generating data, a central target of such programmes can be to raise awareness of the need to reduce nutrient loads and thus increase support for the necessary management measures.

Site inspection is an important basis for planning a monitoring programme, 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.

Water quality analysis

A range of biological, biochemical and physicochemical methods can be used to determine the likelihood of cyanobacterial blooms and their development, and concentrations of cyanotoxins. For more detailed information, refer to Chapters 12–14 of TCiW.

Key methods for assessing the likelihood of cyanobacterial blooms

As discussed in section 5.1.3, conditions relevant for bloom formation include nutrient concentrations (phosphorus and nitrogen), transparency, thermal stratification in the water body and the water exchange rate. Welker et al. (TCiW, 2021) introduce methods for measuring thermal stratification, flow rate and transparency.

Padisák et al. (TCiW, 2021) briefly outline the international standard methods for analysing nutrient concentrations, as well as emerging on-site methods. These are:
- ISO (2004) for phosphorus, both total and dissolved
- ISO (1988) for nitrogen
- ISO (1986a) if interference from other substances is a problem
- ISO (1984a, b; 1986b) for ammonium.

Observation of cyanobacterial occurrence

Methods to assess cyanobacterial occurrence include:
- straightforward visual examination on-site (e.g. the presence of scum or greenish turbidity, measuring transparency with a Secchi disc);
- sampling, cell counting and determination of the biomass of key species; microscopy to identify the dominant cyanobacteria present (TCiW, Padisák et al., 2021);
- estimation of biomass using
  - microscopy to determine cell numbers and biovolume (TCiW, Padisák et al., 2021), and/or
  - the concentrations of chlorophyll a (ISO, 1992) and phycocyanin (the pigment specific to cyanobacteria), measured by chemical means 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; and
- remote sensing to identify and track cyanobacterial blooms (TCiW, Welker et al., 2021).

Toxin analysis
Methods to detect and measure concentrations of many cyanotoxins in water include:
- enzyme-linked immunosorbent assay (ELISA);
- for microcystins, the protein phosphatase inhibition assay; and
- liquid chromatography (LC) 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 (UV/PDA).

Lawton et al. (TCiW, 2021) give 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 (refer to TCiW, Padisák 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).

5.2   Toxic algae and cyanobacteria in coastal water bodies

HABs in coastal and estuarine waters range from single-celled planktonic algae to seaweed-like filaments of cyanobacteria growing on sediments and surfaces. In marine water, dinoflagellates and diatoms cause most HABs, whereas, in fresh water, cyanobacteria cause HABs (refer to section 5.1). In marine water, cyanobacteria cause benthic HABs. One type is the underwater mats (seaweed-like cyanobacteria growing on surfaces), which can colonize sediment down to 30 m in depth, mostly but not exclusively in the tropics, and form filaments of 10–30 cm (mermaids' hair). Their former genus *Lyngbya* has now been reorganized, with some species now belonging to the genus *Moorea* and others to *Microcoleus*. The other type is the blooms of *Nodularia spumigena* in brackish waters, particularly the Baltic Sea (refer to section 5.1).

Blooms are mostly dominated by a single species, but can also consist of mixtures of species and strains, some toxin producing and some non–toxin producing. Contact with the bloom, particularly by ingestion, may result in negative health impacts caused by the toxins, by other unknown components of the cells, or possibly by other microorganisms associated with the bloom.

5.2.1   Marine algal toxins
Marine HABs primarily affect health through the ingestion of contaminated seafood (Berdalet et al., 2016). Many of the toxins are named by the syndromes they cause, such as paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP), amnesic shellfish poisoning (ASP), neurotoxic shellfish poisoning (NSP) and ciguatera fish poisoning (CFP) (Lehane & Lewis, 2000; Backer et al., 2005a). See Table 5.5 for a summary of the marine algal toxins relevant to human health.

Table 5.5
Marine algal toxins relevant to human health

Toxin	Organism and examples of genera that commonly produce the toxins	Health effects and comments
Aplysiatoxin, debromoaplysiatoxin	Benthic cyanobacteria: *Lyngbya, Phormidium/Schizothrix* (TCiW, Osborne, 2021)	Swimmer's itch or seaweed dermatitis
Azaspiracid	Dinoflagellate: *Protoperidinium*	Azaspiracid shellfish poisoning, known from eating contaminated seafood
Brevetoxins	Dinoflagellate: *Karenia*	Neurotoxic shellfish poisoning known from eating contaminated shellfish Respiratory irritation from inhaling contaminated aerosols
Ciguatoxins	Epibenthic dinoflagellate: *Gambierdiscus*	Ciguatera fish poisoning, known from eating contaminated finfish
Domoic acid	Diatom: *Pseudo-nitzschia*	Amnesic shellfish poisoning (ASP), known from eating contaminated shellfish
Lyngbyatoxin-a	Benthic cyanobacteria: *Lyngbya* (Cardellina, Marner & Moore, 1979)	Swimmer's itch or seaweed dermatitis, eye irritation
Nodularins	*Nodularia* *Nostoc*	Reports of fatal dog poisonings; see also Table 5.1
Oakadaic acid, dinophysistoxins	Dinoflagellate: *Dinophysis, Prorocentrum*	Diarrheic shellfish poisoning (DSP), known from eating contaminated shellfish
Palytoxins	Benthic dinoflagellate *Ostreopsis* (Carnicer et al., 2016)	Respiratory and skin irritation from exposure to aerosols, particularly when handling aquarium corals
Saxitoxins	Dinoflagellate: *Alexandrium, Pyrodinium, Gymnodinium*	Paralytic shellfish poisoning, known from eating contaminated shellfish; see also Table 5.1 and section 5.1 for recreational guideline values

Source: Adapted from Backer et al. (2003); Backer & Moore (2011).

5.2.2   Health effects

Exposure through dermal contact

Marine cyanobacteria can produce toxins, including aplysiatoxin, debromoaplysiatoxin and lyngbyatoxin-a (Fujiki et al., 1985; Shimizu, 1996; refer to overview by Osborne, 2021). Some of these toxins are responsible for severe contact dermatitis, known as swimmer's itch or seaweed dermatitis (refer to discussion in TCiW, Osborne, 2021; section 6.1.1.7). Severe skin lesions may occur when benthic cyanobacterial material is trapped under bathing garments, and these are the HAB symptoms for which the cause–effect relationship through recreational exposure has most tightly been demonstrated.

Except for reports of skin irritation in people using waters with an ongoing bloom of the dinoflagellate *Karenia brevis* (Backer et al., 2003, 2005b), there is little information on adverse effects of dermal contact with marine waters containing algal species producing DSP, PSP, ASP or NSP toxins, or species of marine dinoflagellates and flagellates that have been associated with the death of fish and invertebrates.

Exposure through ingestion of marine waters or scum

Some species of marine and estuarine HAB organisms can form dense scums or foams that contain high concentrations of cells and their toxins. However, scums occur less frequently in marine water than in fresh water. There is no evidence of significant human health impacts caused by direct ingestion of scums or HAB-affected marine recreational water.

Large blooms of the cyanobacterium *Nodularia spumigena* occur regularly in the Baltic Sea, and high concentrations of the associated toxin nodularin have been reported from coastal areas. Ingestion of toxic N. spumigena has been the cause of dog deaths, triggering concern about the safety of recreational uses of the affected sites.

Exposure through inhalation

There have been reports of respiratory symptoms and general malaise following water contact or inhalation of aerosols associated with planktonic HABs. Most arise from handling corals, with inhalation as the primary route of exposure and health effects possibly caused by aerosols containing toxins, cell fragments or accompanying microbiota (Casabianca et al., 2013; Ciminiello et al., 2014).

People visiting or working on beaches can be exposed to sea spray containing fragments of marine dinoflagellate cells and/or toxins released into the surf by lysed algae. Respiratory effects in beach visitors, lifeguards and people with asthma have been associated with exposure to brevetoxins during *Karenia brevis* red tide events (Backer et al., 2003, 2005b; Fleming et al., 2011). A study of the inland transport of brevetoxins during bloom events found measurable levels of toxins 4.2 km from the beach and 1.6 km from the coastal shoreline (Kirkpatrick et al., 2010a,b); however, it is not clear if the toxin levels are sufficient to cause adverse health effects at these distances from the blooms. The impacts of such red tide aerosols are also detectable at the population level in terms of respiratory emergency room visits and hospitalizations (Hoagland et al., 2014). Emergency room visits for gastrointestinal and neurological effects have also been associated with these blooms (Kirkpatrick et al., 2010a; Diaz et al., 2019). Although the critical route of exposure (inhalation or swallowing water) is not completely understood, exposure to brevetoxins can cause death of marine animals, including mammals, suggesting that both ingestion and inhalation are potential routes of exposure (Bossart et al., 1998; Flewelling et al., 2005).

Blooms of the dinoflagellate *Ostreopsis* spp. have been accompanied by reports of human illnesses, including 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.

Although research studies have found brevetoxins and microcystins in aerosol samples collected during *Karenia brevis* and *Microcystis aerusginosa* blooms, respectively, the data available at the time of publication of these guidelines are not sufficient to characterize toxin concentrations to expect in spray and aerosols, and their associated health effects. Thus, guidance for risk assessment or to support development of health-based guidance for this form of exposure cannot (yet) be given. For areas with stands of *Moorea producens* (formerly *Lyngbya majuscula*), not only the skin lesions mentioned above but also eye and respiratory irritation have been reported by people swimming in such areas (TCiW, Osborne, 2021; Osborne, Shaw & Webb, 2007).

5.2.3 Risk assessment and management

As for freshwater HABs, the potential for bloom development in marine and estuarine waters is associated with elevated nutrient concentrations, particularly total nitrogen (Anderson, Glibert & Burkholder, 2002). However, the environmental conditions that support excessive proliferation of specific harmful algal species are species specific; they depend not only on water quality but also on a range of environmental conditions, such as the presence or absence of algal species, the weather, and the presence or absence of grazing animals (Davidson et al., 2014).

Assessing exposure risks and short-term responses to prevent exposure

Available data indicate that the risk to human health associated with the occurrence of marine toxic algae or cyanobacteria during recreational activities is limited to a few species and geographic areas. For effective risk assessment, it is important to choose parameters that indicate HAB or toxin occurrence and to define the levels at which they trigger specific actions. The ALF introduced in section 5.1.3 for freshwater planktonic HABs may serve as model to adapt to marine settings, provided that suitable indicator parameters can be found to trigger responses. Example 5.2 describes a bloom response for marine benthic cyanobacteria using a three-level response plan to manage Moorea blooms and associated seaweed dermatitis in Australia.

Example 5.2. Management of *Moorea* blooms in Moreton and Deception bays, 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, monitoring for *Moorea* blooms has included monthly visual inspections from boats, combined with shore-based inspections for deposited material.[a] Inspections have been undertaken by state and local government officers, community groups and fishers.

Moreton Bay Regional Council published a Harmful Algal Bloom Response Plan in 2018,[b] with a focus on management of *Moorea* blooms. The plan includes monthly monitoring of northern Moreton Bay for blooms and a three-level response plan, as shown in the table.

Level	Detection	Response
1	Small to moderate bloom material at locations away from developed areas	No action required to remove material, but signs to inform the public of the presence of a potentially harmful algal bloom may be appropriate. Activate stakeholder communications.
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.
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.

[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] Moreton Bay Regional Council. (https://www.moretonbay.qld.gov.au/Services/Environment/Waterways/Lyngbya, accessed 29 May 2021)

Sustainable management of water bodies to remediate or prevent occurrence

Marine HABs appear to be increasing in frequency, magnitude and geographic extent (Anderson, Cembella & Hallegraeff, 2012). Factors that underlie this increase include increasing ocean pollution, particularly eutrophication (NRC, 2000; Glibert et al., 2005; Brown et al., 2006; Flynn et al., 2018), and sea surface warming associated with climate change (Flynn et al., 2018). Eutrophication can be mitigated by reducing nutrient loads (refer to section 5.1.3.2), particularly nitrogen and phosphorus in human and animal wastes and fertilizers, which travel from catchments to rivers and from there to coastal waters (Anderson & Garrison, 1997; Park et al., 2013; Yu et al., 2017).

Establishing platforms for communication and collaboration between the authorities that manage seafood (commercially valuable fish and shellfish) and recreational waters would be valuable to combine monitoring to serve both purposes – recreational and food safety.

5.2.4 Monitoring

In areas subject to marine toxic algae or cyanobacteria, adequate monitoring is important. Monitoring programmes should aim to prevent human exposure in affected areas.

Developing a strategy for monitoring and planning the programme

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 HABs
- allow recognition of a species that is new to the area
- indicate whether recurrent blooms have become toxic.

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 recognized, 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).

Ongoing monitoring programmes that can be used to monitor marine beaches exist in some areas where toxin-producing marine blooms affect commercially and recreationally valuable fish and shellfish. Citizen science programmes are another source of data that can support monitoring (refer to Example 5.1).

Exploring existing data and site inspection

The first steps in assessing the likelihood of HABs in coastal areas are the same as for cyanobacterial blooms in fresh water (refer to section 5.1.4.2).

Water quality analysis

A range of biological, biochemical and physicochemical methods can be used to determine the likelihood of algal blooms, examine their progress and detect toxins.

Identification of marine algae and cyanobacteria

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 et al. (2018) for marine phytoplankton, and Padisák 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 & St Amand, 2015).

Toxin analysis

Toxin analyses are important to allow management measures to focus on situations in which health risks from HABs are likely.

Rapid screening for HAB toxins can be done using immunoassays, receptor binding assays and cell toxicity assays (Diogène & Campàs, 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 (Diogène & Campàs, 2017).

Most of the instrumental analyses for marine toxins have been developed for the control of contaminated seafood. In this context, LC-MS methods are increasingly replacing high-performance liquid chromatography methods with optical detectors (Luckas, Erler & Krock, 2015; Diogène & Campàs, 2017).

Methods to detect HAB toxins in sea spray are an important component of monitoring. 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).

5.3   Public communication

A mainstay of safe site use is to ensure that users of recreational water bodies have sufficient information and are actively engaged in assessing when it is safe to use the water body for recreation. In fresh water, 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 site use. Options to provide information about acute bloom events include:

• the media, including social media;
• signposts, posters or flyers at the sites;
• telephone hotlines;
• local newspapers and websites
• public participation in citizen science projects such as scum scouting projects (refer to Example 5.1).

Such information channels are particularly important where monitoring occurs in the context of a bloom that might present a health risk. For fresh waters, such situations are most effectively managed in the context of an ALF that defines actions to take and communication channels to activate once alert levels are exceeded. Rescinding warnings after a bloom is equally important, both to avoid warning fatigue (leading to people ignoring warnings) and to avoid undue restriction of healthy outdoor water sports activities.

Although very few cases of human illness caused by recreational exposure to marine HAB toxins or cyanobacterial toxins are known, water body managers, lifeguards and so on should be prepared for such incidents. As people become more informed about harmful algal and cyanobacterial blooms and associated toxins, they may be more likely to suspect them to be the cause of symptoms experienced after recreational activity, and to seek medical advice. In addition, medical care providers need access to information about algal and cyanobacterial toxin effects, including what questions to ask their patients about exposure and what symptoms they may expect to see in exposed patients (Box 5.3).

