Guidelines for safe recreational water environments

VOLUME 1
COASTAL AND FRESH WATERS

WORLD HEALTH ORGANIZATION
GENEVA

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VOLUME 1: COASTAL AND FRESH WATERS

WORLD HEALTH ORGANIZATION
2003

WHO Library Cataloguing-in-Publication Data

World Health Organization.
Guidelines for safe recreational water environments. Volume 1, Coastal and fresh waters.

1.Bathing beaches—standards 2.Fresh water—microbiology 3.Water quality—analysis 4.Water pollution—analysis 5.Environmental monitoring—methods 6.Wound and injuries—prevention and control 7.Drowning 8.Risk management 9.Reference values 10.Guidelines I.Title II.Title: Coastal and fresh waters.

ISBN 92 4 154580 1 (NLM classification: WA 820)

Designed by minimum graphics
Typeset in Hong Kong
Printed in Malta

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List of acronyms and abbreviations

AFRI	acute febrile respiratory illness
AIDS	acquired immune deficiency syndrome
ASP	amnesic shellfish poisoning
BCC	basal cell carcinoma
CBO	community-based organization
CDC	Centers for Disease Control and Prevention (USA)
cfu	colony-forming unit
COGP	Code of Good Practice
CPR	cardiopulmonary resuscitation
DALY	disability adjusted life year
DSP	diarrhetic shellfish poisoning
EAP	emergency action plan or procedure
EC	European Commission
GAE	granulomatous amoebic encephalitis
GI	gastrointestinal
HACCP	hazard analysis and critical control point
HAV	hepatitis A virus
HEV	hepatitis E virus
HIA	health impact assessment
HIV	human immunodeficiency virus
IARC	International Agency for Research on Cancer
IBM	integrated basin management
ICAM	integrated coastal area management
ID_{50}	dose of microorganisms required to infect 50% of individuals exposed
ILS	International Life Saving Federation
i.p.	intraperitoneal
LOAEL	lowest-observed-adverse-effect level
MM	malignant melanoma
MOE	Ministry of Environment
MOH	Ministry of Health
MOT	Ministry of Tourism
NGO	nongovernmental organization
NMSC	non-melanoma skin cancer
NOAEL	no-observed-adverse-effect level
NSP	neurotoxic shellfish poisoning

PAM	primary amoebic meningoencephalitis
PDF	probability density function
PFD	personal flotation device
pfu	plaque-forming unit
PSP	paralytic shellfish poisoning
QA	quality assurance
QMRA	quantitative microbial risk assessment
SCC	squamous cell carcinoma
SLRA	screening-level risk assessment
SOP	standard operating procedure
SPF	sun protection factor
TCBS	thiosulfate–citrate–bile salts–sucrose
TDI	tolerable daily intake
USLA	United States Lifesaving Association
UV	ultraviolet
UVR	ultraviolet radiation
WHO	World Health Organization
WTO	World Tourism Organization

Preface

The World Health Organization (WHO) has been concerned with health aspects of the management of water resources for many years and publishes various documents concerning the safety of the water environment and its importance for health. These include a number of normative "guidelines" documents, such as the *Guidelines for Drinking-water Quality* and the *Guidelines for Safe Use of Wastewater and Excreta in Agriculture and Aquaculture*. Documents of this type are intended to provide a basis for standard setting. They represent a consensus view among experts on the risk to health represented by various media and activities and on the effectiveness of control measures in protecting health. They are based on critical review of the available evidence. Wherever possible and appropriate, such guidelines documents also describe the principal characteristics of the monitoring and assessment of the safety of the medium under consideration as well as the principal factors affecting decisions to be made in developing strategies for the control of the health hazards concerned.

The *Guidelines for Safe Recreational Water Environments* are published in two volumes:

- *Volume 1: Coastal and Fresh Waters* provides a review and assessment of the health hazards encountered during recreational use of coastal and freshwater environments. It includes the derivation of guideline values and explains the basis for the decision to derive or not to derive them. It addresses a wide range of types of hazard, including hazards leading to drowning and injury, water quality, exposure to heat, cold and sunlight, and dangerous aquatic organisms; and provides background information on the different types of recreational water activity (swimming, surfing, etc.) to enable informed readers to interpret the Guidelines in light of local and regional circumstances. With regard to water quality, separate chapters address faecal pollution, free-living microorganisms, freshwater algae, marine algae and chemical aspects. It describes prevention and management options for responding to identified hazards.

- *Volume 2: Swimming Pools, Spas and Similar Recreational Water Environments* provides a review and assessment of the health hazards associated with recreational waters of this type; their monitoring and assessment; and activities available for their control through education of users, good design and construction, and good operation and management. It includes the derivation of guidelines including guideline values and explains the basis for the decision to derive or not to derive them. It addresses a wide range of types of hazard, including water quality, hazards leading to drowning and injury, contamination of associated facilities and air quality.

In addition to the above volumes of the *Guidelines for Safe Recreational Water Environments*, a practical guide entitled *Monitoring Bathing Waters*,[1] has been produced. It describes the principal characteristics of and approaches to the monitoring and assessment of coastal and freshwater recreational water environments. It emphasizes the need to utilize information of diverse types and from diverse sources in order to develop a valid assessment; and the need to establish effective links between the information generated and interventions to control risk in both the short and long term. It includes comprehensive practical guidance for the design, planning and implementation of monitoring programmes and assessments; and a Code of Good Practice for the monitoring and assessment of recreational water environments, to assist countries in developing such codes for national use and to promote international harmonization. Material relating to toxic cyanobacteria, including that in chapters 7 and 8 is based upon *Toxic Cyanobacteria in Water*,[2] which was prepared by an international group of experts.

The development of WHO activity on 'recreational' or 'bathing' water can be traced back to two expert consultations in the 1970s.[3] These meetings highlighted the breadth of possible hazards associated with recreational water use and noted that prospective volunteer studies offered the "best hope of progress" in terms of establishing links between water quality and bather health. They also suggested the grading of beaches according to bands of indicator counts and the use of sanitary assessments for beaches. These initial meetings were followed by a series of expert consultations. The meeting in Valetta, Malta held during 1989, reviewed the status of microbial guidelines for bathing waters and examined the potential protocols for epidemiological investigations. The importance of protocol design was clear at the Valetta meeting, and two principal approaches were reviewed—namely, the prospective case–control and the randomized trial. Two years later in Athens, Greece the early results of epidemiological investigations that employed both protocols were reviewed. It was decided at this meeting that both approaches were appropriate and could yield useful data for Guidelines derivation. The results of a series of major epidemiological studies in the United Kingdom were presented and critically reviewed at a meeting held in Athens, Greece in 1993.

The preparation of the *Guidelines for Safe Recreational Water Environments* Volume 1 covered a period of almost a decade and involved the participation of numerous institutions, more than 130 experts from 33 countries worldwide, and further reviewers and meetings. The work of the individuals concerned (see Acknowledgements) was central to the completion of the work and is much appreciated.

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[1] Edited by J. Bartram and G. Rees, published in 2000 by E & FN Spon on behalf of WHO.

[2] Edited by I. Chorus and J. Bartram, published in 1999 by E & FN Spon on behalf of WHO

[3] Meetings: Ostend, 1972; Bilthoven, 1974; Valetta 1989; Athens 1991; Athens 1993; Bad Elster 1996; Jersey 1997; Farnham 1998; Annapolis 1999; Farnham 2001.

In 1994, following discussions between the WHO Regional Office for Europe and WHO Headquarters, it was agreed to initiate development of guidelines concerning recreational use of the water environment, examining all possible health outcomes from both natural waters and swimming pools, including those related to water quality. This was undertaken as a collaborative initiative between WHO Headquarters and the WHO European Centre for Environment and Health, Rome, Italy. A comprehensive review of the scientific literature on sewage pollution of recreational water and health, eventually published as Prüss (1998), provided the focus for an expert consultation in Bad Elster in 1996. This meeting concluded that the epidemiological basis had been laid for evidence-based normative guidelines on faecal pollution of recreational water. The consultation also received information on new research findings quantifying the impacts of non-sewage sources of faecal bacteria on recreational water compliance with microbial water quality criteria. The implications of these findings were that many bathing waters might fail current water quality norms because of the influence of diffuse source pollution, which would not be reduced by sewage treatment alone.

At a further expert consultation hosted and co-sponsored by the States of Jersey in 1997 drafts of all chapters of the two volumes of Guidelines were reviewed, these were revised and further reviewed at a meeting the following year in Farnham, UK 1998. The Draft Guidelines for coastal and fresh waters were then submitted for international expert appraisal and received intensive review.

In 1999, an expert consultation co-sponsored by the US EPA and held in Annapolis, USA, resulted in the "Annapolis Protocol" (WHO, 1999), which suggested a new approach towards evaluation and regulation of faecal pollution of bathing waters. The Annapolis Protocol outlines a combined sanitary inspection and microbial measurement approach that is used to classify recreational waters. In addition, the protocol suggests the use of relevant information to facilitate real-time public health protection. Thus, the principal focus of regulation is expanded from retrospective numerical compliance assessment to include real-time management and public health protection. A further expert consultation to take account of the Annapolis protocol and other newly available information in the draft guidelines was held in Farnham, UK, in 2001. The Guidelines were finalized through a series of chapter-by-chapter conference calls with selected experts, in November 2002.

During the development of the Guidelines, careful consideration was given to previous assessments, in particular the work of the Mediterranean Action Plan, the Black Sea Environmental Programme, the activities undertaken by and for the European Commission, the activities undertaken by the US Environmental Protection Agency, including its "BEACH" programme and others.

In light of the importance of the subject area for health and the degree of attention it receives from the political and scientific communities and the general public, it is envisaged that new information will become available rapidly during future years. WHO would be pleased to learn of major related developments and will endeavour to ensure the continuing validity of the Guidelines through issuing addenda or further editions as appropriate.

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Acknowledgements

The World Health Organization wishes to express its appreciation to all those whose efforts made possible the production of the *Guidelines for Safe Recreational Water Environments. Volume 1: Coastal and Fresh Waters*, in particular to Jamie Bartram (Coordinator, Water Sanitation and Health at WHO Headquarters and formerly Regional Advisor for Water and Wastes, WHO European Centre for Environment and Health, Rome), who coordinated the development of the Guidelines.

An international group of experts provided material and participated in the development and review of the *Guidelines for Safe Recreational Water Environments. Volume 1: Coastal and Fresh Waters*. Many individuals contributed to each chapter, directly and through associated activities. The contributions of the following to the development of these Guidelines is appreciated:

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Thanks are also due to Marla Sheffer for editing the complete text of the Guidelines, and Lorna Fewtrell for overseeing the review process and finalization of the document.

The preparation of these Guidelines would not have been possible without the generous support of the following, which is gratefully acknowledged: the European Commission; the States of Jersey, United Kingdom; the Department of the

Environment, Transport and the Regions of the United Kingdom; the Ministry of Health of Germany; the Ministry of Environment of Germany; the Ministry of Health of Italy; the Swedish International Development Cooperation Agency, Sweden and the United States Environmental Protection Agency.

Executive summary

This volume of the *Guidelines for Safe Recreational Water Environments* describes the present state of knowledge regarding the impact of recreational use of coastal and freshwater environments upon the health of users—specifically drowning and injury, exposure to cold, heat and sunlight, water quality (especially exposure to water contaminated by sewage, but also exposure to free-living pathogenic microorganisms in recreational water), contamination of beach sand, exposure to algae and their products, exposure to chemical and physical agents, and dangerous aquatic organisms. As well, control and monitoring of the hazards associated with these environments are discussed.

The primary aim of the Guidelines is the protection of public health. The purpose of the Guidelines is not to deter the use of recreational water environments but instead to ensure that they are operated as safely as possible in order that the largest possible population gets the maximum possible benefit. The adverse impacts of recreational use of coastal and freshwater environments upon the health of users must be weighed against the enormous benefits to health and well-being—rest, relaxation and exercise—associated with the use of these environments.

The Guidelines are intended to be used as the basis for the development of international and national approaches (including standards and regulations) to controlling the health risks from hazards that may be encountered in recreational water environments, as well as providing a framework for local decision-making. The Guidelines may also be used as reference material for industries and operators preparing development projects in recreational water areas, as a checklist for understanding and assessing potential health impacts of recreational projects, and in the conduct of environmental impact and environmental health impact assessments in particular.

The information provided is generally applicable to any coastal or freshwater area where recreational water use occurs. The preferred approaches adopted by national or local authorities towards implementation of the Guidelines, including guideline values, may vary depending on social, cultural, environmental and economic characteristics, as well as knowledge of routes of exposure, the nature and severity of hazards, and the effectiveness of control measures.

A guideline can be:

- a level of management;
- a concentration of a constituent that does not represent a significant risk to the health of members of significant user groups;

- a condition under which such exposures are unlikely to occur; or
- a combination of the last two.

When a guideline is not achieved, this should be a signal to investigate the cause of the failure and identify the likelihood of future failure, to liaise with the authority responsible for public health to determine whether immediate action should be taken to reduce exposure to the hazard, and to determine whether measures should be put in place to prevent or reduce exposure under similar conditions in the future.

Drowning and injury prevention

Drowning, which has been defined as death arising from impairment of respiratory function as a result of immersion in liquid, is a major cause of death worldwide, particularly for male children. Near drowning is also a serious problem as it may have life-long effects. The recovery rate from near drowning may be lower among young children than among teenagers and adults. Studies show that the prognosis for survival depends more on the effectiveness of the initial rescue and resuscitation than on the quality of subsequent hospital care.

Drowning may be associated with swimming as well as with recreational water uses involving minimal water contact, such as recreational use of watercraft (yachts, boats, canoes) and fishing. Alcohol consumption is one of the most frequently reported contributory factors associated with drownings for adults, whereas lapses in parental supervision are most frequently cited for children. In cold weather, immersion cooling may be a significant contributory factor.

Of sports-related spinal cord injuries, the majority appear to be associated with diving. Injuries in diving incidents are almost exclusively located in the cervical vertebrae, resulting in quadriplegia or paraplegia. Data suggest that body surfing and striking the bottom is the most common cause of spinal injury. Alcohol consumption may contribute significantly to the frequency of injury. Other injuries associated with recreational water use activities include brain and head injuries, fractures, dislocations and other minor impact injuries, and cuts, lesions and punctures.

Prevention is the best way to reduce the incidence of injury and death related to the aquatic environment, and the majority of injuries can be prevented by appropriate measures at a local level. Physical hazards should first be removed or reduced if possible, or measures should be taken to prevent or reduce human exposure. Physical hazards that cannot be completely dealt with in this way should be the subject of additional preventive or remedial measures. These include drowning prevention programmes, public information and warnings (such as signs, flags and general education and awareness raising), the provision of effective lifeguard supervision and rescue services, and the establishment of different recreation zones for different recreational activities using lines, buoys and markers.

Monitoring of a site for existing and new hazards should be undertaken on a regular basis. The frequency and timing of inspections will vary with the location.

Sun, heat and cold

The recreational use of water environments sometimes leads to exposure of individuals to extreme solar radiation and to extreme conditions of heat or cold.

Ultraviolet radiation (UVR) from sunlight can be divided into three bands: UVA, UVB and UVC. As the ozone layer becomes depleted, the protective filter provided by the atmosphere is progressively reduced, and human beings are exposed to higher UV levels, in particular higher UVB levels.

Overexposure to UVR may result in acute and chronic damage to the skin, the eyes and the immune system. The most noticeable acute effect of excessive UV exposure is erythema, the familiar inflammation of the skin commonly termed sunburn. Photokeratitis and photoconjunctivitis are other acute effects of UV exposure. Chronic effects include two major public health problems: skin cancers (both non-melanoma skin cancers and malignant melanoma) and cataracts. Chronic exposure to UVR also causes a number of degenerative changes in the skin (e.g., freckles) and accelerates skin aging. There is also increasing evidence for an immunosuppressive effect of both acute high-dose and chronic low-dose UV exposure on the human immune system.

Not all effects of UV radiation are adverse. The best known beneficial effect is the stimulation of the production of vitamin D in the skin. UVR from artificial sources is also used to treat several diseases and dermatological conditions, including rickets, psoriasis, eczema and jaundice.

Simple protective measures are available and should be adopted to avoid adverse health effects on the skin, eyes and immune system. These include minimizing the amount of time spent in the sun, including complete avoidance of midday sun exposure; seeking shade; and wearing loose-fitting and tightly woven clothing, a broad-brimmed hat and wrap-around sunglasses. Furthermore, a broad-spectrum sunscreen with sun protection factor of 15 or more should be applied liberally on all areas of the body not covered by clothing and should be reapplied often. Sun protection programmes to raise awareness and achieve changes in lifestyle are urgently needed to slow down and eventually reverse the trend towards more skin cancers. The global solar UV index is an important vehicle to raise public awareness of UVR and the risks of excessive UV exposure and to alert people to the need to adopt protective measures.

Exposure to cold water may cause considerable problems for users of recreational waters. The immediate effect of sudden immersion in cold water can be a debilitating reflex response called cold shock, which includes life-threatening respiratory and cardiovascular effects and may lead to drowning. Sudden immersion in cold water often results in impaired swimming ability, which is believed to be responsible for the majority of sudden cold-water immersion deaths. Safety precautions include wearing suitable protective garments when swimming in cold water and using a life-jacket when boating to keep airways clear of water even when unconscious.

In a hot environment, people can suffer serious physical ailments, such as heat cramps, heat exhaustion and heat stroke. The very young, the elderly, patients using drugs that interfere with temperature regulation, people suffering from pre-existing chronic diseases and frequent consumers of alcohol appear to be particularly susceptible. Avoidance measures include consumption of non-alcoholic, non-caffeinated beverages, replacement of salt lost through sweating and retreat to shaded areas. Disorders due to heat occur most frequently when there are rapid changes in thermal conditions, such as during heat waves.

Faecal pollution and water quality

The most frequent adverse health outcome associated with exposure to faecally contaminated recreational water is enteric illness. A cause–effect relationship between faecal or bather-derived pollution and acute febrile respiratory illness (AFRI), which is a more severe health outcome than gastroenteritis, has also been shown.

There is consistency in the overall body of evidence concerning health effects from faecally polluted recreational waters, and a series of randomized controlled trials performed in the United Kingdom form the key studies for derivation of guideline values for the microbiological quality of recreational waters. For marine waters, only intestinal enterococci (faecal streptococci) showed a dose–response relationship for both gastrointestinal illness and AFRI. The guideline values are expressed in terms of the 95th percentile of numbers of intestinal enterococci per 100 ml and represent readily understood levels of risk based on the exposure conditions of the key studies.