Box 5.3. Criteria for establishing whether algal or cyanotoxins are likely causes of symptoms presented

The approach to establishing whether algal toxins or cyanotoxins are the cause of illness varies depending on the patient's presentation. For assessing cases with nonspecific symptoms (e.g. skin irritation, gastrointestinal illness), the co-occurrence of algal toxins or cyanotoxins does not necessarily indicate cause and effect. It is possible that the symptoms are associated with other etiologies (e.g. bacteria) or exposure to other agents associated with a bloom (e.g. in the mucilage of colony-forming cyanobacteria). In contrast, cause–effect relationships are more easily established if symptoms or analytical results are toxin specific (e.g. for hepatotoxins, elevated serum enzyme levels such as gamma glutamyl transferase; for neurotoxins, respiratory difficulties, tingling of extremities, confusion or visual disturbance). While finding algal toxins or cyanotoxins in body fluids of patients and/or cells in their stool confirms exposure, even this does not necessarily allow the conclusion that these were the cause of symptoms, as it is currently unknown how concentrations (e.g. in serum) relate to damage (e.g. in the liver).

Source: TCiW, Chorus & Testai (2021).

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 site closure). Beyond such immediate management responses, reporting suspected human and animal exposure, and collating such reports, is important for improving the evidence on the relevance of algal and cyanobacterial 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 site where patients were exposed.

Public health authorities should be informed when 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.

Minimizing the risk of exposure can be approached in two ways: as an immediate response to HABs by minimizing human exposure to HABs, and as longer-term management action, including site remediation to prevent or reduce HAB occurrence.

Precautionary measures to protect health and educate site users in areas where HABS may occur include:
- HAB bulletins published at intervals, irrespective of current bloom events;
- preparation and response plans (e.g. Abbott et al., 2009);
- risk communications plans; and
- information provided to the public using media such as telephone hotlines, social messaging or warning signs (Nierenberg et al., 2009).

The following provide useful general guidance for any area potentially affected by HABs (TCiW, Chorus & Testai, 2021).
- Avoid areas with visible algal concentrations and/or algal 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 aerosolized 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 algae or cyanobacterial blooms, or 'mermaid's hair' 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 bloom material.
- 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.

Although very few cases of human illness caused by toxic cyanobacteria are known, preparedness for such incidents is recommended: as people are more informed about toxic cyanobacteria, they may be more likely to suspect them to be the cause of symptoms experienced after recreational activity, and to seek medical advice. Medical services therefore need information about toxic cyanobacteria and guidance on assessing whether or not possible symptoms are likely to be caused by cyanotoxins (Box 5.2).

5.4   Research needs

Two primary research needs for recreational waters, for both marine and freshwater HABs, are 1) the quantitative and qualitative characterization of toxins in spray and aerosols generated during blooms, and 2) the signs and symptoms experienced by people and animals when exposed to these. Aerosol concentrations should be measured at various distances from the bloom event to assess how far concentrations that might induce symptoms or illnesses could be carried away from the bloom itself. Investigation of aerosol samples under bloom conditions, combined with epidemiological studies of the public health risks from exposure to bloom-related aerosols, would contribute to the body of evidence needed to develop public health guidance to appropriately describe and, if needed, limit human and animal exposures to these aerosols.

For freshwater HABs, 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 & Welker, 2021). Furthermore, some of the symptoms reported in connection with blooms might be due to microorganisms associated with the bloom.

So far, the guideline values for microcystins (MCs) are based on the derivation of tolerable intake 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, intraperitoneal data cannot be used for guideline derivation, and therefore currently the only option is a worst-case assessment based on MC-LR as one of the most toxic congeners. Chronic or subchronic animal assays with the 5–10 most frequently occurring congeners would be needed to allow derivation of guideline values for these as well. This is important to enable more realistic risk assessments, as the worst-case approach based on MC-LR may lead to undue measures such as closure of sites where the risk is actually very low.

A key problem for risk assessment is the rapid change of planktonic HAB biomass, depending on buoyancy of blooms, currents and wind direction. This rapid change raises questions about the value of snapshot-type monitoring. Developing approaches to continuous integrative monitoring would enable more appropriate risk assessment – for example, with permanently installed probes collecting indicative data such as pigment fluorescence, or with remote sensing. Although basic knowledge for these approaches exists (TCiW, Welker et al., 2021), they need to be further developed for affordable practical application.

Furthermore, standardization of methods for analysis of other HAB toxins, as well as provision of stadardized reference material for their quantification, is important for routine monitoring. This needs to encompass low-cost methods that can be implemented in many operational laboratories.

As for many hazards occurring in water used for recreation, studies of the economic impacts of HABs would be valuable to promote preventive measures, particularly when risk assessments lead to restrictions on site use.

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6 Other microbial hazards

In addition to microorganisms introduced to recreational waters through human or animal faecal contamination (Chapter 4), some other microorganisms may be relevant in some areas. These organisms may be indigenous to such areas or introduced – once introduced, they may be able to colonize the environment or be sustained through animal hosts.

This chapter describes the principal microorganisms of concern, where sufficient epidemiological evidence is available to link human infections to recreational water activities, and potential control measures. The chapter also discusses vector-borne pathogens and the risk of antimicrobial resistance in the context of recreational water exposure. Hazards associated with cyanobacteria and algae are described in Chapter 5. Pathogens transmitted via contact with beach sand (e.g. soil-transmitted helminths) are addressed in Chapter 7.

6.1   System assessment

6.1.1   Hazard identification

The range of microorganisms of possible concern is outlined in Table 6.1. These are covered in more detail in the subsections below.

Table 6.1
Microorganisms of possible concern in recreational water

Organism	Disease or condition	Source	Water type
Bacteria			
Aeromonas spp.	Wound infection, pneumonia, gastroenteritis	Autochthonous	Fresh and marine
Leptospira spp.	Leptospirosis	Animal urine	Fresh
Pseudomonas aeruginosa	Skin, ear and eye infections	Autochthonous	Fresh and marine
Staphylococcus aureus	Skin and wound infections	Humans, warm-blooded animals	Fresh and marine
Bacteria – noncholera vibrios			
Vibrio alginolyticus	Ear infections, soft tissue infections	Autochthonous	Marine
Vibrio cholerae non-O1/O139	Gastroenteritis, ear and wound infections	Autochthonous	Fresh and marine
Vibrio parahaemolyticus	Wound infection, pneumonia	Autochthonous	Marine
Vibrio vulnificus	Severe wound infection	Autochthonous	Marine
Free-living amoebae			
Acanthamoeba spp.	Amoebic keratitis	Autochthonous	Fresh
Naegleria fowleri	Primary amoebic meningoencephalitis	Autochthonous	Fresh (thermal)
Helminths			
Schistosomes – human *Schistosoma mansoni, S. intercalatum, S. guineensis S. mekongi, S. japonicum*	Intestinal schistosomiasis	Human or animal (in presence of snail intermediate host)	Fresh
S. haematobium	Urogenital schistosomiasis	Human or animal (in presence of snail intermediate host)	Fresh
Schistosomes – animal *Trichobilharzia* spp.	Swimmer's itch	Waterfowl (in presence of snail intermediate host)	Fresh and brackish

Aeromonads (*Aeromonas* spp.)

Aeromonas spp. are ubiquitous in aquatic environments (Janda & Abbott, 2010), and some have potential human health significance. They are generally considered to be opportunistic pathogens. 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 (Joseph et al., 1991; Vally et al., 2004; Kimbrough et al., 2016). Skin trauma (such as an open wound or penetrating injury) is typically required for wound infection. Respiratory tract infection in near-drowning patients and bacteraemia have also been observed. Pneumonia has been reported following aspiration of contaminated water and near-drowning incidents (e.g. Gonçalves et al., 1992; Ender et al., 1996).

Leptospires (*Leptospira* spp.)

Leptospires have a complex life cycle involving asymptomatic animal reservoirs, the susceptible host and the natural environment. Rodents (particularly rats) are major animal hosts (Goarant et al., 2019). Fresh water contaminated with urine and tissues of infected animals is an established source of pathogenic leptospires. Warm, nutrient-rich environments favour their persistence; leptospires have a relatively low resistance to adverse environmental conditions (e.g. low pH, desiccation, direct sunlight).

Leptospirosis has a worldwide distribution, and is endemic in tropical and subtropical regions. In Europe, it shows a strong seasonality, with the highest incidence rates from August to November.

The severity of illness and the types of symptoms vary widely, from subclinical or mild infections to serious, potentially fatal, disease. Leptospirosis is difficult to diagnose; quick and simple diagnostic tests are not readily available (Picardeau, 2013). Diagnosis is based on clinical suspicion and laboratory confirmation (Ahmed, Goris & Meijer, 2020).

Pathogenic leptospires can enter the body through cuts and abrasions, or via the mucous membranes of the mouth, nose and eyes during contact with contaminated fresh water (or direct contact with infected animals). Freshwater exposure associated with recreational activities other than swimming (e.g. canoeing, kayaking, water rafting, triathlon) has been linked to clusters of leptospirosis worldwide (Brockmann et al., 2010; Stern et al., 2010; Hochedez et al., 2011; Schreiber et al., 2015; Pagès et al., 2016; Bourque & Vinetz, 2018; Guillois et al., 2018; refer to Box 2.2 in Chapter 2). Potential preventive measures include protective clothing, dressing skin abrasions and chemoprophylaxis (Sejvar et al., 2003; Monahan, Miller & Nally, 2009).

Heavy rainfall and flooding contribute to emergence of leptospirosis, implying that climate change might lead to a further increase (Brockmann et al., 2010).

Pseudomonas aeruginosa

Pseudomonas aeruginosa is a ubiquitous environmental organism and can be found in faeces, soil, water, sewage and faecal sludge. It can be frequently isolated from marine and fresh water.

P. aeruginosa has been associated with skin rashes (folliculitis), and eye and ear infections, following body exposure to *Pseudomonas*-contaminated recreational water. Ingestion is not thought to be a significant route of infection. *P. aeruginosa* can also cause infections of the lungs, urinary tract and gastrointestinal tract. Although it is a leading cause of septicaemia, this is less likely via recreational exposures.

Staphylococcus aureus

Staphylococcus aureus is mainly associated with skin infections in recreational water users (principally from swimming-pool use). Common infections include infected cuts and scratches, boils, pustules, dermatitis, folliculitis and impetigo (WHO, 2006).

Although *S. aureus* is not a natural inhabitant of environmental waters, it has been found in both sand and water of marine sites and in fresh waters (Soge et al., 2009; Thapaliya et al., 2017). The major reservoirs for *S. aureus* are the skin, nose, ears and mucous membranes of warm-blooded animals. Recreational water users shed these organisms into the water (Plano et al., 2011).

Vibrio non-cholerae

Vibrio species occur naturally in marine, estuarine and freshwater environments in both temperate and tropical regions. They have been isolated from a variety of environmental samples, including water, sediment, plankton, shellfish and finfish.

Illness caused by *Vibrio* spp. has historically been observed primarily as cholera (in which a proportion of cases suffer fulminating and severe watery diarrhoea), which results from infection with toxigenic *V. cholerae* serogroup O1 or O139. The infectious dose for cholera appears to be high (10^6 organisms or more). It is unlikely that people bathing or involved in other recreational water activities would ingest vibrios in sufficient numbers to cause gastrointestinal illness in the absence of extreme faecal pollution (refer to Chapter 4). Thus, the focus is on the vibrios that have been recognized within the past two decades as causing illness following exposure to recreational water. Although there are a number of pathogenic Vibrio species, mainly the following four species have been associated with recreational water infection: *V. alginolyticus*, *V. vulnificus*, *V. parahaemolyticus* and non-O1/O139 *V. cholerae*.

The infections caused by these pathogens can be classified as intestinal (i.e. gastrointestinal illness) or extraintestinal (such as wound infection). The incidence of vibriosis – both intestinal and extraintestinal – is increasing. However, few countries have comprehensive surveillance systems for noncholera vibrio infections.

Intestinal vibrio infections are usually a result of consuming raw or undercooked seafood that is contaminated with vibrios (especially *V. parahaemolyticus*). Gastroenteritis caused by noncholera vibrios is often mild and self-limiting. A notable exception is *V. vulnificus*, which accounts for 95% of seafood-related mortalities in the USA (Baker-Austin & Oliver, 2018). Intestinal infections have been reported following ingestion of recreational fresh water (De Keukeleire et al., 2018), although at marine beaches quantitative microbial risk assessment (QMRA) identified oral exposure as being low risk (Dickinson, Lim & Jiang, 2013).

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). *V. vulnificus* causes wound infections following entry through a skin lesion or after trauma. Such infections are almost always associated with contact with seawater and/or 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 aerosol. 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*. Some other serotypes can also be toxigenic. Nontoxigenic, non-O1/O139 *V. cholerae* infections 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 nontoxinogenic *V. cholerae* has also been associated with pneumonia (Marinello et al., 2017).

Vibrios have been isolated in waters showing a broad range of salinities and pH values. *V. cholerae* and *V. mimicus* are the only species found in fresh water. They preferentially proliferate in warm (≥15 °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 (Vezulli et al., 2012; Baker-Austin et al., 2017), and nontoxigenic *V. cholerae* in fresh water (Kirschner et al., 2008).

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, Moura & Schuster, 2007; Diaz, 2011). Only members of the genus *Acanthamoeba* and *Naegleria fowleri* are known to be important in natural recreational waters (Health Canada, 2012). Both organisms are frequently isolated from warm fresh waters (Siddiqui & 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 cooling waters in temperate regions (Behets et al., 2007; Zbikowska, Walczak & Krawiec, 2013; Montalbano et al., 2017). However, the incidence of infection associated with these waters is extremely low.

Free-living amoeba, including *Acanthamoeba* spp., can act as natural hosts for a number of amoeba-resisting bacterial pathogens, including *Legionella* spp. and *Mycobacterium* spp. (Lu et al., 2015). They also seem to be capable of packaging pathogens (bacterial, viral, protozoan and fungal), which retain their infectivity and may aid in their dispersal (Atanasova et al., 2018; Samba-Luaka et al., 2019; Folkins, Dey & Ashbolt, 2020).

Acanthamoeba

Pathogenic species of *Acanthamoeba* cause two distinct clinical illnesses: granulomatous amoebic encephalitis, an extremely rare, fatal disease of the central nervous system occurring in immunocompromised patients; and amoebic keratitis (AK), a rare, vision-threatening infection of the cornea (Kot, Łanocha-Arendarczyk & Kosik-Bogacka, 2018). AK affects immunocompetent people of all ages. It is more common among contact lens wearers (Lorenzo-Morales et al., 2013; Garg, Kalra & Joseph, 2017), and the main risk of infection is poor contact lens hygiene (Carnt et al., 2018). Most cases are associated with poorly maintained swimming pools (Carnt et al., 2018). In people who do not wear contact lenses, predisposing factors are trauma and exposure to contaminated water or soil (Garg, Kalra & Joseph, 2017). Overall, the risk of infection from natural waters is low (Lorenzo-Morales et al., 2013), and recreational water is not considered to be a significant risk factor for acanthamoebic diseases. As a general precaution, swimmers should remove contact lenses before bathing in warm fresh water to avoid opportunistic microorganisms that may infect the eyes.

Naegleria fowleri

Naegleria fowleri is a free-living amoeba found in thermal freshwater habitats worldwide. Of more than 40 species in the *Naegleria* genus, *N. fowleri* is the only known human pathogen. The organism causes a rare, fatal primary amoebic meningoencephalitis (PAM) in humans. PAM results from the instillation of *N. fowleri* into the nasal passages, usually while swimming or diving. Infection usually results from swimming in contaminated (thermal) water (Heggie, 2010; Tung et al., 2013; Ali, Jamal & Farhat, 2020), although other water exposure pathways, such as ritual nasal ablution, have also been linked to PAM cases (Siddiqui & Khan, 2014).

N. fowleri has been isolated from both natural and artificial thermally enriched habitats, including geothermal hot springs, freshwater lakes and cooling tower effluent. Most important for recreational exposure is the ubiquitous presence of *N. fowleri* in tropical and subtropical fresh waters and hot springs (Martínez-Castillo et al., 2016). *Naegleria* can tolerate temperatures up to 46 °C. Although *N. fowleri* is most likely to be isolated from sites where the temperature is above 30 °C, the cysts can survive at 4 °C for at least 12 months, with retention of virulence (Martinez-Castillo et al., 2016).

Accurate diagnosis of PAM is difficult and often delayed, because symptoms are similar to any meningitis. The incubation period varies from 2 to 15 days. The infectious dose is not known.

Risk prevention measures include refraining from submersion and diving in warm freshwater bodies (>26 °C), and wearing a nose clip while bathing. Similar care should be taken for water sports involving a high degree of water contact, such as waterskiing (Heggie, 2010; Hlavsa et al., 2011).

Schistosomes

Schistosomes are parasitic blood trematodes with worldwide distribution. Different species have diverse (human or animal) host specificity, but all require freshwater snails as intermediate hosts. The nature and severity of the infection depend mainly on the causative agent.

Human schistosomes

Schistosomiasis caused by human schistosomes (*Schistosoma mansoni, S. intercalatum, S. guineesis, S. mekongi, S. japonicum* and *S. haematobium*) is one of the most prevalent waterborne parasitic infections, with 230 million people infected worldwide and 800 million at risk in 78 countries (Boissier, Mouahid & Moné, 2019). Human schisostomes are endemic in many tropical countries.

Human schistosomes are excreted in the faeces or urine of infected people (depending on the species). Excreted eggs contaminate freshwater environments, where, in the presence of a specific snail host, infectious cercariae (larvae) are released. Five of the six human *Schistosoma* species cause intestinal schistosomiasis, whereas *S. haematobium* infects the blood vessels of the urogenital system. Manifestations in other body organs are also possible (e.g. granulomatous lesions in the central nervous system, liver or spleen). Chronic infection may also lead to female infertility (Colley et al., 2014). In endemic regions, infection usually occurs in early childhood and may be sustained for several years or even for life. Peak infection rates are seen in early adolescence. Recreational bathing is one of the major risk factors, as it involves longer exposure than other activities, such as water collection (Sow et al., 2011; Phillips et al., 2018). In travellers or immigrants, acute schistosomiasis presents as Katayama syndrome, with nonspecific symptoms (fever, myalgia, headache and abdominal pain) that are difficult to differentiate from other travel-associated infections.

There have been several reports of schistosomiasis in tourists or participants in sports events following recreational water use in endemic areas, such as white-water rafting and kayaking in Uganda and Ethiopia (Schwartz et al., 2005; Morgan et al., 2010; Röser et al., 2018).

Cercarial dermatitis (swimmer's itch)

A very wide range of schistosomes from other species – mainly birds, but some mammals – can cause a condition known as cercarial dermatitis or, colloquially, swimmer's itch. Most reports are related to freshwater lakes, but some brackish waters and seawaters can also be a source of infection (Kolářová et al., 2012). Most swimmer's itch from recreational exposure is attributed to *Trichobilharzia* spp., especially in temperate climates (Horák et al., 2015).

Swimmer's itch is usually a harmless (if unpleasant) skin reaction, caused by cercariae burrowing into the skin, resulting in an allergic reaction and rash (Kolářová et al., 2012; Soldánová et al., 2013; Horák et al., 2015). Symptoms occur 1–48 hours after exposure on the body parts that came into contact with water; they can include tingling, burning or itching of the skin; small reddish pimples; and small blisters (Graciaa et al., 2018; Macháček et al., 2018). Repeated infections may lead to sensitization of the skin and more severe skin symptoms (Kolárová et al., 2012). Freshwater and marine cercariae have an identical clinical manifestation.

Cercarial dermatitis has been reported from every continent (Horák et al., 2015). In temperate regions of the northern hemisphere, swimmer's itch is usually reported in the summer, peaking in July and August (Gordy, Cobb & Hanington, 2018; Marszewska et al., 2018). This is associated with both higher activity among recreational water users and the effect of temperature on the schistosome life cycle: warmer water facilitates the release of cercariae (Marszewska et al., 2018).

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, Soldánová & Sures, 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).

Other organisms of potential concern

Several other aquatic bacteria have been implicated in infections following water exposure, including *Shewanella* spp., *Chromobacterium violaceum* and *Plesiomonas shigelloides* (Brulliard et al., 2017; Allou et al., 2018; Bourque & Vinetz, 2018). Most cases are secondary wound infections after trauma, but infections may proceed to bacteraemia in immunocompromised people (Diaz & Lopez, 2015). *Plesiomonas* infection more commonly manifests as gastroenteritis, although extraintestinal cases have also been reported (Janda, Abbott & McIver, 2016). Geothermal hot springs often harbour *Legionella* species (Hsu et al., 2006). However, natural hot springs have not been linked to legionellosis outbreaks. *Legionella* infections (manifesting as a severe respiratory disease or pneumonia) occur when thermal water is used in built spa facilities (Leoni et al., 2018).

Pathogenic fungi (such as *Candida* and *Cryptococcus* spp.) have been detected in surface water, but the association with human infection through recreational water exposure is unclear). Swimming was found to be a risk factor for otomycosis (Gharaghani, Seifi & Zarei Mahmoudabadi, 2015), and for keratitis while wearing contact lenses (Zimmerman, Nixon & Rueff, 2016). Near-drowning situations can be opportunities for infection by many opportunistic microorganisms (Sympardi et al., 2019).

Vector-borne pathogens

Several important insect vectors, such as *Anopheles* mosquitoes (which are responsible for malaria transmission) and *Aedes* mosquitoes (which harbour dengue, chikungunya, yellow fever, Zika and West Nile viruses), breed in stagnant warm water, such as the shallow regions of recreational areas (Caminade, McIntyre & Jones, 2019).

The geographic distribution and seasonality of several vector-borne infections are expanding, mainly in association with increasing global temperature. Other factors, such as international travel, also contribute to the emergence of vector-borne diseases in previously unaffected areas. The presence of a suitable vector helps introduced pathogens to become established (Sousa et al., 2012; Baylis, 2017).

Mosquitoes and ticks can transmit the zoonotic disease tularemia, caused by the bacterium *Francisella tularensis* (Hennebique, Boisset & Maurin, 2019). There are also documented cases of waterborne tularemia, following exposure to recreational water (swimming and near-drowning accidents).

6.1.2   Risk assessment

Detection

Detection techniques for environmental samples are available for most of the organisms listed above. They include culture methods, polymerase chain reaction (for quantitative determination) and phylogenetic analysis (needed for species-level identification of schistosomes; Horák et al., 2015). Environmental concentrations, where available, are listed in Table 6.2.

Quantitative microbial risk assessment

Several uncertainties hinder QMRA for these organisms. Dose–response relationships are often lacking, and exposure assessment for extraintestinal infections is also difficult, even if environmental concentration data are available.

In most cases, for the microbial hazards outlined in this chapter, initial risk assessment should be based on an understanding of the recreational water catchment, and the risk factors and preferences of the pathogens of concern (Table 6.2). An approach using QMRA modelling to identify critical concentrations of *P. aeruginosa* to control folliculitis associated with bathing has been presented by Roser et al. (2015).

Table 6.2
Risk matrix for organisms of concern

Organism	Water type	Environmental proliferation	Environmental numbers	Temperature requirements	Animal carrier(s)	Shedding by water users	Other risk factors	Population susceptibility
Aeromonas spp.	Fresh, marine	Yes	10^3–10^5 CFU (MPN)/100 mL (river, lake and marine water)[a]	Mesophilic – grow at 15–38 °C	No	No	Increased proliferation at higher temperature	Wound or trauma (bacteraemia more likely in immunocompromised)
Leptospira spp.	Fresh	No	10^2–10^3 CFU/mL (rural and urban surface water)[b]	More common in tropical and subtropical climates	Yes, especially rats	No	Presence of rodents, flooding. Extreme weather events due to climate change increase risk.	Existing skin lesion Adventure travel and recreational water sports Higher incidence in males
Pseudomonas aeruginosa	Fresh, marine	Yes	0–10^3 CFU/100 mL (lake and river water)[c] <1–44 CFU/mL (marine beach water)[d]	Mesophilic	No	No		
Staphylococcus aureus	Fresh, marine	No	<1–700 CFU/100 mL (marine beach water)[d,e]	Longer survival at colder temperature	Possible	Yes	Shedding by recreational water users	
Vibrio non-cholerae • *V. alginolyticus* • *nt-V. cholera* • *V. parahaemolyticus* • *V. vulnificus*	Fresh, marine	Yes	ND–104 CFU/100 mL; ND–105 GC/100 mL (*nt-V. cholera*; alkaline freshwater lake)[f] ND–7000 CFU/100 mL (*V. parahaemolyticus*; marine water)[g,i] ND–470 000 CFU/100 mL (*V. vulnificus*; marine water)[g]	Preferentially grow in warm water (>15 °C)	No	No	Shows strong association with water temperature. Climate change increases risk in temperate climates.	Existing wound or trauma Comorbidity (hepatic disease) increases risk of severe outcome.
Naegleria fowleri	Fresh	Yes	Up to 871 cells/L (river water)[h] 1.1–24.2 cells/L (thermal spring)[i]	Thermophilic (30 °C and above)	No	No	Naturally or artificially warm water bodies and hot springs. Climate change can extend habitat.	Most cases are children or adolescents; higher incidence for males

Table 6.2 continued

Organism	Water type	Environmental proliferation	Environmental numbers	Temperature requirements	Animal carrier(s)	Shedding by water users	Other risk factors	Population susceptibility
Avian schistosomes	Fresh, marine	Yes	Up to 3200 cercariae/25 L (temperate lake; qPCR)[j]	Prefers warm water	Yes – waterfowl and snails both required	No	Eutrophication, shallow water. Climate change can extend transmission and distribution.	Higher prevalence in children; more severe reaction on repeated contact
Human schistosomes	Fresh	Yes	Up to 52 cercariae/100 L (tropical lake; cercarometry)[k]	Prefers warm water	Yes – snail host required	Yes	Poor sanitation	Higher prevalence in children; acute reaction in travellers

CFU: colony-forming unit; GC: gene copies; MPN: most probable number; ND: not detectable; nt: nontoxigenic; qPCR: quantitative polymerase chain reaction.

[a] Figueras Salvat & Ashbolt (2019).
[b] Monahan, Miller & Nally (2009).
[c] Mena & Gerba (2009).
[d] Pinto et al. (2012).
[e] Plano et al. (2011).
[f] Bliem et al. (2018).
[g] Shaw et al. (2015).
[h] Cabanes et al. (2001).
[i] Kao et al. (2013).
[j] Rudko et al. (2018).
[k] Aoki et al. (2003).

6.1.3   Climate change

Natural water environments, including recreational waters, are expected to undergo major changes as a result of climate change: increasing water temperature, changing precipitation patterns, and expanding seasonality and geographic distribution of vectors. The trend is already evident in many regions.

Table 6.2 shows that several organisms of concern prefer warm temperatures. The prevalence of these organisms and the infections they cause may increase under conditions of global warming. For example, high temperatures (sea surface temperatures >18 °C) increase proliferation of vibrios (Schets et al., 2011).

Leptospirosis may also increase under conditions of climate change, because the survival of leptospires outside the host depends on humid and warm conditions. Thus, 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, Collares-Pereira & Ellis, 2011). Extreme weather events, such as flooding, also contribute to higher host interactions (Monahan, Miller & Nally, 2009).

Naegleria fowleri also preferentially proliferates in warm-water environments.

Schistosomes are sensitive to changes in temperature; 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, Cobb & Hanington, 2018).

6.2   Monitoring

6.2.1   Guideline values

Regular monitoring for these pathogens is currently not required in national guidelines and standards for natural recreational water, although *P. aeruginosa* and, in some countries, *S. aureus* are monitored in swimming pools. However, targeted screening for easily detectable organisms can be useful for investigative and research purposes (Kirschner et al., 2008; Strathmann et al., 2016; Rudko et al., 2018). Molecular methods provide fast screening tools for most of the organisms in this chapter.

Although infection with some of these pathogens via recreational water may be severe or even life-threatening, there are no dose–response relationships for these organisms. Consequently, it is not possible to recommend generally applicable, specific guideline values. However, authorities should be aware of the potential hazards posed and act using a risk-based approach. Where monitoring data are available and infections are known, site-specific values to trigger intervention can be defined, if required. If the prevalence of an organism is strongly dependent on environmental factors, indirect monitoring is also an option (e.g. water temperature as a warning sign for vibrios) (Semenza et al., 2017).

6.2.2   Operational monitoring of environmental factors

Regular monitoring data are generally not available for these microorganisms. Since they are indigenous or persistent in water environments, and not related to faecal pollution, monitoring of faecal indicator organisms cannot predict their occurrence. 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 vibrios and *Naegleria fowleri*)?
- Are waterfowl encroaching on a site?
- Has there been there heavy rainfall, which might increase the risk of leptospirosis?
- Are snail hosts of schistosomes present in the water body?

Under particular circumstances, such as the organization of a water sports event, it may be useful to take environmental samples before and after the event (DeNizio & Hewitt, 2019). As well, participants could be asked to report any symptoms to the organizers for approximately 2 weeks after the event so that appropriate data are available to track and attribute cause if infections arise.

6.2.3 Illness surveillance

Illness surveillance at a national level allows information on symptoms, severity, pre-existing conditions and the likely source of infection to be examined. 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, Cobb & Hanington, 2018). Where potentially fatal infections (e.g. PAM, severe leptospirosis) are suspected to be linked to a specific site, this information should be conveyed to local authorities and site managers.

6.3   Management and communication

Several types of control methods are appropriate for managing risk from some of these pathogens. The exact components of these methods, and the bodies responsible for their implementation, will depend on the pathogen and the setting. Potential control measures include site management, surveillance (illness and environmental) and awareness raising (including hygiene measures for recreational water users).

6.3.1   Site management

Animal control

Where animal carriers play a role in disease transmission (Table 6.2), the recreational 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 minimize the rodent population can be effective (Mohan, 2006).

For avian schistosomiasis, measures to discourage waterfowl and/or snails could be taken. Manual removal of snails and destruction of their habitat (by removing vegetation) has been successful and is preferable to chemical control methods (Horák et al., 2015). Use of chemical molluscides such as copper sulfate is not sufficient in itself to reduce the incidence of swimmer's itch, although it can reduce the number of snails (Froelich et al., 2019). Biological control of snails by the introduction of competing species or predators has been successful in preventing human schistosomiasis (Sokolow et al., 2016), and is also being tested for swimmer's itch sites (Marszewska et al., 2018). Another option to break the life cycle of schistosomes is treating waterfowl with antihelmintics (De Liberato et al., 2019).

WASH interventions

Of the organisms discussed in this chapter, human schistosomiasis is the only one for which appropriate WASH (water, sanitation and hygiene) interventions can significantly reduce incidences. Available sanitation facilities that safely retain urine and faeces for at least 24 hours significantly reduce the number of viable schistosome eggs, as most eggs will hatch in the first 8 hours (Grimes et al., 2015). For more information on reducing faecal contamination, refer to Chapter 4.

Advisories

Where a site has been linked to infection or has conditions that are suitable for the causative organism, this information should be made available to site 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, precipitation, time of day), advisories should be issued accordingly. Signage can be posted on-site or made available online. Advisories should also include advice on appropriate water user behaviour and specific risks for vulnerable groups (refer to section 6.3.2).