There is inadequate evidence with which to directly derive a water quality guideline value for fresh water. Application of the guideline values derived for seawaters to fresh waters would be likely to result in a lower illness rate in freshwater swimmers, providing a conservative guideline in the absence of suitable epidemiological data for fresh waters. Studies under way may provide a more adequate basis on which to develop freshwater guideline values.

The guideline values should be interpreted or modified in light of regional and/or local factors. Such factors include the nature and seriousness of local endemic illness, population behaviour, exposure patterns, and sociocultural, economic, environmental and technical aspects, as well as competing health risk from other diseases that are not associated with recreational water.

The initial classification of a recreational water environment is based upon the combination of evidence for the degree of influence of (human) faecal material (by sanitary inspection of beach and water catchment) alongside counts of suitable faecal index bacteria (a microbial quality assessment). Information to be collected during sanitary inspections should cover at least the three most important sources of human faecal contamination of recreational water environments for public health purposes: sewage; riverine discharges (where the river is a receiving water for sewage discharges and either is used directly for recreation or discharges near a coastal or lake area used for recreation); and bather contamination, including excreta. Where human inputs are minimal, investigation of animal faecal inputs should be explored.

In the microbial water quality assessment, the sampling programme should be representative of the range of conditions in the recreational water environment while it is being used. An important issue is that of collecting sufficient numbers of samples so as to make an appropriate estimation of the likely densities to which recreational water users are exposed. The precision of the estimate of the 95^{th} percentile is higher when sample numbers are increased. The number of results available can be increased significantly by pooling data from multiple years, unless there is reason to believe that local (pollution) conditions have changed. For practical purposes, data on at least 100 samples from a 5-year period and a rolling 5-year data set can be used for microbial water quality assessment purposes.

The outputs from the sanitary inspection and the microbial water quality assessment can be combined to give a five-level classification for recreational water environments—very good, good, fair, poor and very poor. Following initial classification, it is proposed that all categories of recreational water environment would be subject to an annual sanitary inspection (to determine whether pollution sources have changed) and continued water quality monitoring.

Another component of the assessment of a recreational water environment is the possible "upgrading" of a recreational water environment if a significant change in management reduces human exposure to microbial risk.

Follow-up analyses are recommended when the intestinal enterococci counts are high but the sanitary inspection suggests low sanitary impact, or vice versa. A primary role of the follow-up is to help identify the source of the faecal pollution, thereby assisting in the assessment and management of faecal contamination in recreational water environments.

In certain circumstances, there may be a risk of transmission of pathogens associated with more severe health effects (such as infectious hepatitis or typhoid fever) through recreational water use. Public health authorities should be alert to such hazards where exposure may occur and should take appropriate action to protect public health.

Population groups that may be at higher risk of disease include the young, the elderly and the immunocompromised, as well as visiting populations susceptible to locally endemic disease. If such groups are significant water users, then this should be taken into account in risk assessment and management.

Management action in response to a recreational water environment classification indicating unacceptable faecal contamination can be both immediate, such as public health advisories, and long term, such as pollution abatement.

Free-living microorganisms

In addition to microorganisms introduced to recreational waters through human or animal faecal contamination, a number of pathogenic microorganisms are free-living in such areas or, once introduced, are capable of colonizing the environment.

Vibrio species are natural inhabitants of marine aquatic environments in both temperate and tropical regions. The occurrence of vibrios does not correlate with the occurrence of the traditionally used bacterial faecal index organisms, except perhaps in waters receiving human wastes from disease outbreaks (mainly cholera). Due to the ubiquitous nature of *Vibrio* species in the aquatic environment, their presence in bathing water cannot be controlled by water quality control measures such as wastewater treatment and disinfection. Human carriers and shedding appear to be of only limited importance in the epidemiology of *Vibrio* infections associated with recreational water use. For *V. cholerae*, 10^6 organisms or more are typically needed to cause cholera, so that it is unlikely that persons bathing or involved in other recreational water activities would ingest vibrios in numbers high enough to cause gastrointestinal disease. However, the risk of extraintestinal infections associated with human pathogenic *Vibrio* species, especially wound and ear infections, during recreational activities in water is of health importance, although the infectious doses for such infections are unknown.

Aeromonas spp. are considered autochthonous inhabitants of aquatic environments and are ubiquitous in surface fresh and marine waters, with high numbers occurring during the warmer months of the year. Clinical isolation of these microbes presents the same seasonal distribution. Numbers may be high in both polluted and unpolluted habitats with densities ranging from <1 to 1000 cells per ml. Sewage can also contain elevated numbers (10^6–10^8 cells per ml) of aeromonads. *Aeromonas* has been found to have a role in a number of human illnesses including gastroenteritis. Cases of wound infections in healthy people associated with recreational water have been described, as have cases of pneumonia following aspiration of contaminated recreational water.

Free-living amoebae are unicellular protozoa common to most soil and aquatic environments. Of the many hundreds of species of free-living amoebae, only members of the genus *Acanthamoeba*, *Naegleria fowleri* and *Balamuthia mandrillaris* are known to infect humans, often with fatal consequences. *Acanthamoeba* have been isolated from natural and artificial waters. Certain species are pathogenic to humans and cause two clinically distinct diseases affecting the central nervous system: granulomatous amoebic encephalitis (GAE) and inflammation of the cornea (keratitis). *Naegleria fowleri*, which is found in thermal freshwater habitats worldwide, causes primary amoebic meningoencephalitis (PAM) in humans. PAM is usually fatal, with death occurring in 3–10 days after exposure. Infection usually results from swimming in contaminated water, although the infectious dose for humans is not known. *B. mandrillaris* encephalitis is largely a disease of the immunocompromised host, and certain cases of GAE attributed to *Acanthamoeba* have in fact been shown to have been caused by *B. mandrillaris*.

Leptospires are excreted in the urine of infected animals, which can then contaminate soil, mud, groundwater, streams and rivers. Humans become infected either directly through contact with infected urine or indirectly via contaminated fresh water or soil. Virulent leptospires gain entry to the body through cuts and abrasions of the skin and through the mucosal surfaces of the mouth, nose and conjunctiva. In cases due to exposure to recreational water, the incubation period seems to vary between 2 and 30 days, but generally is between 7 and 14 days. The clinical manifestations of leptospirosis vary considerably in form and intensity, ranging from a mild flu-like illness to a severe and potentially fatal form of the disease, characterized by liver and kidney failure.

Evidence suggests that although infection with free-living microorganisms or pathogenic leptospires via recreational water use may be life-threatening, the incidence of such infection is very low and, in many cases, is limited to specific areas. As such, no specific guideline values have been recommended, although authorities should be aware of the potential hazards posed by these organisms and act accordingly. Assessment of the likely hazard (e.g., the likelihood of thermal warming of fresh waters) and education of water users and health professionals are important control measures.

Microbial aspects of beach sand quality

Bacteria, fungi, parasites and viruses have all been isolated from beach sand. A number of them are potential pathogens. Factors promoting the survival and dispersion of pathogens include the nature of the beach, tidal phenomena, the presence of sewage outlets, the season, the presence of animals and the number of swimmers. Transmission may occur through direct person-to-person contact or by other means, although no route of transmission has been positively demonstrated.

Concern has been expressed that beach sand or similar materials may act as reservoirs or vectors of infection. However, the capacity of microorganisms that have been isolated from beach sand to infect bathers and beach users remains undemonstrated, and the real extent of their threat to public health is unknown. There is therefore no evidence to support establishment of a guideline value for index organisms or pathogenic microorganisms on beach sand.

The principal microbial risk to human health encountered upon beaches and similar areas is that arising from contact with animal excreta, particularly from dogs. Regulations that restrict access seasonally on frequently used beaches or place an obligation upon the owner to remove animal excreta, increased public awareness and beach cleaning are preventive management actions.

Algae and cyanobacteria in coastal and estuarine waters

Several human diseases have been reported in association with many toxic species of dinoflagellates, diatoms, nanoflagellates and cyanobacteria (blue-green algae) that occur in the marine environment. The toxicity of these algae to humans is due to the presence of algal toxins. Marine algal toxins become a problem primarily because they concentrate in shellfish and fish that are subsequently eaten by humans, causing shellfish poisoning (not dealt with in this volume).

Marine cyanobacterial dermatitis ("swimmers' itch" or "seaweed dermatitis") is a severe contact dermatitis that may occur after swimming in seas containing blooms of certain species of marine cyanobacteria. The symptoms are itching and burning within a few minutes to a few hours after swimming in the sea where the cyanobacteria are suspended. Some toxic components, such as aplysiatoxin, debromoaplysiatoxin and lyngbyatoxin A, have been isolated from marine cyanobacteria. These toxins are highly inflammatory and are potent skin tumour promoting compounds.

Nodularia spumigena was the first cyanobacterium recognized to cause animal death. The toxin produced by *N. spumigena*, called nodularin, acts as a hepatotoxin, in that it induces massive haemorrhages in the liver of mammals and causes disruption of the liver structure. To date, there have been no reports of human poisoning by *N. spumigena*, but humans may be as susceptible to the toxins as other mammals. Therefore, it is possible that small children may accidentally ingest toxic material in an amount that may have serious consequences.