6.3.2 Awareness raising

Raising the awareness of users 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 recognized as quickly as possible.

Water users

Users of recreational water can 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 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, Cobb & Hanington, 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).

Showering and towelling are also advised to prevent swimmer's itch, although the impact might be limited, as cercariae 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) can reduce exposure (Rudko et al., 2018).

When using warm freshwater sites and hot springs, it may be prudent to assume a possible risk from *Naegleria fowleri* (Tung et al., 2013). Exposure can be reduced by minimizing the amount of water entering the nose (e.g. keeping the head above water, holding the nose shut, using a nose clip) (Heggie, 2010).

Users of recreational water should familiarize themselves with the possible risks and symptoms of infection. 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 and human schistosomiasis has been suggested for participants in water sports events or adventure travellers in endemic areas (Sejvar et al., 2003; Röser et al., 2018).

If an infection develops 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 site, type of water (fresh or marine) and details of any incident.

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.

Everyone travelling to areas where these diseases are endemic should be aware of the potential risks and seek medical advice, especially if they plan to engage in recreational water activities (Bourque & Vinetz, 2018).

Advice to medical professionals

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 & Trimmier, 2017). Practitioners should pay attention to risk behaviours such as travel to endemic areas, adventure travel and extreme water sports (Bourque & Vinetz, 2018; Mavridou et al., 2018).

6.4   Research needs

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 for these other microbial hazards is the lack of data to inform quantitative 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 range of the host species (i.e. for schistosomes) and conditions that favour proliferation.

In addition, for most pathogens, available research is from temperate climates (with the exception of human schistosomiasis and leptospirosis). More data are needed on the prevalence of these other hazardous microorganisms and their associated infections in subtropical and tropical areas.

Research is also needed to develop QMRA models to inform action level concentrations of non-enteric pathogens. Follow-up studies on the efficiency of various management practices, including communication campaigns to reduce infections, should be expanded.

Large water sports events could be used as sentinel study sites to monitor both health and environmental outcomes from these other microbial hazards.

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7 Beach sand

Beaches consist of the unconsolidated sediment that lies at the junction between water (oceans, lakes and rivers) and land; they are usually composed of sand, mud or pebbles. Sand beaches are sought after for recreation. In some cases, especially at higher latitudes, a significant proportion of time is spent on the beach rather than in the water. Activities involving sand may include beachside sports and playing with sand, which have health benefits through exercise and recreation.

Microorganisms are a significant component of beach sand – bacteria, fungi, parasites and viruses have all been isolated from beach sand, and some are potential pathogens. Accordingly, concern has been expressed that beach sand or similar sediments may act as reservoirs or vectors of infection, as well as a source of water contamination (Whitman et al., 2014; Solo-Gabriele et al., 2016; Weiskerger et al., 2019).

This chapter describes microorganisms in beach sand, links to human health and recommended management actions.

Other hazards that affect beach sand quality include chemical contaminants (refer to Chapter 8), and the presence of solid wastes, plastics, insects and sea wrack on the beach (refer to Chapter 9).

7.1 System assessment

7.1.1 Pathogens of relevance for beach sand

Table 7.1 provides data on infectivity and concentrations observed in beach sand for selected microorganisms.

Faecal indicator organisms

Faecal indicator organisms (FIOs; refer to section 4.2.3.1) are nonpathogenic microorganisms that are used to indicate the degree of faecal contamination of the environment. FIOs include intestinal enterococci, Escherichia coli, bacteriophages, Candida albicans and clostridia. Intestinal enterococci are the recommened FIO for beach sand; guideline values are shown in section 7.2.1.

Thermotolerant coliforms and 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 & Fujioka, 1995; Aulicino, Volterra & Donati, 1985; Roses Codinachs et al., 1988; Badilla-Aguilar & Mora-Alvarado, 2019).

Numbers of FIOs in recreational waters correlate with the numbers of FIOs in adjacent beach sand (Phillips et al., 2011). For recreational beaches, improved sand quality is often associated with improved water quality.

Bacteria

Staphylococcus aureus

The origin of Staphylococcus aureus (refer to section 6.1.1.4) in beach sand is human activity. Its occurrence correlates with the number of swimmers on the beach (Papadakis et al., 1997; Plano et al., 2011). Many studies in the USA have demonstrated the presence of *S. aureus* in beach sand, including methicillin-resistant *S. aureus*, at both marine beaches (e.g. Soge et al., 2009; Plano et al., 2011; Shah et al., 2011; Goodwin et al., 2012) and freshwater beaches (Thapaliya et al., 2017). A study conducted at 10 beaches in South Africa found that 100% of the S. aureus isolates evaluated showed multiple antibiotic-resistance patterns (resistant to three or more antibiotics) (Akanbi et al., 2017).

Table 7.1
Selected microorganisms in beach sand

Microorganism	Disease/role	Sources	Infectivity (low, medium, high)	Type of data available	References
Bacteria					
Campylobacter spp.	Gastroenteritis	Animal and human faeces	Low (800–10^6 CFU)	Prevalence	Yamahara et al. (2012)
Clostridia	FIO	Animal and human faeces	NA	—	—
Escherichia coli	FIO	Animal and human faeces	High (1–100 CFU)	Quantitative	Abdelzaher et al. (2010) Shah et al. (2011)
Intestinal enterococci	FIO	Animal and human faeces	NA	Quantitative	Abdelzaher et al. (2010) Shah et al. (2011)
Salmonella spp.	Gastroenteritis	Animal and human faeces	Low (>10^5 CFU)	Prevalence	Viji et al. (2019)
Staphylococcus aureus	Skin infections, sepsis	Humans	Low (>10^5 CFU)	Prevalence	Thapaliya et al. (2017)
				Quantitative	Abdelzaher et al. (2010)
				Quantitative	Plano et al. (2013)
Pseudomonas aeruginosa	Ear, respiratory and skin infections; sepsis	Natural	NA	Quantitative	Tugrul-Icemar & Topaloglu (2011)
Vibrio alginolyticus	Ear and wound infections, gastroenteritis	Natural	NA	—	—
Vibrio parahaemolyticus	Ear and wound infections, gastroenteritis	Natural	Low (10^7–10^8 CFU)	—	—
Vibrio vulnificus	Ear and wound infections, gastroenteritis, sepsis	Natural	NA	Presence/ absence	Abdelzaher et al. (2010)
Vibrio cholerae non-01/0139	Ear and wound infections, gastroenteritis	Natural	Low (10^3–10^8 CFU)		
Viruses					
Bacteriophages	FIO	Animal and human faeces	NA		
Norovirus	Diarrhoea	Human faeces and vomitus	High (~20 viral particles)	Presence/ absence	Abdelzaher et al. (2010)
Adenovirus	Diarrhoea, respiratory infections	Human faeces	Medium (~150 PFU)	Prevalence	Monteiro et al. (2016)
Enterovirus	Gastroenteritis, fever, skin rash, conjunctivitis	Human faeces	High (<18 PFU)	Presence/ absence	Abdelzaher et al. (2010)
Reovirus	Gastroenteritis, fever	Human faeces	NA		
Hepatitis A virus		Human faeces	NA	Presence/ absence Prevalence	Abdelzaher et al. (2010) Monteiro et al. (2016)
Hepatitis E virus		Animal and human faeces	NA	Prevalence	Monteiro et al. (2016)
JC polyomavirus		Human urine	NA	Prevalence	Monteiro et al. (2016)

Table 7.1 continued

Microorganism	Disease/role	Sources	Infectivity (low, medium, high)	Type of data available	References
Helminths					
Toxocara spp.	Diarrhoea, abdominal pain, malnutrition	Dog faeces	NA	Prevalence	Bojar & Klapec (2018)
Ancylostoma spp.	Diarrhoea, abdominal pain, malnutrition	Cat or dog faeces Human faeces	Medium (~10 larvae)	Prevalence	Bojar & Klapec (2018) Silva et al. (2009)
Tricuris spp.	Diarrhoea, abdominal pain, malnutrition	Human faeces	Medium (~10 larvae)	Prevalence	Bojar & Kłapec (2018)
Ascaris spp.	Diarrhoea, abdominal pain, malnutrition	Human faeces	Medium (~10 larvae)		Silva et al. (2009)
Protozoa					
Giardia lamblia	Gastroenteritis	Animal and human faeces	Medium (10–100 cysts)	Presence/absence	Abdelzaher et al. (2010)
				Quantitative	Shah et al. (2011)
Cryptosporidium parvum	Gastroenteritis	Animal and human faeces	High (1–5 oocysts)	Presence/absence	Abdelzaher et al. (2010)
				Quantitative	Shah et al. (2011)
Fungi					
Aspergillus spp.	Aspergilloma, aspergillosis, onychomycosis, allergy	Natural	Opportunist	Prevalence	Sabino et al. (2011)
Dermatophytes	Onychomycosis, tinea	Skin of animals and environmental (depending on species)	High	Prevalence	Sabino et al. (2011)
Candida spp.	Candidosis (systemic and superficial infections)	Gut, skin and mucosae of animals	Opportunist	Prevalence	Sabino et al. (2011) Zanoli Sato et al. (2005)
Histoplasma capsulatum	Histoplasmosis (flu-like syndrome)	Guano of birds and bats	Medium	No data	NA
Blastomyces dermatitidis	Blastomycosis (flu-like syndrome)	Decaying vegetable matter	Low	No data	NA
Cryptococcus spp.	Cryptococcocal meningitis, pneumonia, systemic infection	Decaying vegetable matter and bird droppings (especially pigeons)	Low (medium for C. deuterogatii)	No data	Maziarz & Perfect (2016)
Cladophialophora bantiana	Cerebral infection (phaeohyphomycosis)	Soil and rotten plant material	Low	No data	Sabino et al. (2014)
Fusarium spp.	Keratitis, onychomycosis, endophthalmitis, skin infection, musculoskeletal infections	Water and plants	Opportunist	Prevalence	Sabino et al. (2014)

CFU: colony-forming unit; FIO: faecal indicator organism; NA: not applicable; PFU: plaque-forming unit.

Pseudomonas aeruginosa and Vibrio spp.

P. aeruginosa (refer to section 6.1.1.3) has been isolated from beach sand in a number of countries (Ghinsberg et al., 1994; Mendes et al., 1998; Esiobu et al., 2013; Elmanama et al., 2005; Tugrul-Icemar & Topaloglu, 2011). Vibrio species (refer to section 6.1.1.5) have also been detected in beach sand (Elmanama et al., 2005; Abdelzaher et al., 2010; Shah et al., 2011; Viji et al., 2019).

Other bacteria

Other bacteria that can be zoonotic, such as *Campylobacter* spp. and *Salmonella* spp., which mainly cause gastrointestinal infections in humans, have been isolated from wet and dry sand at beaches in a number of countries (Bolton et al., 1999; Shatti & Abdullah, 1999; Vieira et al., 2001; Elmanama et al., 2005; Byappanahalli et al., 2009; Yamahara et al., 2012; Kahn et al., 2013). Bird faeces may be an important source of these pathogens (Whitman et al., 2014).

Viruses

Viruses that have been detected in beach sand include enteric viruses, hepatitis A virus and human adenovirus (Nestor et al., 1984; Pianetti et al., 2004; Monteiro et al., 2016). Relatively little work has been done on the presence in beach sand of enteric viruses that cause diarrhoea in humans.

Protozoa

The zoonotic and human protozoan parasites *Cryptosporidium* spp. and *Giardia* spp. have both been detected in beach sand (Zanoli Sato et al., 2005; Abdelzaher et al., 2010; Shah et al., 2011). These organisms cause gastrointestinal illness in humans.

Helminths

Beach sand has been found to contain eggs and/or larvae of the human and zoonotic parasites *Toxocara* spp. (roundworm), *Ancylostoma* spp. (hookworm) and *Trichuris* spp. (whipworm) (Schöttler, 1998; Silva et al., 2009; Bojar & Klapeć, 2018); *Ascaris lumbricoides* (roundworm) has also been detected (Silva et al., 2009). Most helminths are transmitted via oral exposure; however, hookworms can penetrate skin that is in contact with sand (e.g. when walking or sitting on the beach).

Infections with these helminths are generally asymptomatic when people are infected with a few worms; however, when infected with large numbers of worms, people may suffer from gastrointestinal disease (*Ascaris*, *Trichuris*, human *Ancylostoma*), and children's growth may be stunted (*Ascaris, Trichuris*). Toxocara larvae travel through the organs of infected people, causing fever, coughing, enlarged liver and pneumonia. Animal hookworms remain in the epidermis, causing cutaneous larva migrans presenting as pruritic rash (Heukelbach & Feldmeier, 2008).

Transmission of parasites to humans from beach settings has been documented during an outbreak of *Ancylostoma* spp. (feline hookworm) (Mann, 2010). The outbreak was linked to overpopulation of feral cats due to illicit feeding stations. Sporadic travel-associated and endemic cases have been reported from both tropical and temperate regions (Heukelbach & Feldmeier, 2008; Sow et al., 2017). Lithuania included helminths in its recreational water regulation in 2018 (Ministry of Health of the Republic of Lithuania, 2007).

Fungi

Exposure to environmental fungi may lead to opportunistic infections, especially in immunocompromised people (de Hoog et al., 2000). Superficial fungal infections are estimated to affect 20–25% of the world's population (Male, 1990); the responsible fungal species and prevalence vary by country and region (Havlickova, Czaika & Friedrich, 2008). Some health problems favour the invasive process of serious fungal infections (Bongomin et al., 2017) – for example, asthma, cystic fibrosis, AIDS, cancer, organ transplantation and corticosteroid therapies. It is therefore desirable to limit exposure to fungi.

Dermatophytes (considered pathogenic and a dominant cause of superficial fungal infections) have been detected at beaches in Portugal (Sousa, 1990). Higher densities of beach users lead to higher levels of dermatophytes during the summer months (Brandão et al., 2002).

To date, relatively few studies outside Europe have looked at fungal contamination of beach sand. However, endemic fungal pathogens may be present in some regions, especially in inland water masses (Kidd et al., 2004; Kantarcioglu et al., 2017; Miceli & Krishnamurthy, 2019). Human migratory movements or expansion of habitats of fungi (e.g. due to climate change) are expected to occur with increasing frequency, thus promoting global spread (Datta et al., 2009; Weiskerger et al., 2019).

Candida albicans and other *Candida* spp. have been detected in sand beaches around the world. Emerging pathogens should be considered when addressing beach sand and possible deposition by nearing waters – for example, the multidrug-resistant and higher-salinity-tolerant *Candida auris* (Jeffery-Smith et al., 2018). Some emerging species, and even some well-characterized and long-reported species, show increasing resistance to antimicrobials – for example, several species in the *Aspergillus* section *Fumigati* (Alcazar-Fuoli et al., 2008), a common beach sand contaminant that has reportedly caused infections in hospitalized patients in the Netherlands (Warris et al., 2003).

Information on infection resulting from fungal inhalation specifically from sand is unavailable. However, exposure to fungal spores can trigger an immune response (Buskirk et al., 2014; Tanaka et al., 2015). The public should be informed about the presence of allergenic fungi.

7.1.2 Dispersion and fate of microorganisms in beach sand

Fig. 7.1 shows a conceptualization of the dispersion and fate of microorganisms in beach sand.

Red spots in Fig. 7.1 represent the distribution of FIOs within the beach. The panel on the left emphasizes the distribution of various sources; the panel on the right emphasizes transport along the wave-impacted shoreline, including the freshwater definition of the foreshore and the marine water definition of the intertidal zone. The figure illustrates the seepage face for times when the mean surface water elevation is below the groundwater table (shown by the dotted lines). It shows infiltration that occurs when the surface water level rises above the groundwater table (shown by dashed lines), as typically occurs during wave run-up. The inverted triangles mark the lines that define the water table for each of these conditions.

Sources of microorganisms

Microorganisms are natural inhabitants of beach sands. Levels of pathogenic microorganisms in beach sands can increase through direct deposition from humans and animals (e.g. dogs, birds, wildlife). Microorganisms can also be introduced to sand from runoff and other sources introduced through water, such as from sewage, septic tank effluent and faecal sludge, or shedding by recreational water users, which can be carried onto the sand by waves and tides (Whitman et al., 2014). River-based beaches may have a dynamic of their own (Whitman, Nevers & Byappanahalli, 2006). Atmospheric processes may also carry microorganisms from local faecal sources (e.g. farms, wastewater plants) and from the global circulation of dust (Kellog & Griffin, 2003).

Proliferation of microorganisms

Once introduced, microorganisms can persist and potentially multiply in the beach environment in response to environmental factors, including availability of moisture, sunlight and nutrients. The availability of nutrients can be influenced by the presence of submerged vegetation and wrack along the shore (Imamura et al., 2011; Weiskerger et al., 2019). Temperature influences survival of bacteria in sand: FIO concentrations can increase over temperature ranges from 4 to 44.5 °C (Byappanahalli et al., 2003; Alm, Burke & Hagan, 2006; Byappanahalli et al., 2007).

Fig. 7.1
Conceptualization of dispersion and fate of microorganisms in beach sand
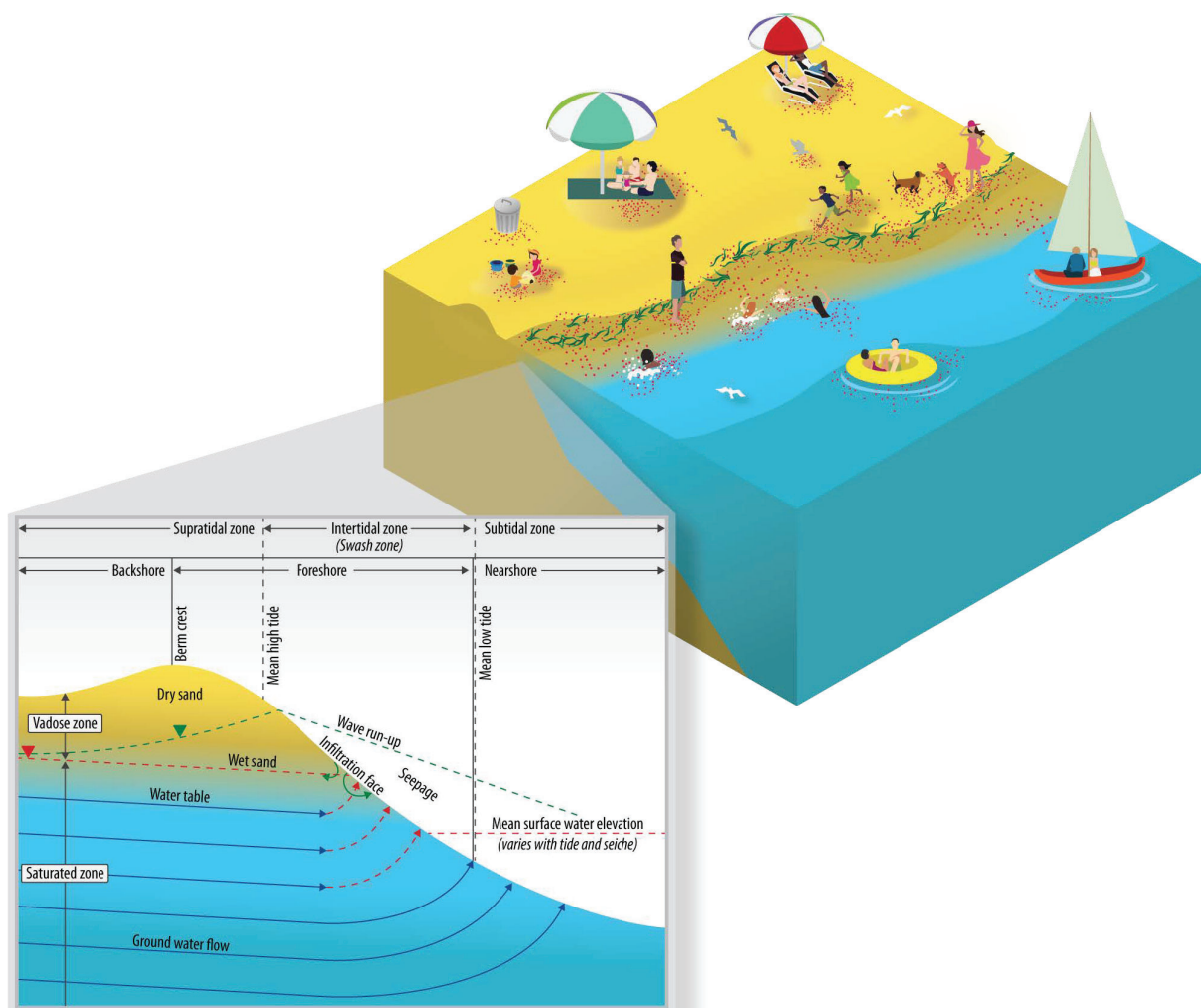
Note: The vertical aspect is intentionally exaggerated. Adapted from Weiskerger et al. (2019) and Whitman et al. (2014); editing courtesy of Elizabeth Gabriele.

The persistence and proliferation of microorganisms in beach sands may be facilitated by the formation of biofilms (Piggot et al., 2012), formed from bacterial secretions. Biofilms create microenvironments that can benefit microorganisms by providing access to nearby nutrients, and protection from harmful chemical and biological agents.

The environmental conditions conducive to survival and proliferation mean that background levels of microorganisms, including FIOs, may be higher in tropical and subtropical climates than in temperate regions (Fujioka et al., 1999; Fujioka, 2001), but this concept has been challenged by Byappanahalli et al. (2003b).

Influence of environmental factors

Various physical and geomorphological factors may encourage the survival and dispersion of FIOs and pathogens on beach sand. These include waves and tidal phenomena (refer to Fig. 7.1). Higher levels of sand microorganisms are observed at beaches with low-energy wave conditions (Gao, Falconer & Lin, 2015; Feng et al., 2016). Thus, enclosed beaches generally accumulate more microorganisms in the sand than direct ocean-facing beaches.

Waves lead to infiltration of large quantities of surface water and associated constituents (e.g. FIOs and nutrients across the beach face; Vogel et al., 2016). During periods of extreme wave conditions, such as hurricanes, the sediments are washed out and eroded, resulting in exposure of sand with lower microorganism levels (Roca, Brown & Solo-Gabriele, 2019). If the waves carry pollutants, the opposite may be observed immediately after hurricane conditions (Suzuki et al., 2018), but there may be a delay in the migration of the contaminants in either direction due to cumulative effects.

Tidal fluctuations (or, in freshwater systems, water fluctuations due to lake standing waves) also drive water across the beach face. Infiltration captures FIOs in the upper intertidal region, and exfiltration leads to FIO loss at the lower tide mark (Gast, Elgar & Raubenheimer, 2015; Wu et al., 2017). The area with the highest levels of FIOs on tidally influenced beaches is the sand just above the high tide mark (Abdelzaher et al., 2010; Whiley et al., 2018); for lakes, it is the backshore (Cloutier & McLellan, 2017; refer to Fig. 7.1 for locations). These areas may have ideal moisture conditions for prolonged persistence. As a result, the sand has been identified as the source of bacteria to the adjacent waters in many studies; levels of bacteria in water decrease with distance from shore (e.g. Tyner et al., 2018).

Urbanization in the vicinity of the beach and periods of heavy beachgoer use have been associated with higher microorganism levels (Aragonés et al., 2016; Villacampa et al., 2017; León-López et al., 2018).

Sediment type may also affect microorganism levels (Hernandez et al., 2014; Abreu et al., 2016; Villacampa et al., 2017). The presence of microplastics in sand has been associated with elevated pathogen levels (Curren & Leong, 2019).

7.1.3 Linking human health to beach sand quality

Methods to relate sand quality to human health include epidemiological studies and risk assessments.

Epidemiological studies

Evidence exists to link beach activities, beach sand quality and human health impacts. Example 7.1 describes an outbreak associated with sand (Brandão et al., 2020). Other epidemiological studies have linked sand contact with gastrointestinal illness (Bonilla et al., 2007; Heaney et al., 2009, 2012; Lamparelli et al., 2015) and skin symptoms (Esiobu et al., 2013; Praveena et al., 2016).

Example 7.1. A sand related outbreak in Azores, Portugal

Thirty people (mostly children) experienced an episode of skin rash days after a sand-sifting beach operation at Porto Pim Beach in Faial, Azores, during June 2019. An environmental and epidemiological investigation was conducted to identify the cause of the outbreak. The epidemiological investigation found that some of the patients experiencing symptoms had never entered the beach water. During the pollution period and throughout the epidemiological investigation, faecal indicator bacteria levels in water remained under the limits used for an "excellent" designation for coastal bathing water. Thus, sand contact was considered as a likely primary exposure route. Sand microbiological analysis for FIOs and electron microscopy strongly suggested faecal contamination. Gas chromatography and subsequent free chlorine analysis suggested the presence of sodium hypochlorite. Inspection of the toilet facilities and sewage disposal system revealed a leaking sewage distribution box. Collectively, results suggest that the cause of the outbreak was the leaking underground sewage distribution box that serviced the beach toilet facilities, where sodium hypochlorite was used for cleaning and disinfection. This sewage then contaminated the surficial sands to which beachgoers were exposed. Chlorine, an irritant substance, was believed to have been the cause of the symptoms, given the sudden presentation and dissipation of skin rashes. No gastrointestinal illness was reported during this episode and during the following 30 days.

Source: Brandão et al. (2020).

Quantitative microbial risk assessment

Quantitative microbial risk assessment (QMRA) provides an alternative to epidemiological studies for assessing health risks from beach-associated pathogens (Haas, Rose & Gerba, 1999; Ashbolt et al., 2010; Jang & Liang, 2017). QMRA methods are generally less expensive and less time-consuming than epidemiological studies; however, the relationships needed for calculating risks and disease rates are not always available (e.g. dose–response relationships for some microorganisms).

QMRA has been applied to estimate health risks from exposure to beach sand. Applying a set level of risk of gastrointestinal illness (19 cases per 1000 swimmers) to beach sand, Shibata & Solo-Gabriele (2012) calculated acceptable risks at <10 oocysts/g sand for *Cryptosporidium*, <5 MPN (most probable number)/g sand for enterovirus, and <10^6 CFU (colony forming units)/g sand for *Staphylococcus aureus*. Sabino et al. (2011) recommended maximum levels of 15 CFU/g for yeasts, 17 CFU/g for potential pathogenic fungi, 8 CFU/g for dermatophytes, 25 CFU/g for *E. coli* and 10 CFU/g for enterococci.

7.2 Monitoring

7.2.1 Guideline values

The recommended provisional guideline value for beach sand is 60 CFU/g of intestinal enterococci, based on the derivation below.

Assessing the relative risk of exposure to sand versus water requires setting an equivalency between the uptake of microorganisms from water versus uptake from sand. The equivalency would correspond to the 200 CFU/100 mL for intestinal enterococci via water ingestion. Values of water and sediment consumed are available in the literature. Seawater ingestion rates by children during swimming have been estimated at 30 mL (Schets, Schijven & de Roda Husman, 2011). Estimated sand ingestion rates for children are variable, depending on whether the children have pica tendencies (i.e. an above-normal tendency to consume soil). The low end of soil consumption for a child with pica tendencies is estimated at 1000 mg/day (USEPA, 2011). For children without pica tendencies, the consumption rate is estimated at 190 mg/day (Van Wijnen, Clausing & Brunekreff, 1990). The equivalent enterococci concentrations in sediments would correspond to 60 CFU/g, assuming sand consumption rates for children with pica tendencies. With assumptions about ingestion rates of seawater and sand, a very rough estimate of acceptable levels of enterococci in sand, C_s (units of CFU per mass of sand), can be established using the following equation:

$$C_s = \frac{C_w V_w}{M_s}$$

where C_w is the concentration in the water, V_w is the volume of water consumed, and M_s is the mass of sediment consumed per beach visit. However, the above expression depends on a significant assumption: that the ratios and uptake of enterococci and pathogens are the same for water and sand. The 60 CFU/g (wet weight) is within the same order of magnitude as the 10 CFU/g level recommended by Sabino et al. (2011) (refer to section 7.1.3.2). Assuming equivalent pathogen ratios and uptake rates, these values can be used provisionally as a rule of thumb to determine whether beach sand is in need of improved management to reduce FIOs.

Although no set guideline values can be provided for other microorganisms in beach sand, local epidemiological and QMRA studies are encouraged to establish such values (risk-based and local characterization approaches). Recently, a pan-European initiative has established 90 CFU/g of sand as a site-blind average value for fungi (Brandão et al., 2021). Further work on fungi and other biological groups is necessary to establish actual exposure thresholds to use in analytical recommendations. In the absence of guideline values, efforts should focus on preventive measures. Management, education and communication (refer to section 7.3) are important precautionary measures, as are components of local water safety plans (refer to Chapter 2).

7.2.2 Operational monitoring

Operational monitoring of sand – through visual inspections of the beach and potential sources of contamination identified in the sanitary survey – is a relatively simple and cost-effective approach to complement periodic microbial testing to verify sand quality. For example:

- Are open defecation or discharges of faecal sludge prevalent at this site? Are public toilets available and clean?
- Are measures to manage animal faeces, particularly from dogs and cats, consistently applied?
- Are there signs of contamination by industrial or agricultural discharges, such as oils or tar?
- Are measures to manage litter, debris and macroalgae (refer to Chapter 9) consistently applied?

In 2017, Argentina included in its recreational water regulation a set of locally relevant "yes or no" sand quality parameters for operational monitoring of industrial discharges, agricultural drainage, navigation pollution, superficial urban runoff, plastic residue, tar, seaweeds, and other residues and chemical contaminants (Departamento de Salud Ambiental, 2017).

7.2.3 Sampling and analysis

Sand is a heterogeneous matrix, so sampling requires collection of fractions (aliquots) to build a representative whole (composite), which should include problematic spots – that is, a worse-case scenario (Brandão, 2019). Sabino et al. (2011) analysed composites of three supratidal equidistant grab samples that were combined and homogenized. This option may be mildly representative of an entire beach, compared with incremental sampling as described by Hadley & Petrisor (2013). However, the history of monitoring a site will eventually define a normal pattern and identify outliers, regardless of the sampling frequency or number of fractions used. Sites with no history might require more intense sampling, both in the number of grab samples and in frequency, until a pattern can be established.

Typically, sample analysis requires enumeration of the microorganisms in a specific mass of sand, on either a gross weight or a dry weight basis. To report microorganism concentrations on a dry weight basis, a separate aliquot of the sand is analysed for moisture content. The most common method to enumerate microorganisms in sand is through extraction.

Historical analytical results may establish an initial water quality assessment of microorganism concentrations that will help detect sporadic pollution events (Brandão, 2019).

Box 7.2 describes recommended sampling and extraction procedures.