Inhalation of a sea spray aerosol containing fragments of marine dinoflagellate cells and/or toxins (brevetoxins) released into the surf by lysed algae can be harmful to humans. The signs and symptoms are severe irritation of conjunctivae and mucous membranes (particularly of the nose) followed by persistent coughing and sneezing and tingling of the lips.

Available data indicate that the risk for human health associated with the occurrence of marine toxic algae or cyanobacteria during recreational activities is limited to a few species and geographical areas. As a result, it is inappropriate to recommend specific guideline values.

Within areas subject to the occurrence of marine toxic algae or cyanobacteria, it is important to carry out adequate monitoring activities and surveillance programmes. In affected areas, it is appropriate to provide health information to general practitioners and the general public, in particular recreational water users. Precautionary measures include avoiding areas with visible algal concentrations and/or algal scums in the sea as well as on the shore, avoiding sitting downwind of any algal material drying on the shore and showering to remove any algal material.

Algae and cyanobacteria in fresh water

Many species of freshwater algae may proliferate quite intensively in eutrophic (i.e., nutrient-rich) waters. However, they do not form dense surface scums or "blooms," as do some cyanobacteria. Toxins they may contain therefore are not accumulated to potentially hazardous concentrations. For this reason, most adverse health impacts from recreational use of fresh waters have been associated with cyanobacteria rather than with freshwater algae.

Progress in analytical chemistry has enabled the isolation and structural identification from toxic cyanobacteria of three neurotoxins (anatoxin-a, anatoxin-a(s) and saxitoxins), one general cytotoxin, which inhibits protein synthesis (cylindrospermopsin), and a group of toxins termed microcystins (or nodularins, found in brackish waters), which inhibit protein phosphatases. Most of them have been found in a wide array of genera, and some species contain more than one toxin.

Allergic or irritative dermal reactions of varying severity have been reported from a number of freshwater cyanobacterial genera (*Anabaena*, *Aphanizomenon*, *Nodularia*, *Oscillatoria*, *Gloeotrichia*) after recreational exposure. Bathing suits and particularly wet suits tend to aggravate such effects by accumulating cyanobacterial material and enhancing disruption of cells and liberation of cell content. It is probable that these symptoms are not due to recognized cyanotoxins but rather to currently largely unidentified substances.

In contrast to dermal contact, uptake of cyanobacteria though ingestion or aspiration involves a risk of intoxication by cyanotoxins. Most documented cases of human injury through cyanotoxins involved exposure through drinking-water, and they demonstrate that humans have become ill—in some cases seriously—through ingestion or aspiration of toxic cyanobacteria. Symptoms reported include abdominal pain, nausea, vomiting, diarrhoea, sore throat, dry cough, headache, blistering of the mouth, atypical pneumonia and elevated liver enzymes in the serum, as well as hay fever symptoms, dizziness, fatigue, and skin and eye irritations.

Health impairments from cyanobacteria in recreational waters must be differentiated between the chiefly irritative symptoms caused by unknown cyanobacterial substances and the potentially more severe hazard of exposure to high concentrations of known cyanotoxins, particularly microcystins. A single guideline value therefore is not appropriate. Rather, a series of guideline values associated with incremental severity and probability of health effects is defined at three levels.

For protection from health outcomes not due to cyanotoxin toxicity, but rather to the irritative or allergenic effects of other cyanobacterial compounds, a guideline level of 20 000 cyanobacterial cells/ml (corresponding to 10 µg chlorophyll-a/litre under conditions of cyanobacterial dominance) can be derived. A level of 100 000 cyanobacterial cells/ml (equivalent to approximately 50 µg chlorophyll-a/litre if cyanobacteria dominate) represents a guideline value for a moderate health alert in recreational waters. The presence of cyanobacterial scum in swimming areas represents the highest risk of adverse health effects, due to abundant evidence for potentially severe health outcomes associated with these scums.

Because adequate surveillance is difficult and few immediate management options are available (other than precluding or discouraging use or cancelling water sports activities such as competitions), provision of adequate public information is a key short-term measure. Medium- to long-term measures are identification of the sources of nutrient (in many ecosystems phosphorus, sometimes nitrogen) pollution and significant reduction of nutrient input in order to effectively reduce proliferation not only of cyanobacteria, but of potentially harmful algae as well.

Aesthetic issues

The aesthetic value of recreational waters implies freedom from visible materials that will settle to form objectionable deposits, floating debris, oil, scum and other matter, substances producing objectionable colour, odour, taste or turbidity, and substances and conditions that produce undesirable aquatic life. Clean beaches are one of the prime parameters that are desired by recreational users. Local economies may depend on the aesthetic quality of recreational water areas, and the environmental degradation of beaches is known to lead to loss of income from tourism.

Water at swimming areas should ideally be clear enough for users to estimate depth, to see subsurface hazards easily and to detect the submerged bodies of swimmers or divers who may be in difficulty. Aside from the safety factor, clear water fosters enjoyment of the aquatic environment. The principal factors affecting the depth of light penetration in natural waters include suspended microscopic plants and animals, suspended mineral particles, stains that impart a colour, detergent foams and dense mats of floating and suspended debris.

Visitor enjoyment of any beach is generally marred by litter. The variety of litter found in recreational water or washed up on the beach is considerable and includes, for example, discarded food/wrapping, bottles/cans, cigarette butts, dead fish, discarded condoms, discarded sanitary towels, and syringes, needles and other medical wastes. Unlike most litter, medical waste and broken glass also represent hazards to health.

Objectionable smells associated with untreated sewage effluent, decaying organic matter such as vegetation, dead animals or fish, and discharged diesel oil or petrol can deter recreational water and bathing beach users. Odour thresholds and their association with the concentrations of different pollutants of the recreational water environment have not, however, been determined.

Marine debris monitoring can be used to provide information on the types, quantities and distribution of marine debris, to identify sources of marine debris, to explore public health issues relating to marine debris and to increase public awareness of the condition of the coastline. Management options include manual or mechanical beach cleaning.

Chemical and physical agents

Chemical contaminants can enter surface waters or be deposited on beaches from both natural and anthropogenic sources. Exposure is one of the key issues in determining the risk of toxic effects from chemicals in recreational waters. The form of recreational activity will therefore play a significant role. Routes of exposure will be direct surface contact, including skin, eyes and mucous membranes, inhalation and ingestion. In assessing the risk from a particular contaminant, the frequency, extent and likelihood of exposure are crucial parts of the evaluation.

pH has a direct impact on the recreational uses of water only at very low or very high pH values. Under these circumstances, it may contribute to irritation of the skin and eyes.

The potential risks from chemical contamination of coastal and freshwater recreational waters, apart from toxins produced by marine and freshwater cyanobacteria and algae, marine animals or other exceptional circumstances, will be very much smaller than the potential risks from microbial contaminants. It is extremely unlikely that water users will come into contact with sufficiently high concentrations of most contaminants to cause ill effects following a single exposure. Even repeated (chronic) exposure is unlikely to result in ill effects at the concentrations of contaminants found in water and with the exposure patterns of recreational users. However, it remains important to ensure that chemical hazards and any potential human health risks associated with them are controlled and that users can be reassured as to their personal safety.

In most cases, the concentration of chemical contaminants will be below drinking-water guidelines. As long as care is taken in their application, the WHO *Guide-*

lines for Drinking-water Quality can provide a starting point for deriving values that could be used to make a preliminary risk assessment under specific circumstances. These guideline values relate, in most cases, to lifetime exposure following consumption of 2 litres of drinking-water per day. For recreational water contact, an intake of 200 ml per day—100 ml per recreational session with two sessions per day—may often be reasonably assumed.

An assessment of the chemical hazards in recreational water may involve inspecting the immediate area to determine if there are any immediate sources of chemical contamination, such as outfalls; considering the pattern and type of recreational use of the water to determine whether there will be extensive contact with the water and/or a significant risk of ingestion; and chemically analysing the water to support a quantitative risk assessment.

It is important that the basis of any guidelines or standards that are considered to be necessary for chemical constituents of recreational waters be made clear. Without this, there is a danger that even occasional, trivial exceedances of guidelines could unnecessarily undermine users' confidence. It is also important in evaluating chemical hazards that the risks are not overestimated. The risks should be related to risks from other hazards such as drowning or microbial contamination, which will almost invariably be much greater.

Dangerous aquatic organisms

Dangerous aquatic organisms may be encountered during recreational use of freshwater and coastal recreational environments. Such organisms vary widely and are generally of local or regional importance. The likelihood and nature of human exposure often depend significantly on the type of recreational activity concerned.

Two types of risks can be distinguished in relation to dangerous aquatic species: injury or intoxication resulting from direct encounters with predators or venomous species, and infectious diseases transmitted by species that have life cycles which are linked to the aquatic environment.

Injuries from encounters with dangerous aquatic organisms are generally sustained by accidentally brushing past a venomous sessile or floating organism when bathing, inadvertently treading on a stingray, weeverfish or sea urchin, unnecessary handling of venomous organisms during seashore exploration, invading the territory of large animals when swimming or at the waterside, swimming in waters used as hunting grounds by large predators or intentionally interfering with, or provoking, dangerous aquatic organisms.