Box 7.2. Beach sand sampling and analysis

Sampling of beach sand

- Select the sand area of the beach that is mostly used (usually the supratidal area of the foreshore of the beach – refer to Fig. 7.1 for definitions).
- Use sterile sampling spoons to collect several shallow aliquots from the surface in the target area (up to 10 cm deep). If more control over sand depth is necessary, shallow cores can also be used instead of scoops to ensure a uniform sampling depth.
- Place the aliquots in a sterile container.
- Thoroughly mix each aliquot before selecting a subsample for analysis.
- Use of standardized methods for sample collection is encouraged (e.g. parts 9, 12, 15 and 19 of ISO 5667: Water quality – sampling).

Extraction of microorganisms from beach sand

FIO (Boehm et al., 2009)

- Use a 10:1 ratio of eluent volume (usually 100 mL) to sand weight; the eluent is phosphate-buffered saline or deionized water.
- Shake by hand for 2 minutes.
- Allow to settle for 30 seconds.
- Analyse the eluent in a similar way to water.

Fungi

- Use gentle orbital shaking (Sabino et al., 2014) in extraction fluids such as water or saline solutions; extraction cannot be violent because of the risk of hypha breakage (generating extra colony forming units).
- Use of Tween may aid extraction of less hydrophilic species, such as *Penicillium* and dermatophytes.

7.3   Management and communication

Pollution sources for beach sand should be included in the system description and sanitary survey for recreational water safety plans (refer to Chapter 2) to identify potential sources of faecal contamination of sand, and appropriate monitoring, management and communication actions.

7.3.1   Management actions

Animal excreta – including that of dogs, birds and other locally significant animals – increases FIO levels and introduces pathogens to beach sands. Exercising of dogs should be avoided in beach areas and should be kept separate from areas used by people during bathing seasons. Sections of the coast should be designated for this particular purpose. Access to the beach should also be limited for feral animals, such as cats, using humane and culturally sensitive methods. Management plans should be put in place for managing birds, whether native (protective measures) or non-native (deterrent measures). Increased public awareness may help to reduce exposure to feral animals and birds, and minimize feeding of these animals. Beach cleaning may remove some animal excreta, but it is more often undertaken for aesthetic reasons, or to remove litter or sharp materials, such as broken glass.

Other management strategies for beaches include proper design of solid waste disposal facilities, provision of toilet facilities and appropriate stormwater drainage (Kelly et al., 2018).
- Garbage disposal should be available in designated areas; the garbage should be covered to minimize access by animals and should be protected from rain.
- Proper solid waste management will help to minimize the presence of non-native bird species that can contribute FIOs to the beach sand environment.
- The availability of toilet facilities at the beach can minimize FIO impacts from humans who visit the beach, and will also encourage proper hygiene practices, such as more frequent handwashing, during beach visits.
- Drainage systems should be appropriately designed at beach areas; drainage from parking lots and nearby areas should not be permitted to flow directly onto the beach.
- Direct stormwater drainage from surrounding communities onto the beach should be discouraged. If outdated infrastructure allows drainage of stormwater onto the beach, access to waters downstream should be restricted to avoid contact by beachgoers.

In some countries, particularly at resort areas, mechanical sand cleaning or beach grooming is used to eliminate visible solid waste mixed with sand. This reduces the amount of organic matter such as seaweed and therefore reduces development of microorganisms. Care should be taken in choosing the beach grooming strategy to minimize impacts on the sand quality (Kinzelman et al., 2004) and ecology (Llewellyn & Shackley, 1996).

Disinfection of sand (e.g. with chlorine, iodine, ultraviolet irradiation or thermal treatment) is not recommended because of negative impacts on native flora and fauna. Alternative simpler methods, such as sifting and aeration, could be applied (Figueras et al., 1992), together with beach supervision to minimize inputs and sources.

Beach sand renourishment is practised at some sites to build artificial beaches and restore natural beaches that are subject to erosion. This consists of fortifying a beach with sand translocated from an external site – offshore sources, sand quarries or another beach. The source of the sand and its quality should be considered in developing a beach renourishment plan, to preserve native ecosystems and avoid importing non-endemic arthropods. Quality considerations for the imported sand should include its microbiological and chemical quality, and mineralogy.

Human faeces are the major risk factor in areas without safe sanitation services. Sewage should not be dumped near recreational areas.

Example 7.3. Beach sand classification under the Blue Flag award in Portugal

The Blue Flag organization is incorporating sand in the list of awarding criteria during the 2021 bathing season in Portugal. The classification is based on three parameters: all fungi, enterococci and *E. coli* per gram of sand.

For fungi, guidance is set at a mean value of 89 CFU/g of total fungi in sand (as determined by Brandão et al., 2021), and a rejection limit at the 80% percentile of 490 CFU/g. For example, in five sampling events, only one is allowed to exceed the value for total fungal count of 490 CFU/g.

For enterococci, the guideline value of 60 CFU/g or MPN/g of sand (section 7.2.1) is used as the compliance criterion for all sampling events. The value is considered provisional, as it is the result of QMRA that does not consider the native flora of a beach.

E. coli is used as an extra faecal indicator to connect with the European Bathing Water Directive parameter, using as compliance cut-off a reference value of 25 CFU/g (as described in Sabino et al., 2011).

7.3.2 Communication

Education and communication campaigns can include signage about policies concerning dogs, feeding of wildlife and disposal of trash. The location of toilet facilities should be identified. Beachgoers should be encouraged to practise good hygiene, such as using clean towels while on the beach, washing their hands before eating and showering immediately after beach visits. They should be encouraged to wear shoes to minimize cuts when walking during beach visits. Use of the beach should be discouraged if an individual has significant wounds; minor wounds can be covered with waterproof bandages.

More details about dissemination of educational materials are provided in Chapter 3; Box 7.4 provides some suggestions.

Box 7.4. Suggested communication messages for the general public and beach managers

Communication for the general public

- When visiting the beach, leave nothing behind but your footprints. You may even help clean up if you see an item of solid waste.
- Shower thoroughly when you get home, but also use the showers at the beach. Make sure you wash off sand from your skin and from the inside of your ears.
- If you have wounds, dress them properly with waterproof bandages before you go to the beach and avoid exposure to water; otherwise, the wound may get infected.
- Don't rub your eyes if you have sand in them; rinse with clean water instead. Rubbing may cause abrasions that might result in infections.
- Do not take pets to the beach. Take them to non-bathing areas instead.

Communication for beach managers

- Conduct sanitary inspections to identify possible sources of contaminants and develop a plan to manage these sources.
- Keep litter contained, and make sure it is removed at the end of the day, to avoid foraging by feral animals during the night.
- Develop a management plan for controlling birds and feral animals.
- Develop a policy concerning dogs and enforce the policy.
- If ecologically acceptable, develop an appropriate sand grooming plan.
- Provide signage for beachgoers to encourage appropriate beach use and inform them about possible health risks.

7.4 Research needs

Studies are needed to establish beach guideline values for acceptable levels of microorganisms in beach sands. Epidemiological studies that include sand measures, detailed documentation of child play activities, and follow-up concerning possible health outcomes would be ideal to establish the relationships needed to confirm acceptable levels of FIOs for beach sands. This is particularly the case for emerging concerns such as opportunistic fungi, which are not addressed in current water quality recommendations. More information about non-point sources of contamination – including birds, macroalgae, forest and agricultural runoff, and storm runoff – is desirable. The ability of sand to convey contaminated groundwater remains obscure and unsettled.

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8 Chemicals

Chemical hazards can enter surface waters or be deposited on beaches from anthropogenic sources or natural sources (e.g. hyperalkaline lakes). Contamination may be from point sources, such as industrial outfalls, or non-point (diffuse) sources, such as runoff from land. In most cases, particularly where there are riverine flows or tidal movement, contaminants will be significantly diluted or dispersed, minimizing public health risks. There are very few reports of human health impacts associated with recreational exposure to chemicals in fresh or marine waters.

Chemicals may also degrade the aesthetic quality of recreational water environments, as discussed in Chapter 9. Toxins from cyanobacteria are addressed in Chapter 5.

8.1 System assessment

8.1.1 Exposure assessment

The frequency, extent and likelihood of exposure are important inputs into assessing the risks from chemicals in recreational waters. The form and frequency of recreational activity (7–8 swimming events per year in temperate climates and up to 150 swimming events per year in warmer climates; Schets, Schijven & de Roda Husman, 2011; NHMRC, 2019) will therefore play a significant role. Routes of exposure can include contact with the skin (dermal), eyes and mucous membranes; inhalation; and ingestion.

Many substances of potential concern have low water solubility and will tend to migrate to sediments, where they may accumulate. Skin exposure may occur if the sediments are disturbed and resuspended, or where recreational water users are in direct contact with sediments. Although little evidence is available, this type of exposure is considered to make only a minor contribution to overall exposure.

Dermal exposure

Skin and eye irritation result from exposure to some chemicals, including cyanobacterial toxins such as lyngbyatoxin-a (refer to Chapter 5), 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/cyanobacterial blooms (Chapter 5) or specific circumstances such as swimming in unsuitable water bodies (e.g. abandoned quarry or mine pits filled with water).

Potential health impacts from most substances depend on dermal absorption (refer to USEPA, 2004; ATSDR, 2005; enHealth, 2012). Skin is an effective barrier for many chemicals; its permeability is influenced by 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. Dermal exposure may need to be considered if concentrations nearing guideline values, based on ingestion (refer to section 8.1.1.2), are reached 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 use of wetsuits (e.g. by windsurfers, surfers, divers) can trap water inside the suit, producing a micro-environment that could potentially increase the risk of skin irritation and the absorption of chemicals through the skin (see also Chapter 5).

Ingestion

Limited data are available on volumes of water ingested during recreational activities. Estimates of volumes ingested per swimming event (95th percentiles) are 170–179 mL in children and 87–210 mL in adults in fresh waters, and 140–250 mL in children and 124–170 mL in adults in marine waters (Schets, Schijven & de Roda Husman, 2011; DeFlorio-Barker et al., 2017).

However, most hazardous chemicals cause harm following chronic exposure for many years. For example, most of the chemical guideline values in the World Health Organization *Guidelines for drinking-water quality* (GDWQ) are based on ingestion of 2 L per day over many years (WHO, 2017). Based on worst-case ingestion levels per swimming event of 250 mL (children) and 210 mL (adults), and estimated frequencies of eight events per year in temperate waters and 150 events in warmer waters, the volume of water ingested through recreational activities would be 2 L (children) and 1.7 L (adults) per year in temperate waters, and 38 L (children) and 32 L (adults) per year in warmer waters.

Inhalation

Inhalation can be important where there is a significant amount of spray, such as during waterskiing or whitewater canoeing. Inhalation can be of greater significance in swimming pools and related environments where chemical disinfection is practised (WHO, 2006).

8.1.2   Chemical hazards

Potential sources of chemical hazards include:
- onshore and offshore industrial discharges and spills
- wastewater discharges
- discharges from contaminated sites
- local use of motorized crafts
- petroleum receiving stations
- pesticides
- mining wastes
- naturally occurring chemicals, including algal toxins.

Information on past industry in the recreational water catchment area will give an indication of whether contaminated sediments are likely to be present and the identity of possible contaminants.

For recreational water users, risks associated with chemical hazards will depend on the type and concentration of the chemical contaminants, and the characteristics of the area. Isolated upland lakes and drinking-water reservoirs used for recreational activities are typically protected from chemical contamination. River flows, and tidal and wave action can dilute and disperse chemical discharges. In contrast, slow-flowing lowland rivers and lowland lakes may be more susceptible to contamination and provide low levels of dilution or dispersal. Water bodies subject to continuous or intermittent discharges could accumulate contaminated sediments.

Oil spills and uncontrolled discharges of industrial and mining waste waters have the potential to release high concentrations of petroleum hydrocarbons and dissolved metals and metalloids. In many cases, spills and discharges have substantial impacts on aesthetic quality of receiving waters that lead to avoidance by recreational users.

In most cases, with the exception of spills, unregulated industrial discharges and accidental discharges, chemical exposures will be well below guideline values in the GDWQ (WHO, 2017), which are based on ingestion of 2 L of water per day – this is well above ingestion associated with recreational activities.

Excluding algal toxins (refer to Chapter 5), significant concentrations of naturally occurring chemical hazards in most surface waters are less likely than contamination by industrial, agricultural and municipal pollution. However,

small recreational water bodies containing water from mineral-rich strata could contain high concentrations of some substances under some circumstances. Aesthetic degradation of the water (refer to Chapter 9) is the most likely scenario – for example, as a result of contamination with metals, such as iron.

Chemical mixtures

Chemicals in natural fresh and marine waters are always present in mixtures. However, separate guideline values are calculated for most chemicals of public health significance without consideration of additive effects, and synergistic or antagonistic interactions. For many chemicals, this is appropriate for a number of reasons.

- Differences in mechanisms of toxicity mean that interactions are unlikely.
- The large uncertainty included in the calculation of individual guideline values is considered sufficiently conservative to account for unexpected interactions.
- It is unusual for hazardous chemicals to be continuously present at concentrations at or near their guideline values.

Exposures through recreational water are also low and intermittent compared with, for example, exposures from chemicals in drinking-water.

However, there may be occasions when a number of chemical hazards with similar toxicological mechanisms are present. In such cases, potential impacts of chemical mixtures need to be considered (WHO, 2017, 2019). Where necessary, guidance on chemical mixtures in source water and drinking-water (WHO, 2017) can be applied to recreational water.

Microplastics

Waste plastics make up about 80% of all marine debris. The most visible impacts are effects on marine wildlife, and aesthetic impacts on beaches and shorelines. Microplastics have been detected at concentrations of $0–10^3$ particles/L in fresh water (WHO, 2019). Concentrations in marine water can vary over a wide range; the average global concentration is estimated as $0.2–0.9 \times 10^3$ particles/L, and concentrations can be up to 9–16 particles/L in surface ocean water (Lusher, 2015; Everaert et al., 2018).

A review of microplastics in drinking-water found no evidence of human health risks associated with their ingestion (WHO, 2019). Levels of exposure to chemicals associated with microplastics in drinking-water are very small compared with the exposures leading to toxicity, and the relative contribution of pathogens and biofilms attached to microplastics in drinking-water is insignificant compared with other sources. This also applies to fresh and marine waters.

The much lower ingestion of water associated with recreational activities compared with drinking-water also reduces any potential risks associated with microplastics.

8.1.3 Risk assessment

Information on the pattern and type of recreational 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.
Chemical analysis will be required to support a quantitative risk assessment if contamination is present and there is significant exposure of users. The sampling programme should take into account variation in contamination with time and water movement. If resources are limited and the situation is complex, samples should first be taken at the point considered to give rise to the worst-case scenario; only if this gives rise to concern is there a need for wider sampling.

Quantitative risk assessments should consider the anticipated exposure in terms of both dose (e.g. whether there is significant ingestion) and frequency of exposure. The assessment should also consider the form of the contaminant, particularly for inorganic chemicals. For example, the form of metals detected can significantly influence solubility and absorption.

Example 8.1. Potential PFAS contamination in Australia

Historical use of firefighting foams at Australian Government Air Force bases has been identified as a potential source of per- and polyfluoroalkyl substances (PFAS) in surface waters. Extensive environmental and health investigations and assessments have been instigated. Initial risk assessments showed that off-site migration of these substances through groundwater and across-surface stormwater flows was likely. Streams, drainage channels and impoundments were identified as potential receptors. The water bodies were generally slow moving in summer, and some were used for swimming and other recreational activities.