Disease vectors include mosquitoes, which transmit malaria parasites and the viruses responsible for dengue fever, yellow fever and various types of encephalitis; and certain species of freshwater snails, which host the larval development of trematode parasites of the genus *Schistosoma*, which can cause a chronic, debilitating and potentially lethal tropical disease known as bilharzia or schistosomiasis in humans. Preventive measures include asking local health authorities for guidance on the local vector-borne disease situation and risk prevention, wearing protective clothing, using repellents and avoiding skin contact with water in schistosomiasis endemic areas.

"In-water" hazardous organisms include piranhas, snakes, electric fish, sharks, barracudas, needlefish, groupers, and moray and conger eels. Many have been known to attack and wound humans. Preventive measures include avoiding swimming in areas where large sharks are endemic; avoiding wearing shiny jewellery in the water where large sharks and barracudas are common; avoiding attaching speared fish to the body where sharks, barracudas or groupers live; avoiding wearing a headlight when fishing or diving at night in needlefish waters; and looking out for groupers and moray or conger eels before swimming into caves or putting hands into holes and cracks of rocks.

"Water's-edge" hazardous organisms include hippopotami, crocodiles and alligators. Preventive measures include keeping the animals at a distance whenever possible, avoiding swimming in areas inhabited by crocodiles or alligators, and embarking on safaris in hippopotamus- and crocodile-infested waters with a knowledgeable guide who can assess risks properly and judge the territorial behaviour of hippopotami in water.

The effects of invertebrate venoms on humans range from mild irritation to sudden death. The invertebrates that possess some kind of venomous apparatus belong to one of five large phyla: Porifera (sponges), Cnidarians (sea anemones, hydroids, corals and jellyfish), Mollusca (marine snails and octopi), Annelida (bristleworms) and Echinodermata (sea urchins and sea stars). Preventive measures include wearing suitable footwear when exploring the intertidal area or wading in shallow water, avoiding handling sponges, cnidarians, cone shells, blue-ringed octopus, bristleworms or the flower sea urchin, avoiding brushing against hydroids, true corals and anemones, and avoiding bathing in waters where Portuguese man-of-war are concentrated.

Venomous vertebrates deliver their venom either via spines, as with many fish species (e.g., catfish, stingray, scorpionfish, weeverfish, surgeonfish), or through fangs, as in sea snakes. Injuries caused by venomous marine vertebrates are common, especially among people who frequently come into contact with these marine animals. Potent vertebrate toxins generally cause great pain in the victims, who may also experience extensive tissue damage. Preventive measures include shuffling feet when walking along sandy lagoons or shallower waters where stingrays frequent, exercising caution when handling and sorting a fishing catch, wearing suitable footwear in shallow water and snake-infested areas, and carrying anti-venom in snake-infested areas.

Monitoring and assessment

WHO has developed a book based upon a framework "Code of Good Practice for Recreational Water Monitoring". This Code comprises a series of statements of principle or objectives that, if adhered to, would lead to the design and implementation of a monitoring programme of scientific credibility. It applies in principle to the monitoring of all waters used for recreational activities that involve repeated or continuous direct contact with a water body.

The Code is published in *Monitoring Bathing Waters*. It provides a linkage to the various health effects associated with recreational waters and incrementally builds up the component parts of a successful programme—key health issues, monitoring and assessment strategies, and principal management considerations. It also provides sufficient detail to allow a manager to undertake such a programme, integrating all the component parts in a consolidated whole. Cross-referencing between the Code and the various chapters of these Guidelines should ensure that a valid and replicable monitoring and assessment programme is established.

The Code and *Monitoring Bathing Waters* provide guidance on the design and implementation of a monitoring programme, including the design of a monitoring programme that includes appropriate quality assurance, data collection, data handling, data interpretation and reporting. In addition to this general guidance, guidance is given in relation to specific hazards that may be encountered in recreational water use areas.

Application of guidelines and management options for healthy recreational water use

The possible negative health outcomes associated with the use of recreational water environments result in the need for guidelines that can be converted into locally (i.e., nationally or regionally) appropriate and applicable standards and associated management of sites to ensure a safe, healthy and aesthetically pleasing environment.

A number of points need to be considered in converting guidelines into regulations adapted to local circumstances. Using the recreational water quality classification system for faecal pollution as an example, the principal requirements that would need to be incorporated into provisions would normally include:

- the establishment of a water quality classification system;
- the obligation upon the national or appropriate regulatory authorities to maintain a listing of all recognized recreational water areas in a publicly accessible location;
- the definition of responsibility for establishing a plan for recreational water safety management and its implementation;
- independent surveillance and provision of information to the public;
- the obligation to act, including the requirement to immediately consult with the public health body and inform the public as appropriate on detection of conditions potentially hazardous to health; and
- a general requirement to strive to ensure the safest achievable recreational water use conditions;

Several management interventions can be identified:

- Regulatory compliance, which includes risk management, is the making of decisions on whether or not risks to well-being are acceptable or ought to be controlled or reduced and for which responsibility lies in the hands of society regulators and participants in the activities; regulatory action at both the local level (i.e., improvements to facilities to eliminate hazards and thereby to reduce risks) and the policy level (usually taking the form of creating standards or guidelines to control risk); enforcement of regulatory compliance; and monitoring and standards, whose aim is to promote improvement.

- Control and abatement technology (e.g., the control and abatement of pollution discharges with respect to the various levels of sewage treatment). When planning for the development of new recreational water projects or for the upgrading of existing ones, a health impact assessment (HIA), which considers changes in environmental and social determinants of health resulting from development, should be incorporated. HIA results in a package of recommended measures to safeguard health or mitigate health risks, as well as health promotional activities.
- Public awareness raising and enhancing the capacity for informed personal choice are increasingly seen as important factors in ensuring the safe use of recreational water environments and an important management intervention. One important tool used by associations and governments to enhance the public's capacity for informed personal choice is beach grading or award schemes.
- The provision of public health advice, is a key input to public awareness and informed personal choice, since it is vital that the public receive the correct information. One aspect of this management intervention is response to short-term incidents and breaches of standards. Prevention and rescue services can also be considered to fall within this intervention.

Multiple stakeholders are involved in the process of adapting and applying guidelines and standards. One way in which all the relevant stakeholders can be brought together is through the establishment of an integrated management system for marine and freshwater recreational areas based on the concept of integrated coastal area management (ICAM). This involves comprehensive assessment, the setting of objectives, and the planning and management of coastal systems and resources. It also takes into account traditional, cultural and historical perspectives and conflicting interests and uses. In an ICAM programme, the exact package of management options to reduce or eliminate health hazards and risks related to recreational water uses will be driven by the nature (including frequency and severity) of the health impacts. Upon assessing the combined level of risk, three levels of response may be considered (basic, expanded and full), each geared for a certain level of intervention.

CHAPTER 1
Introduction

This volume of the *Guidelines for Safe Recreational Water Environments* describes the present state of knowledge regarding the possible adverse impact of the recreational use of coastal and freshwater environments upon the health of users. It also outlines monitoring, control and prevention strategies relating to the hazards associated with these environments. Any possible adverse impacts must be weighed against the enormous benefits to health and well-being associated with the use of recreational water environments.

Recreational uses of inland and marine waters are increasing in many countries worldwide. These uses range from whole-body water contact sports, such as swimming, surfing and slalom canoeing, to non-contact sports, such as fishing, walking, birdwatching and picnicking.

The hazards that are encountered in recreational water environments vary from site to site, as do the nature and extent of exposure. Most available information relates to health outcomes arising from exposure through swimming and ingestion of water. In the development of these Guidelines, all available information was taken into consideration, accounting for the different routes of exposure as much as possible.

In order to properly interpret and apply the Guidelines in a manner appropriate to local conditions, it will be necessary to take into account social, cultural, environmental and economic characteristics of the site, alongside knowledge of activities undertaken, routes of exposure and the nature and severity of hazards. In doing so, local, national and international standard-setting bodies may develop standards that differ between regions and within regions according to differences in these factors.

National and local agencies working in the area of recreational water use have a responsibility to promote and ensure a safe environment. Recreational water areas may be under some form of ownership or associated with a provider of facilities or services. Owners or service providers and their personnel are key players in the control of hazards to human health and in some jurisdictions may have a legal obligation to execute continued "due diligence" relative to the safety of water or beaches. Rural or undeveloped recreational water areas often have different management arrangements and priorities. In all cases, considerable capacity to limit health risks is in the hands of the user, who should assume a degree of responsibility when engaged in recreational activities. Nongovernmental organizations and special interest groups also have an important role to play.