The initial assessment found that potential health risks associated with PFAS arise from ingestion; dermal absorption and inhalation were not considered significant sources of exposure (NHMRC, 2019). Precautionary advice was issued for the public to avoid recreational contact that might lead to accidental ingestion from potentially contaminated surface waters while investigations were undertaken. Warning signs were installed.

Health-based guideline values were developed for investigation of potentially contaminated sites in 2016 (Australian Government Department of Health, 2016). Guideline values for recreational activity (0.7 µg/L for PFOS/PFHxS; 5.6 µg/L for PFOA) were set at 10 times drinking-water guideline values, based on the approach described in the 2003 WHO Guidelines for safe recreational water environments: volume 1 – coastal and fresh waters. In 2019, the guideline values were replaced using a more refined analysis of exposure, based on ingestion volumes per swimming event (200 mL) and a conservative estimate of the annual frequency of swimming events per person (150 events per year) (NHMRC, 2019). Guideline values were set at 2 µg/L for PFOS/PFHxS and 10 µg/L for PFOA.

The formal setting of guideline values for recreational use of surface waters provided certainty for assessment of public health risks. Exceedances have been detected in drains and creeks near defence bases, although the number of exceedances has been reduced by the increase in the guideline value concentrations published in 2019. Exceedances have not been detected in larger bodies of water, such as coastal waters.

Communities are being informed about results, and advice is issued about surface waters (generally drains and creeks) that are not suitable for recreational use.

Source: Australian investigations (http://www.defence.gov.au/environment/pfas/).

Except for spills and unregulated discharges, it is unlikely that water users will come into contact with sufficiently high concentrations of chemical contaminants to cause adverse effects following a single exposure. Even repeated exposure is unlikely to result in adverse effects at the concentrations of chemicals typically found in surface water.

Example 8.1 provides a case study relating to surface water contamination with per- and polyfluoroalkyl substances.

Some water bodies will be assessed as being permanently unsuitable for recreational contact – for example, quarries and abandoned mine pits that have filled with water. These will typically contain high concentrations of the mineral being extracted, may contain high concentrations of chemicals used in extraction processes, and can have very high or low pH. Quarry and 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 >11 or <4 can cause irritation of the eyes, skin and mucous membranes.

Chemical spills

Oils spills can release complex mixtures of chemicals, primarily hydrocarbons. Most are not soluble and spills produce large, visible floating slicks that discourage recreational exposure. 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 render water unsuitable for recreational use. 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 use of the waters (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. Uncontrolled discharges often cause visible and distinct discolouration of receiving waters.

8.2   Monitoring

8.2.1   Guideline values

Targeted chemical analyses should be undertaken to support quantitative risk assessments when contamination is known or suspected (e.g. from industrial discharges, historical contaminated sites or mineral rich strata, if identified by sanitary surveys).

No specific rules can easily be applied to calculate guideline values for chemical contaminants in recreational waters that take account of the various degrees and frequencies of contact (e.g. passive, incidental, whole body) and types of exposure (e.g. dermal, ingestion, inhalation). However, provided that care is taken in their application, the GDWQ (WHO, 2017) 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. As discussed in section 8.1.1.2, ingestion of water when swimming ranges from 1.7 L to 2 L per year in temperate waters and 32 L to 38 L per year in warmer waters. This represents less than 0.3% and 5%, respectively, of the volume of drinking-water ingested per year. A simple screening approach is therefore to investigate a substance occurring in recreational water at a concentration 20 times higher than the guideline value in the GDWQ (Table 8.1).

Exceedances do not necessarily indicate that a problem 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.

Table 8.1
Screening values for indicative chemicals in recreational waters

Chemical[a]	Drinking-water guideline value (mg/L)	Recreational water screening value (mg/L)
Aluminium	0.9[b]	18
Arsenic	0.01 (P)	0.2
Benzene	0.01 (P)	0.2
Cadmium	0.003	0.06
Chromium	0.05 (P)	1
Copper	2	40
Ethylbenzene	0.3[c]	6
Lead	0.01 (P)	0.2
Manganese	0.4[b]	8
Nickel	0.07	1.4
Toluene	0.7[c]	14
Xylenes	0.5	10

P: provisional.
[a] No guideline values or health-based values are specified for iron, tin or zinc in the GDWQ.
[b] Health-based value.
[c] The guideline value exceeds the lowest reported odour threshold.

8.2.2   Operational monitoring

Operational monitoring involves observations and measurements to assess whether control measures are working. In terms of chemical quality, this could include measures such as:

- monitoring of control of industrial discharges, including treatment, where used, and compliance with discharge permits (including flow rates);

- monitoring fencing and signage installed to prevent access to water bodies such as quarry lakes that are permanently unsuitable for recreational use;
- monitoring implementation of good management practices associated with use of agricultural chemicals; and
- monitoring of soil and underlying groundwater downstream of historical contaminated sites.

8.3 Management and communication

Pollution events should be managed, and timely and effective communication should be provided about recreational water environments affected by chemical hazards. 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
- 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 values applied
- activities to be avoided
- potential health risks
- remedial action.

Where waters have been assessed as being permanently unsuitable for recreational use, it is essential that the public is informed and regularly reminded of the risks associated with water contact. If fencing is installed to prevent access, it needs to be regularly checked and maintained; signage also needs to be maintained.

Management of pollution events will be influenced by the type and form of contamination. For example, spills can entail 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 will be directed by environmental protection agencies. Detection of potentially persistent events, such as pollutants being carried from sites separated 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.

8.4 Research needs

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.

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9 Aesthetics and nuisance

Aesthetic and nuisance issues are important in the public's perception of a recreational water area. Public opinion surveys about desirable seaside resort characteristics, for example, have found that beach choice depends on clean, litter-free sand and water (Tudor & Williams, 2006; Botero et al., 2015). The principal aesthetic concern is obvious pollution of the water body, turbidity, scums or odour. Other health-related nuisance issues include jellyfish, insects, wildfowl, dogs, and physical hazards such as barnacles and oysters. All of these issues are relevant to natural ecosystems for which protection measures need to be considered alongside human aesthetic and nuisance concerns.

Although health impacts of aesthetic and nuisance aspects are low, they can have a significant economic impact on coastal communities. Large-scale or widespread environmental issues may lead people to cancel their trips to an area altogether. The costs to local municipalities of beach cleaning are high (Mouat, Lozano & Bateson, 2010). Although cleaning beaches is expensive, it is driven by the potential reduction in revenue that could result from littered and polluted beaches. Jellyfish swarms can have economic consequences through beach closures, bad publicity and loss of tourist revenue (Purcell, Uye & Lo, 2007; Pitt & Purcell, 2009; Albeck-Ripka, 2019; Madkour, Safwat & Hanafy, 2019). The indirect losses related to tourist avoidance of jellyfish-prone areas are difficult to calculate but are expected to be higher than direct costs (e.g. those related to medical care). The possibility of jellyfish-associated human injury or death – real or perceived – is particularly high in regions where highly venomous cubozoans are found.

This chapter describes aesthetic parameters and some nuisance organisms that affect the acceptability of a recreational water area.

9.1   System assessment

9.1.1   Aesthetics

For aesthetic acceptability of recreational water, the transparency, odour and colour of the water should not be significantly worse than natural background values. The water should be free from (Health Canada, 2012):
- visible materials that will settle to form objectionable deposits, floating debris, oil, scum and other matter;
- substances producing objectionable colour, odour, taste or turbidity; and
- substances and conditions that produce undesirable aquatic life.

Transparency and colour

Transparency
Ideally, water at swimming areas should be clear enough for users to estimate depth, to see subsurface hazards easily and to detect the submerged bodies of swimmers or divers in the vicinity. Aside from the safety factor, 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 mineral particles, dissolved substances, detergent foams, and dense mats of floating and suspended debris.

Colour
There are two measures of colour in water: true and apparent. The true colour of natural water is the colour of water from which turbidity has been removed (i.e. filtered water). 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.

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 (Chapter 5).

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 high turbidity and greater amounts of dissolved organic substances. This characteristic colour can also affect coastal recreational waters receiving estuarine input, where public perception may be that the colour difference represents some form of pollution (refer to Example 9.1).

Example 9.1. Aesthetic revulsion to water colour produced by a nontoxic algal bloom in Spain

The monitoring programme for bathing waters of Catalunya (north-east Spain), which is the responsibility of l'Agència Catalana de l'Aigua – Departament de Medi Ambient-Generalitat de Catalunya, detected a persistent problem at La Fosca beach (Costa Brava), characterized by the discolouration of water. Water that appeared to be clean in the early morning became green-brown by late morning and remained so into the evening. This generated numerous complaints from the public, who assumed the problem to be related to sanitation system inputs. An intensive monitoring programme was conducted, which included:
• sanitary inspection of the beach and sewerage system to search for unauthorized outlets
• inspection of possible inland water influence
• study of the temporal and spatial variations of the microbial water quality
• analysis of physicochemical parameters
• study of sediments and flora
• investigation of phytoplankton.

The programme unequivocally ruled out sanitation system inputs. The discolouration was eventually attributed to a nontoxic dinoflagellate, *Alexandrium taylori*. Once the origin of the problem was identified, the public was informed through press conferences and a local publicity campaign.

This incident illustrates that not all water discolouration should be assumed to be due to pollution by sewage or septic tank effluent. In this instance, a preliminary investigation to identify dinoflagellate species would have saved time and money.

Some regulatory authorities have recommended absolute values for transparency, colour and turbidity in recreational waters. This approach can be difficult to apply at a local level because many waters have naturally high levels of turbidity and colour. For recreational waters, changes from the normal situation can be used to indicate potential water pollution.

Oils, grease and detergents

Even very small quantities of oily substances make water aesthetically unattractive. Oils and tars can form films on the surface. 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. Fat balls (fatbergs) are increasingly being found at beaches. They may be derived 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. The material can be harmful to dogs, and pets should be prevented from eating it. Tar may also present a problem on the shore.

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.

Litter

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 can be roughly categorized according to its source: either water based (e.g. from fisheries, recreational

boats and shipping) or land based (domestic, agricultural, industrial and beach-user sources). Rivers can transport litter from land-based areas towards the coast (Winton et al., 2020). Recreational visitors to beaches are a predominant or major source of litter, at both freshwater and coastal sites (Hoellein et al., 2015; Asensio-Montesinos, Anfuso & Williams, 2019; Kiessling et al., 2019).

The variety of litter found in recreational water or washed up on the beach is considerable (e.g. Munari et al., 2016; Nelms et al., 2017; Asensio-Montesinos, Anfuso & Williams, 2019). Although proportions vary, beach litter is typically dominated by plastic (e.g. Khairunnisa, Fauziah & Agamuthu, 2012; Kuo & Huang, 2014; Munari et al., 2016). Cigarette butts 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 & Costa, 2019; Ocean Conservancy, 2019).

Levels of litter may be particularly elevated after sporting events, festivals, holiday periods and long weekends. In addition to being aesthetically undesirable and an environmental issue, beach litter may present a health hazard, such as injury from broken glass in beach sand, and diminish the psychological benefits associated with exposure to nature (Campbell et al., 2016). The most benefits are reported when the coast looks natural: either clean or with some seaweed (JRC/EC, 2016, 2020).

Macroalgae

Large accumulations of macroalgae (seaweed) are likely to be an aesthetic problem (in terms of visual impact and odour), a nuisance and a health risk. Many beach visitors prefer beaches to be free of algal wrack because it decomposes quickly, can produce an unpleasant smell, attracts nuisance insects and birds, and can be a source of bacterial contamination (Williams et al., 2016; Zielinski, Botero & Yanes, 2019).

Although macroalgae play an important role in maintaining coastal ecosystems, excessive amounts are detrimental. In excess, macroalgae block sunlight from seagrass, causing seagrass die-offs and anoxic conditions. When macroalgae form extremely dense mats, sea turtles may be unable to surface, and perish as a result of the physical barrier. When on-shore, the macroalgae decay, discolouring the water by releasing dissolved organic materials; decomposition results in excessive particulates nearshore. Once the macroalgae die and become anoxic, hydrogen sulfide can be released, causing noxious odours.

The source of seaweed is associated with global processes that cannot be controlled at the local scale.

Odour

Objectionable smells associated with sewage and septic tank effluent, decaying organic matter (e.g. vegetation, dead animals, dead fish) and discharged diesel oil or petrol can deter recreational water and beach users. Odours can be natural, such as when anoxic sediments in vegetated coastal areas (e.g. mangrove swamps) are exposed during low tide.

Odour thresholds and their association with the concentrations of different pollutants of the recreational water environment have not been determined.

9.1.2   Nuisance

Insects

Many beaches can be unsuitable for recreation because of large numbers of mosquitoes, biting midges, sandflies and flies. Insect bites can be painful or uncomfortable and can cause intensely itchy lesions. Some species of insects found on the coast can spread diseases to humans and animals.

Mosquitoes (Culicidae, Anophelinae) are commonly found around salt marshes and temporary fresh water (e.g. next to public showers at beach facilities). They are often most active at dawn, around late afternoon and just after sundown. They can be vectors for diseases of public health concern, such as dengue, malaria, leishmaniasis and West Nile fever (ECDC, 2014).

Biting midges (Ceratopogonidae) are a common nuisance in some coastal areas. They tend to be found near marshes or wooded areas along the beach, or on beaches where the sand is slightly more earthy. Biting midge larvae, unlike mosquito larvae, are not aquatic and can be found in humid/mud substrates enriched with organic matter, such as coastal salt mud flats and freshwater vegetated swamps (Zimmer, Haubruge & Francis, 2014). Although they do not usually spread illness to humans, some species of *Culicoides* midges are vectors of bluetongue disease of ruminants.

Phlebotomine sandflies (Psychodidae), mostly known as vectors of leishmaniasis, are also vectors of arboviruses. They are typically crepuscular or nocturnal but will bite during the day when disturbed (Alten et al., 2016).

The presence of flies (Diptera, Brachycera) is irritating, especially at high densities. Nuisance flies at beaches are generally associated with animal excrements and waste bins, since decaying organic matter and garbage are essential for females to lay eggs. Flies may transmit some diseases and, in extreme cases, lead to public health problems, such as enteric, eye and skin infections. Physical contact of flies with dead animals, faeces and trash allows them to spread a variety of disease-causing bacteria and parasites that have been associated with outbreaks of diarrhoea and food poisoning (Fly Management Guidance, 2018).

Mainly in the Palearctic region, massive outbreaks of anthropophilic blackflies (Simuliidae) can have an impact on beach tourism and other forms of human activity. Blackflies are persistent and irritating pests that swarm around humans and other animals, particularly during the summer months at dawn and dusk. Females bite to feed on blood, causing a wound that is accompanied by a strong allergic reaction in susceptible people. Blackflies are also responsible for transmitting parasitic disease organisms, such as filarial worms, protozoans and arboviruses, to a wide variety of domesticated animals.

Jellyfish

Jellyfish is a generic term that encompasses free-swimming or floating cnidarians falling in the classes Scyphozoa (free-swimming jellyfish), Hydrozoa (which includes Portuguese man-of-war) and Cubozoa (box-shaped medusae). Jellyfish can be found in oceans worldwide. They are capable of high individual growth rates, and asexual reproduction can result in rapid population growth, which can generate sudden blooms; these can remain aggregated for days to weeks. Blooms or swarms of jellyfish can lead to beach closures (Albeck-Ripka, 2019) and have been known to cause mass envenomations (e.g. Haddad, Morandini & Rodrigues, 2018).

Jellyfish stings are common in warm coastal waters. Although most stings are mild, some, depending on the culprit and the extent of stinging, can be extremely painful and even fatal (Staggs & Pay, 2019).

The Scyphozoa, or true jellyfish, are frequently driven ashore and stranded by wind and currents. All the true jellyfish are capable of stinging, but only a few species are a significant hazard to human health. Species of some genera (e.g. *Cyanea, Catostylus, Pelagia*) may occur in large groups or swarms.

The Cubozoa are the most dangerous jellyfish. They are characterized by a roughly cube-shaped body or bell, with tentacles arising from fleshy extensions in the lower corner of the bell. Several species of box jellyfish have led to human deaths.

Most of the Hydrozoa are harmless; a notable exception is the Portuguese man-of-war (*Physalia* spp.). The Portuguese man-of-war is easily recognized by the prominent, floating, blue or purple gas-filled bubble that supports the stinging cells on the tentacles hanging below. The tentacles may reach a length of up to 10 m. Physalia may be blown onto beaches in swarms after strong onshore winds. The stinging cells (nematocysts) remain active even when beached. Stings by *Physalia* species are the most common marine stings.

Nematocysts of the larvae of some cnidarians (most notably the thimble jellyfish, *Linuche unguiculata*) can become trapped in swimwear, causing an acute dermatitis known as seabather's eruption or sea lice (Quail, 2019).

Non-native animals

As well as contributing to faecal bacteria, excessive numbers of dogs and non-native birds can degrade the aesthetics of the beach. Domestic dogs on beaches may be perceived by some as a nuisance, depending on the level of control exerted by the owner. Complaints include dogs running free and barking, and owners failing to clean up faecal deposits. Dogs can also disturb native wildlife (Schneider et al., 2019).

Non-native birds (including waterfowl) can also be considered a nuisance, especially if they approach beachgoers in search of food. Droppings from large flocks are unsightly, can transmit disease (Goodwin et al., 2017), and can contribute to over-fertilization of small lakes and reservoirs (Conover & Chasko, 1985).

9.2   Monitoring

9.2.1   Guideline values

As guidelines are aimed at protecting public health, no guideline values have been established for aesthetic and nuisance aspects.

9.2.2   Operational monitoring

Aesthetics

Methods for debris surveys are discussed in Bartram & 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.

Example 9.2. Visual inspection for aesthetics and microbial water quality in Spain

The monitoring programme conducted in the Catalunya region of north-east Spain provides the public with information on the aesthetic aspects of water and sand, and microbial water quality. Microbial water quality monitoring is conducted once a week, and aesthetic aspects are assessed more frequently (up to five times a week). Data are collected on the presence and amount of:

- plastics
- sanitary residues
- algae
- tar
- oil
- litter
- abnormal water colour
- anything else that may cause aesthetic revulsion.

In addition, information is recorded on how thoroughly a beach is machine cleaned and how frequently litter containers are emptied.

The aesthetic data are processed alongside the microbial water quality data, resulting in a combined grading for the beach. Aesthetic aspects are considered to be so important that an excellent microbial grading may be reduced to a good or even poor combined grading if the beach looks bad.

Municipalities, tourist information offices, nongovernmental organizations, local newspapers, TV and radio are informed weekly of the results. In addition, municipalities receive a report outlining raw microbial data for each of the evaluated parameters, the results of the visual inspection and suggestions for improvements. This system gives confidence to the public that their concerns are being taken seriously. It has also encouraged many municipalities to improve the aesthetic aspects of their bathing areas.

Marine debris monitoring is well established. For example, OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) has monitored 50 indicator beaches four times a year using a standardized protocol since 1998 (OSPAR Commission, 2010). Such activities, however, are very expensive. International initiatives such as Blue Flag include litter in their certification programmes. Beach litter surveys could be good examples of citizen science projects. In the United Kingdom, Nelms et al. (2017) reported the results of an analysis of 10 years of beach litter data (2005–2014) collected from the Marine Conservation Society's national volunteer beach litter surveying programme, which takes place around the British coastline. In Catalunya (Spain), a programme of aesthetic monitoring was undertaken to supplement microbial water quality data (Example 9.2). Argentina integrated these aspects in its guidelines of 2017 (Departamento de Salud Ambiental, 2017).

9.2.2.2　Nuisance

Operational monitoring for nuisance aspects may include observations and measurements to assess the conditions that promote nuisance levels of insects, jellyfish and non-native animals, and the extent to which control measures in the recreational water safety plan are working. This could include measures such as:
- monitoring of conditions that promote jellyfish swarms, and the effectiveness of public communications on avoiding risks posed by specific species; and
- monitoring measures to discourage non-native waterfowl (e.g. discouraging feeding by the public).

9.3　Management and communication

9.3.1　Aesthetic aspects

Beach cleaning (beach grooming)

Beach cleaning can provide apparently litter-free beaches and remove algal wrack. The most appropriate form of beach cleaning (mechanical or manual) is likely to vary according to the resources available, the cleaning required (litter and/or algal wrack), the type of beach (urban or rural), and the need to protect the native ecosystem.

Mechanical beach cleaning usually involves motorized equipment, using a sieve that is dragged through the top layer of the sand. The sieve retains the litter, but usually cigarettes and other small items pass through. Resort beaches use such equipment because it is fast and provides an aesthetically clean recreational area for visitors. It also reduces health risks for those cleaning the beach, because no manual picking-up of material is involved. However, the effectiveness and potential ecological impacts of beach cleaning are not well studied, and mechanical cleaning is unlikely to be appropriate for all beaches (Zielinski, Botero & Yanes, 2019).

Tar can be removed by mechanical cleaning of the sand. In Lebanon, the effectiveness of beach cleaning (using compressed water) for a spill of heavy fuel oil was investigated by comparing levels of total petroleum hydrocarbons in unaffected and cleaned beaches; high-pressure cleaning was found to be effective (Mansour et al., 2017).

For excessive amounts of macroalgae (seaweed) on beaches, management may include removal of the seaweed. Some macroalgae, such as *Ulva*, are considered indicators of excess nutrients, and therefore pollution. Addressing the pollution source should improve the *Ulva* spp. status of the beach (Scanlan et al., 2007).

The following recommendations are made.
- Use a scheme of grooming that will leave natural wrack on less used stretches of beaches untouched, to protect the natural macrofauna.
- Relocate wrack to a nearby unused beach to preserve the natural ecosystem and autochthonous fauna.
- Replace mechanical cleaning by manual cleaning to reduce ecological impacts.
- Groom only the lower part of the beach.
- Reduce beach littering by both beach users and staff.

Provision of facilities and restricted use

In combination with public education, provision of appropriately designed litter bins (e.g. bird- and rat-proof, covered from direct rainfall) should reduce beach littering. If bins are not animal-proof, emptying them at the end of the day (rather than early morning) may reduce rat problems, because rats forage at dusk.

Beach smoking bans have been pioneered in the USA; the first was established at Hanauma Bay beach in Hawaii in 1993 (Ariza & Leatherman, 2012). It was enforced by both peer pressure and park rangers. Its success has led other localities, in the USA, Australia, Thailand, Spain and Italy, to follow suit. Fines may be needed to support enforcement of the ban, although in some countries voluntary bans have been set.

As an alternative to smoking bans, handing out portable ashtrays has been trialled (Widmer & Reis, 2010). The ashtrays were used (to some degree) and not left on the beach (i.e. they did not contribute to the litter problem), so they may have potential; however, more research is required.

For beaches that allow dogs, disposal of dog faeces should be highly encouraged; litter bins and dog waste containers with bags may encourage owners to clean up after their pets.

User education (awareness raising and behaviour change)

User education has an important role in beach litter reduction (refer to Example 9.3). The methods used and specific messages are likely to vary according to local culture and beach location. They can make use of a variety of channels, such as media, purpose-made signs (which can be electronic to facilitate dynamic communication of risk in real time – for example, as installed at Swansea in the United Kingdom) or use of beach groynes and unused structures to post public messages. Staff training, adequate provision of bins and fines for littering can also be used as tools to modify beachgoer behaviour. As well as removing beach debris, litter clean-up efforts can serve as an educational tool for those involved in the clean-up effort (Rayon-Viña et al., 2018; Box 9.4).

Interventions should be trialled before widespread implementation to maximize their effectiveness (Example 9.3).

Example 9.3. The My Beach, Your Beach initiative in Scotland

The My Beach, Your Beach initiative was trialled at three Scottish beaches during summer 2018. It was a behaviour change and awareness-raising campaign that addressed dog fouling, litter and gull-feeding behaviours. The beaches selected were all at risk of poor bathing water classifications (Keep Scotland Beautiful, 2018). The aims of the project were to:
• encourage behaviour change in relation to littering to remove this source of food for gulls
• encourage bagging and binning of dog waste
• create more community ownership of the quality of the local bathing waters
• create a campaign that can be replicated at other locations.

Interventions included community and business engagement, and material interventions to raise awareness, such as beach signage (e.g. bin wraps, lamp-post signs and railing banners), beach events (e.g. information stalls, beach clean-up days), social media presence, leaflets and newspaper articles.

Monitoring during the intervention found a 12–15% reduction in litter at the sites. In a follow-up study after the bathing season, 82% of those asked reported being aware of at least one intervention. The engagement work identified several infrastructure changes, such as combined litter/dog waste bins, an increase in bin capacity to cope with busy days and more targeted bin locations.

Example 9.4. Litter picks

Volunteer beach clean-ups, such as those organized by the Marine Conservation Society, have increased dramatically in recent years. In 1986, for example, the Ocean Conservancy began conducting clean-ups on a single Texas beach; in 2018, more than 1 million people from 122 countries were involved in their international coastal clean-up initiatives. These not only remove large quantities of litter but also raise environmental awareness and have the potential to positively affect behaviour and attitudes (Wyles et al., 2017).

9.3.2 Nuisance

Insects

The most appropriate management actions for insects will depend on the insects in question. From a beach user perspective, preventing contact is the main way to minimize insect problems. Use of insect repellents (preferably containing diethyltoluamide [DEET]) and keeping covered up (e.g. wearing long-sleeved shirts, long trousers and hats) are effective measures.

Mosquitoes: In heavily mosquito-laden areas, beach amenities can be fitted with protective window screens, electric diffusers that release small doses of insecticide, and air conditioning. Municipalities and public health entities can have proactive programmes to manage mosquitoes. These include regular surveillance and larval treatments of mosquito-prone areas – for example, through ground and aerial applications of insecticides such as pyrethrins and pyrethroids (EMCA, 2011). Because mosquitoes live and breed in standing water, avoiding containers, pot plants and other items holding water at beach facilities is a simple way to prevent mosquito nurseries.

Biting midges: At beach amenities, the use of outdoor fans can be an effective deterrent because biting midges fly poorly. Beach managers can use ultraviolet light traps to assess the presence and abundance of midges. Removing decomposing seaweed and other organic debris that washes up during storms and becomes trapped in intertidal areas is the best approach to reducing breeding sites at beaches.

Sandflies: In infested areas, avoiding the beach in the early morning or at sunset is recommended because sandflies are more active when weather is cooler. Also, lying or sitting directly on the sand is not advisable. A lounge chair or a beach towel should be used, as well as DEET insect repellent reapplied regularly throughout the day – especially on high-target areas such as feet and ankles. Sandfly control by authorities requires an integrated approach. The most common methods are insecticide application in peridomestic environments, and deltamethrin-impregnated dog collars and light traps to catch host-seeking females (ECDC, no date).

Flies: Although killing adult flies can reduce infestations, good sanitation is the basic step for any fly management programme. Eliminating breeding sites near beaches is critical. Waste containers should have tightly fitting lids and be cleaned regularly, and all garbage should be placed in tightly closed bags. Beach sand cleaning should be used to remove animal excrement, including from pets. When nuisance flies become a major pest, control often involves using adulticides or larvicides to directly or indirectly suppress the high densities. It is important to avoid the development of resistance to insecticides by alternating formulations with different modes of action.

Blackflies: Complete control of blackflies is difficult, but several measures can be used to mitigate and manage blackfly populations. Reducing suitable habitat for blackfly larvae seems to be the best strategy, either by removing organic debris and decaying seaweed from the beach or by spraying *Bacillus thuringiensis israelensis* on vegetation and breeding sites (Currie & Adler, 2008) – this is a bacterium that releases toxins with insecticidal properties.

Jellyfish

Avoiding contact is the first line of defence against jellyfish stings. Beach signage (e.g. warning notices) or beach closures may be used where there are swarms of stinging jellyfish.

In the absence of swarms, beach users are advised to:
- avoid handling cnidarians, even those washed ashore, as the stinging mechanism can still function if the jellyfish is dead;
- avoid swimming in waters where Portuguese man-of-war are concentrated (often indicated by beached specimens); and
- if swimming where jellyfish are prevalent, wear a wetsuit or other form of protective clothing, such as the full-length stretch-fitting suits used by divers in tropical waters; stings of most jellyfish cannot penetrate these suits.

The reported efficacy of different suggested first aid treatments (e.g. removing nematocysts using gentle pressure, rinsing the affected site with vinegar, applying heat, applying lidocaine/local anaesthetics) varies. This may partly be due to species-specific differences (e.g. Ward et al., 2012; Berling & Isbister, 2015; Montgomery, Seys & Mees, 2016; Remigante et al., 2018). Medical intervention should be sought for severe stings, especially if caused by a Portuguese man-of-war or box jellyfish.

Birds and waterfowl

Where flocks of birds (e.g. gulls, Canada geese) present a nuisance, dogs have been used to reduce their numbers (Jordon et al., 2019; Castelli & Sleggs, 2000). Proper management of solid waste is also a deterrent because it removes a potential food source. The beachgoing public should be discouraged from feeding birds, which encourages congregation of nuisance bird species.

Dogs

In many countries, beach dog bans (during the bathing season) are a widely accepted management technique. In some areas, depending on the size and popularity of the beach, zoning may be possible, allowing some beach areas where dogs can be exercised. In some areas, beaches are marketed as being dog-friendly tourist destinations.

9.4   Research needs

Suggested areas for additional research include:
- economic valuation of recreational beach resources;
- examining public perceptions of values of bathing sites (Suthanthangjai et al., 2013);
- quantifying the positive feelings associated with aesthetically appealing beach environments; research is emerging that focuses on using the ocean environment, or Blue Gym, for promoting human health and well-being (White et al., 2016);
- quantifying the value of transparent water and litter-free beaches with minimal nuisance in promoting the health of coastal communities and ecosystems; and
- developing global strategies for minimizing nuisances that are not local in scale, such as excessive macroalgae, jellyfish and offshore litter; reductions in nuisances from offshore areas are possible only through implementation of global strategies.

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The World Health Organization (WHO) *Guidelines for recreational water quality: volume 1 – coastal and fresh waters* aims to protect public health by ensuring that the quality of recreational waters is safely managed. The guidelines:

- describe the current state of knowledge about the possible adverse health impacts of recreational use of coastal, estuarine and freshwater environments; and

- set out recommendations for setting national health-based targets, conducting surveillance and risk assessments, putting in place systems to monitor and control risks, and providing timely advice to users on water safety.

Use of coastal, estuarine and freshwater recreational water environments has significant benefits for health and well-being, including rest, relaxation, exercise, cultural and religious practices, and aesthetic pleasure, while also providing substantial local, regional and national economic benefits. These guidelines focus on water quality management for coastal and freshwater environments. Application of these guidelines therefore needs to take into account targets and measures for the protection of coastal and aquatic ecosystems.

These guidelines are aimed at national and local authorities, and other entities with an obligation to exercise due diligence relating to the safety of recreational water sites. They may be implemented in conjunction with other measures for water safety (such as drowning prevention and sun exposure) and measures for environmental protection of recreational water use sites.