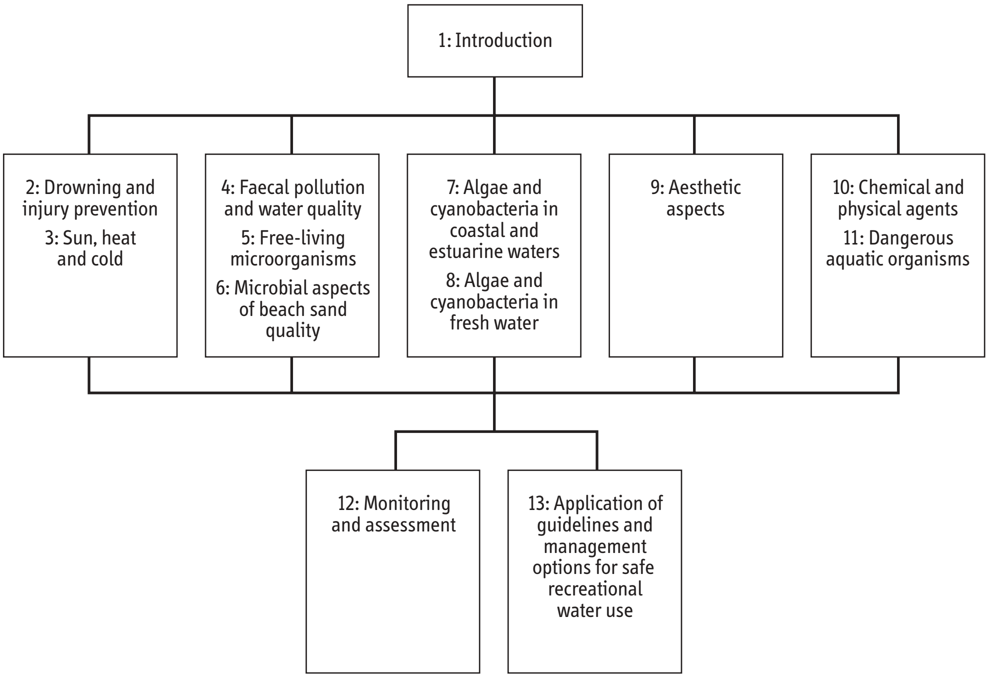

FIGURE 1.1. STRUCTURE OF *GUIDELINES FOR SAFE RECREATIONAL WATER ENVIRONMENTS. VOL. 1: COASTAL AND FRESH WATERS*

In seeking to control the health hazards associated with the recreational use of the water environment, responsible and concerned bodies have at their disposal a diverse range of interventions, including:

- monitoring and enforcing quality standards;
- general awareness-raising activities;
- adopting technical solutions to remediate problems; and
- preventing exposure to hazardous areas or conditions.

Ideally, these interventions should be adopted through proper planning and development of recreational water areas using a framework such as that provided by Integrated Coastal Area Management (see section 1.7.2)

In light of the diversity in exposure, hazard and nature of interventions, this Guidelines document is structured as shown in Figure 1.1.

1.1 General considerations

The primary aim of the *Guidelines for Safe Recreational Water Environments* is the protection of public health. The use of coastal and freshwater recreational water environments—and the resulting rest, relaxation and exercise—is associated with significant benefits to health and well-being. The purpose of the Guidelines is not to deter recreational water use but, instead, to ensure that recreational water areas are operated as safely as possible in order that the largest possible population gets the maximum possible benefit.

The Guidelines are intended to be used as the basis for the development of international and national approaches to controlling the health risk from hazards that may be encountered in recreational water environments, as well as providing a framework for local decision-making. The Guidelines may also be used as reference material for industries and operators preparing development projects in recreational water areas, as a checklist for understanding and assessing potential health impacts of recreational projects, and in the conduct of environmental impact and environmental health impact assessments in particular.

Where guideline values are presented, these are not mandatory limits, but measures of the safety of a recreational water environment. The main reason for not promoting the adoption of international standards for recreational water environments is the advantage provided by adoption of a risk–benefit approach. In the specific case of recreational water use, development of such approaches not only concerns health risks and benefits, but interrelates with other risks and benefits, especially those concerning environmental pollution/conservation, local and national economic development, and the health benefits and well-being derived from recreational use of the water environment.

This approach can often lead to the adoption of standards that are measurable and can be implemented and enforced. These would deal with, for example, water quality and dissemination of information. Other standards may relate to the education of children and adults or to the obligation to prepare and disseminate comparative studies of the safety of alternative locations for recreational water use. In developing strategies for the protection of public health, competent government authorities would take into account the general education of both adults and children and also the efforts and initiatives of nongovernmental organizations and industry operators in this area.

Clearly, a broad-based policy approach will be required that will include legislation as well as positive and negative incentives to alter behaviour and monitor situations. Such a broad base will require significant efforts in intersectoral coordination and cooperation at national and local levels, and successful implementation will require development of suitable skills and expertise as well as the elaboration of a coherent policy and legislative framework.

1.2 Types of recreational water environment

Coastal and freshwater recreational water environments are defined, for the purposes of these Guidelines, as any coastal, estuarine or freshwater area where any type of recreational usage of the water is made by a significant number of users. While uses may be diverse and the Guidelines are intended to be applicable to all types of use (see section 1.3), most concern relates to uses entailing water contact and, in the case of water quality, significant risk of water ingestion.

1.3 Types of use

There are many different types of recreational usage of water environments. These include, for example, sunbathing, wading, swimming, diving, boating, fishing and sailboarding.

Competition for suitable waters and the popularity of recreation often create conflicts between activities, as indicated in Table 1.1. These conflicts can be resolved by supervision, regulation, codes of good practice and voluntary agreements. High-activity sports often present an internal conflict between enjoyment of the excitement and hazard, resolvable by proper attention to safety, training and supervision.

Within the socioeconomic context of recreational water use, the importance of tourism is considerable—in terms of its size, impacts on socioeconomic and environmental spheres and the responsibility and means to intervene that it has at its disposal. Each year, millions of tourists flock to coastal areas. Tourism is the world's third largest industry and the prime economic sector in some states and regions, such as the Caribbean. This is creating increased competition for use of coastal waters and beach areas, increasing the need for clear regulations and codes of conduct.

TABLE 1.1. EXAMPLES OF CONFLICTING INTERACTIONS BETWEEN AND WITHIN DIFFERENT WATER RECREATIONAL ACTIVITIES, AND POSSIBLE CONTROL MEASURES

Recreational Activities	Conflicting interactions	Possible control measures
Whitewater rafting and canoeing, canoe slalom	Challenge and excitement enhance enjoyment but also present hazard of injury and drowning to participants and other water users	Wearing of buoyancy aids, safety helmets; organized training in life-saving; local and national codes of practice; classification of courses by difficulty; supervision and rescue cover at organized events; separation of conflicting uses
Waterskiing, jetskiing, windsurfing	Hazard of injury to swimmers; conflict with movements of commercial shipping, fishing and yachting; powered craft create noise and oil pollution, affecting enjoyment of other users	Creating local restriction zones to avoid conflict; engine designs and oil formulations to avoid visible emission of oil
Use of inland waterways for boating under power, canoe touring and angling	Injury to swimmers	Prohibit swimmers where water quality and conditions are unsuitable; otherwise create or designate swimming areas
Recreational use of drinking-water reservoirs	Contamination of drinking-water sources by faeces, litter, oil and fuel	Restrict uses to angling from shore or rowboat, dinghy sailing, birdwatching and walking, with local codes of practice, supervised by wardens and clubs; no dogs; provision of litter collection and toilets
Dog-walking and horse-riding on beaches	Fouling of beaches; potential transmission of toxocariasis from dog faeces, particularly to children; horses colliding with people on the beach	Banning dogs and horses from recognized swimming beaches during the swimming season

The recognition that all legitimate activities can be accommodated is the essence of integrated coastal area management (ICAM) or integrated river basin management (IBM). The process of ICAM or IBM (see section 1.7.2) introduces mechanisms to facilitate the resolution of conflicts between such competing sectors of the coastal zone or river basin and to help reach agreeable solutions, with respect to the carrying capacity of the environment, while satisfying the general needs of the area. In coming to agreement, management will usually have to adopt pragmatic solutions.

1.4 Types of user

Users of coastal and freshwater recreational water environments may include:

- the general public;
- children/babies;
- hotel guests;
- tourists;
- competitive swimmers;
- clients of camping parks; and
- specialist sporting users, including anglers, canoeists, boat users, scuba divers and so on.

Certain groups of users may be more predisposed to hazards than others. Children, for example, particularly when unattended, may cause an elevated risk of accidents for themselves and others because of their desire for attention and their general reluctance to observe formal rules of safety and hygiene. In addition, they generally play for longer periods of time in recreational waters and are more likely to intentionally or accidentally swallow water.

The elderly and disabled may have strength, agility and stamina problems that limit their ability to recover from problems encountered in recreational water environments. The elderly and immunocompromised individuals may also be at higher risk of health damage from microbial deterioration of water quality, as they are more susceptible to the pathogenic organisms that may occur in this environment.

1.5 Hazard and risk

Popularly, the terms hazard and risk are used interchangeably. Correctly, a *hazard* is a set of circumstances that could lead to harm—harm being loss of life, injury or illness. The *risk* of such an event is defined (Lacey & Pike, 1989) as the probability that it will occur as a result of exposure to a defined quantum of hazard. The *rate of incidence* or *attack rate* is the expected number of events that occur for this defined quantum of hazard. Strictly speaking, probabilities and rates obey different laws, but if the probabilities are small and events are independent, the two values will be approximately equal. Risks can vary from negligible—an adverse event occurring at a frequency of below one per million—to high—fairly regular events that would occur at a rate of greater than one in a hundred (Calman, 1996).

1.5.1 Types of hazard encountered

The hazards associated with the use of coastal and freshwater recreational water environments fall into a number of groups:

- physical hazards (leading, for example, to drowning or injury);
- cold, heat and sunlight;
- water quality (especially exposure to water contaminated by sewage, but also exposure to pathogenic microorganisms free-living in recreational water);
- contamination of beach sand;
- algae and their toxic products;
- chemical and physical agents; and
- dangerous aquatic organisms.

The existence of a diverse range of hazards in the recreational water environment indicates the need for an understanding of their relative importance for health. Examples of adverse health outcomes associated with these hazards are given in Table 1.2.

Drowning and spinal injury are severe health outcomes of great concern to public health. Other injuries, such as cuts from glass and other wastes, while less severe, cause distress and decrease the benefits to well-being arising from recreation. Human behaviour—especially alcohol consumption—is a prime factor that increases the likelihood of injury (see chapter 2), for example, up to 50% of drowning deaths are associated with alcohol in some countries.

Notwithstanding the above, much attention has focused in recent years upon microbial hazards. In particular, health risks associated with contamination of water by sewage and excreta and associated gastroenteric outcomes have been the topics of both scientific and general public interest (see chapter 4). The hazards concerned are not restricted to gastroenteric outcomes and potentially include acute febrile respiratory illness and ear infections arising from pollution of water by excreta and swimmers and other naturally occurring or non-faecally derived infectious agents, such as leptospires (see chapter 5). However, in general terms, it appears that contamination of recreational water with excreta and sewage is widespread and common and affects large numbers of recreational water users, the majority of whom exhibit mild gastroenteric symptoms.

Hazards to human health exist even in unpolluted environments. For example, eye irritation in bathers may occur as a result of a reduction in the eye's natural defences through limited contact with water and does not necessarily relate to water quality or pollution *per se*.

1.5.2 Assessment of hazard and risk

Assessments of hazard and risk inform the development of policies for controlling and managing risks to health and well-being in water recreation. Both draw upon experience and the application of common sense, as well as the interpretation of data. Isolated measurements of risk are not very helpful when decisions have to be made for managing risks or developing policies for controlling them.

TABLE 1.2. EXAMPLES OF ADVERSE HEALTH OUTCOMES ASSOCIATED WITH HAZARDS ENCOUNTERED IN RECREATIONAL WATER ENVIRONMENTS

Type of adverse health outcome	**Examples of associated hazards (with chapter references in parentheses)**
Drowning	• Caught in tidal or rip currents, cut off by rising tides, falling overboard, caught by submerged obstacles, falling asleep on inflatables and drifting into deep water far from shore, slipping off rocks or washed off rocks by wave, misjudging swimming ability (2).
Impact injury	• Impact against hard surfaces or sharp objects (2), driven by the participant (diving, collision, treading on broken glass or jagged metal) or by the force of wind and water. • "Needle stick" injuries from used needles that have washed up or have been discarded on the beach (2). • Coral cuts, oyster cuts and abrasions from slipping on rocks (2). • Attack by aquatic animals (shark, conger and moray eels, piranhas, seals) (11).
Physiological	• Chilling, leading to coma and death (3). • Acute exposure to heat and ultraviolet radiation in sunlight—heat exhaustion, sunburn, sunstroke (3). • Cumulative exposure to sun—skin cancers (basal and squamous cell carcinoma, melanoma) (3).
Infection	• Ingestion of, inhalation of, or contact with pathogenic bacteria, viruses, fungi and parasites, which may be present in water as a result of faecal contamination, carried by participants or animals using the water, or naturally present (4–6). • Bites by mosquitoes and other insect vectors of parasitic diseases (11).
Poisoning and toxicoses	• Ingestion of, inhalation of, or contact with chemically contaminated water (10). • Stings of poisonous and venomous animals (jellyfish, snakes, sting rays) (11). • Ingestion of, inhalation of, or contact with blooms of toxigenic cyanobacteria in fresh (8) or marine water (7) and/or of dinoflagellates in marine water (7).

The assessment of a beach or water should take into account several key considerations, including:

- the presence and nature of natural or artificial hazards;
- the severity of the hazard as related to health outcomes;
- the availability and applicability of remedial actions;
- the frequency and density of use; and
- the level of development.

Health risks that might be tolerated for an infrequently used and undeveloped recreational area, for example, may justify immediate remedial measures at other areas that are more widely used or highly developed.

Figure 1.2 provides a schematic approach to comparing health hazards encountered during recreational water use. A severe health outcome such as permanent paralysis or death, as a result of diving into shallow water, may affect only a small number

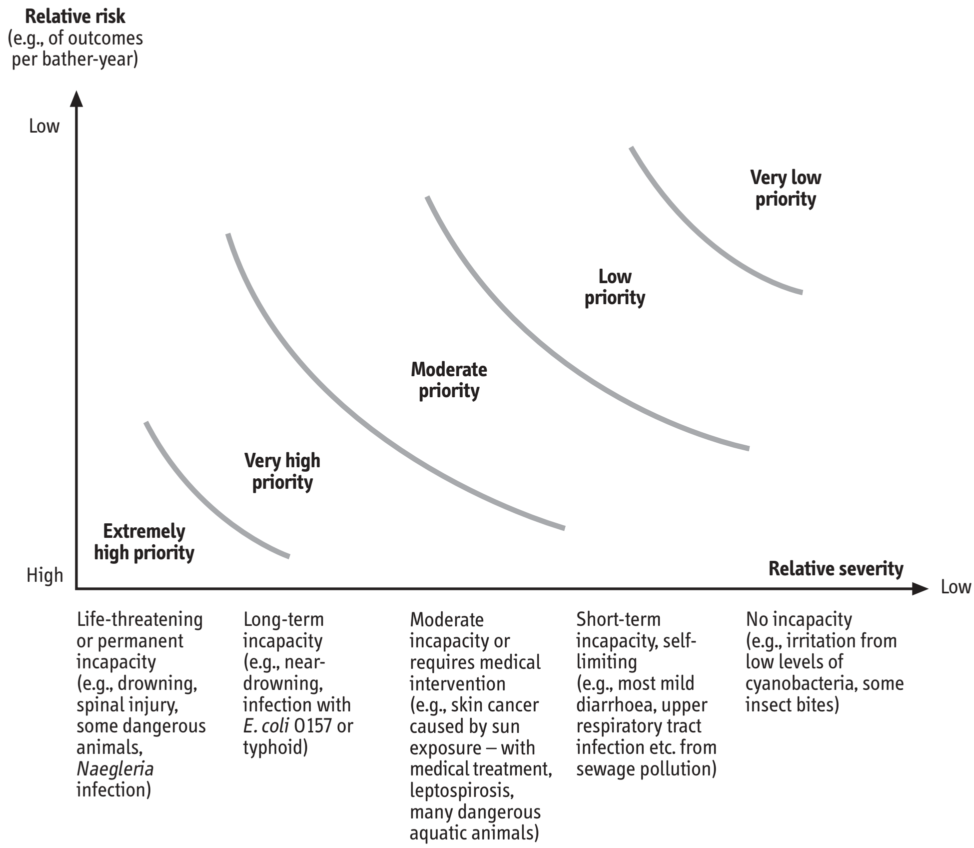

FIGURE 1.2. SCHEMATIC APPROACH TO COMPARING HEALTH HAZARDS ENCOUNTERED DURING RECREATIONAL WATER USE

of swimmers annually but may warrant a high management priority. Minor skin irritations, encountered at the other end of the scale, may affect a higher number of swimmers per year but do not result in any incapacity and thus require lower management priority.

Figure 1.2 can be applied throughout the Guidelines. For each hazard discussed, the "severity" of the hazard can be related to the relative risk in this figure and can serve as a tool to initiate further research or investigation into the reduction of risk as well as to highlight or emphasize priority protective or remedial management measures.

Data related to risk take four main forms:

- national and regional statistics of illness and deaths;
- clinical surveillance of incidence of illness and outbreaks;
- epidemiological studies and surveys; and

- accident and injury records held by recreational water area owners/managers and local authorities.

Although "incident records" held by local authoritative bodies are often comprehensive, published statistics are seldom sufficiently detailed for risk assessment. Processes of surveillance for drinking-water supplies (definined as the continuous and vigilant public health assessment of the safety and acceptability of supplies) have been recommended by WHO (1976, 1997) and involve a dual responsibility of a national, governmental regulator and the supplier or provider of the service. Systems for surveillance of public health operate in most countries. They serve the broad purpose of alerting either regulator or supplier to changes in incidence of disease and to the need for initiating immediate investigation of the causes and remedial action. Such investigation will involve epidemiology (the study of the occurrence and causes of disease in populations). Galbraith & Palmer (1990) give details of the use of epidemiology in surveillance. Epidemiology may also be used as a research tool to investigate hypotheses concerning the causes of illness (section 1.5.3).

There are other reasons why it is difficult to estimate risk directly, such as the following:

- In most active water sports, enjoyment arises from the use of skill to avoid and overcome perceived hazards. The degree of competence of participants and the use of properly designed equipment and protective clothing, accompanied by supervision and training, will considerably modify the risk.
- Risks of acquiring infectious disease will be influenced by innate and acquired immunity (for examples, see Gerba et al., 1996). The former comprises a wide range of biological and environmental factors (age, sex, nutrition, socioeconomic and geographic), as well as body defences (impregnability of the skin, lysozyme secretion in tears, mucus and sweat, the digestive tract and phagocytosis). Previous challenge by pathogens often results in transient or long-lasting immunity.
- Assessment of harm itself and the degree of harm suffered depend upon judgement at the time. Medical certification of injury and of physiological illness and infection, accompanied by clinical diagnosis, is the most reliable information. Information obtained by survey or questionnaire will contain a variable degree of uncertainty caused by the subjects' understanding of the questions, their memory of the events and any personal bias of the subject and interviewer. Survey information is only as good as the care that has gone into the design and conduct of the survey. Data for aesthetic insult are subjective by nature, but frequencies of occurrence of particular types of waste objects on stretches of beaches can be quantified.
- The causes of harm must be ascertained as much as possible at the time. There are considerable difficulties in the cases of low-level exposures to chemical and physical agents that have a cumulative or threshold effect and of infectious diseases caused by those pathogens that have more than one route of infection or have a long period of incubation. For example, gastroenteric infections at

resorts may result from person-to-person contact or faulty food hygiene in catering, as well as from ingesting sewage-contaminated water.

- Where data are in the form of published regional or national statistics giving attack rates, the exact basis on which the data are collected and classified must be ascertained. For example, national statistics on deaths by drowning will usually include suicides and occupational accidents (fishermen, mariners, construction workers) as well as misadventure in recreation.
- It cannot be assumed that risk is directly proportional to exposure or that risks from multiple exposures or a combination of different factors will combine additively.

1.5.3 The use of epidemiology in risk assessment

There is a considerable body of epidemiological information concerning the effects of faecal contamination of swimming waters on the incidence of gastroenteritis and other transmissible diseases in swimmers and other participants in water recreation. This has been critically reviewed (Pike, 1989, 1994; Cartwright, 1992; Fewtrell & Jones, 1992; Prüss, 1998) and is examined later in this volume (chapter 4). The level of epidemiological research concerning some other types of recreational water hazard is considerably less than that for faecal contamination. This may relate to a number of factors, including infrequent outcomes and ethical concerns.

Epidemiological information is more reliable than published statistics for assessing risks, since its rigorous disciplines are designed to eliminate sources of bias and errors in interpretation. On the other hand, this rigour limits epidemiological studies to single or a few closely related hazards and carefully defined populations. Hence, epidemiological approaches do not always measure the full range of variation in population responses (Grassman, 1996).

1.5.4 Degree of water contact

The overall basis for development of a risk reduction strategy depends on broad classifications of recreational activities. For hazards where contact with and/or ingestion of water are important, an understanding of the different degrees of contact associated with different recreational water uses is essential. The degree of water contact directly influences the degree of contact with infectious and toxic agents and physical hazards found in water and therefore the likelihood of being injured or contracting illness.

The degrees of water contact encountered in coastal and freshwater recreational water environments may be classified as follows:

- *No contact*—recreational activity in which there is normally no contact with water (e.g., angling from shore), or where water is incidental to enjoyment of the activity (such as sunbathing on a beach).
- *Incidental contact*—recreational activity in which only the limbs are regularly wetted and in which greater contact (including swallowing water) is unusual—for example, 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 or whitewater canoeing. Inadvertent immersion, through being swept into the water by a wave or slipping, would also result in whole-body contact.

Routes of exposure to infectious and toxic agents in water will vary depending on the degree of water contact. Generally, exposure of skin and mucous membranes during recreational water activities is most frequent. For whole-body contact activities, the probability that some water will be ingested will be greater, although actual data on the quantities of water ingested while indulging in water sports are difficult to obtain. Inhalation can be important in circumstances where there is a significant amount of spray, such as in waterskiing. The skill of the participant in water recreation will also be important in determining the extent of involuntary exposure, particularly water ingestion.

1.6 Measures to reduce risks in water recreation

Because hazards may give rise to health effects after short-term exposures, it is important that standards, monitoring and implementation enable preventive and remedial actions within real time frames. For this reason, emphasis in the Guidelines is placed upon identifying circumstances and procedures that are likely to lead to a continuously safe environment for recreation. This approach emphasizes monitoring of both conditions and practices and the use of threshold values as key indicators, assessed through programmes of monitoring and assessment.

Table 1.2 in section 1.5.1 lists and classifies the main adverse health outcomes associated with exposure to hazards encountered in water recreation. Study of the examples given indicates that reduction of most, if not all, of their associated risks can be obtained by avoiding the circumstances giving rise to the hazard or mitigating their effect. Table 1.2 also suggests particular types of recreation that may be prone to certain hazards and actions that may be taken to reduce the risk. For example, glass left on a beach will cause the hazard of cuts to walkers with bare feet, which may be mitigated by regular cleaning of the beach, provision of litter bins, prohibiting the use of glass on the beach and educational awareness campaigns. This suggests that the types of recreational activity undertaken in a given location should be subject to a hazard assessment and the type of control measures that will be most effective determined.

Examples of potential control measures and bases for developing guidelines and for reducing risks in non-contact, incidental contact and whole-body contact water recreation are presented in Tables 1.3 (page 12), 1.4 (page 13) and 1.5 (page 14), respectively. For each recreational use, more than one hazard will be encountered and the list of hazards for each use will differ depending on circumstances. Measures for risk reduction will therefore be specific to each form of recreation and to particular circumstances. Detailed examples of hazards and their associations with particular forms of recreation will be considered in later chapters.

TABLE 1.3. HAZARDS AND MEASURES FOR REDUCING RISKS IN NON-CONTACT RECREATION

Examples of non-contact recreational activities[a]	Principal hazards	Potential risk reduction measures
Angling from shore (1–6) Boating under power (1–4) Picnics (1–4, 6) Walking (1–4, 6) Sunbathing (2–4, 6) Birdwatching (1–4, 6)	1. Falling in, drowning	1. Where appropriate: safety rails, lifebelts/lifejackets, warning notices, broadcast gale warnings, education, legislation regarding use of lifejackets while boating. Personal care.
	2. Sunburn, sunstroke, skin cancer	2. General and local publicity. Use of sunscreen or sunblock, limit exposure. Wearing protective clothing.
	3. Aesthetic revulsion from fish deaths, anaerobic conditions, oil and other visible pollution	3. Control and licensing of discharges from sewage works, industry, storm sewer outfalls, agriculture, landfills and watercraft.
	4. Bites from mosquitoes and other insect vectors of disease	4. Health warnings to travellers, anti-malarial therapy, avoidance of infested regions, application of appropriate insect repellants.
	5. Infection following skin injury and exposure to water	5. Exercising care; covering all injuries with waterproof dressings.
	6. Injury; treading on broken glass or jagged metal waste	6. Litter control, cleansing recreational area. Putting rubbish in bins or taking it away. Prohibiting use of glass on beach.

[a] Numbers in parentheses refer to principal hazards (column 2) and potential risk reduction measures (column 3).

Participants in the whole-body contact sports of sub-aqua diving, surfing, water-skiing, whitewater canoeing, rafting and windsurfing normally wear wet suits or other protective clothing, which limit skin exposure to the agents of leptospirosis and schistosomiasis and to venomous animal stings, as well as to chilling and ultraviolet radiation (UVR), but which may aggravate symptoms caused by contact with toxic cyanobacteria under some circumstances or enhance the absorption of chemicals through the skin. The wearing of helmets and buoyancy jackets in sailing and canoeing activities (Table 1.5) protects against head injuries and drowning, respectively.

1.7 Managing recreational waters

1.7.1 Stakeholders

Mutually supportive actions should take place, coherently, at the local, national and international level in order to reduce risks encountered during recreational water use. Multiple stakeholders intervene in the assessment, use and protection of recreational waters. Their roles and responsibilities should be defined and their efforts harnessed through an integrated planning framework. Figure 1.3 (page 16) illustrates the variety of stakeholders and their roles in the process of assessing and using recreational waters and taking remedial actions to limit health hazards.

TABLE 1.4. HAZARDS AND MEASURES FOR REDUCING RISKS IN INCIDENTAL CONTACT RECREATION

Examples of incidental contact recreational activities[a]	Principal hazards	Potential risk reduction measures
Rowing, sailing, canoe touring (1, 2, 3, 5, 6) Wading (1–8) Fishing (1–8) Paddling, adults (1–8) (for paddling by young children,) see Table 1.5	1. Falling in, drowning	1. Where appropriate: safety rails, lifebelts/lifejackets, warning notices, broadcast gale warnings, education, legislation regarding use of lifejackets while boating, supervision and availability of rescue services. Personal care.
	2. Leptospirosis (fresh water)	2. Bankside management to control rodents, litter collection. Treating and covering cuts and abrasions prior to exposure. Seeking medical advice if influenza-like symptoms are noticed a few days after recreation.
	3. Cyanobacterial toxicoses (fresh water)	3. Control of eutrophication, monitoring and reporting of cyanobacterial populations, curtailing recreation during blooms. Local publicity. Personal awareness: reporting blooms, avoiding contact, washing down body and equipment after recreation.
	4. Injury; treading on broken glass or jagged metal waste	4. Litter control, cleansing recreational area. Putting rubbish in bins or taking it away. Prohibiting use of glass on beach.
	5. Sunburn, sunstroke, skin cancer	5. General and local publicity. Use of sunscreen or sunblock, limit exposure. Wearing protective clothing.
	6. Bites from mosquitoes and other insect vectors of disease	6. Health warnings to travellers, anti-malarial therapy, avoidance of infested regions, application of appropriate insect repellants.
	7 Fish stings	7 Local awareness raising where problem occurs.
	8. Swimmers' itch and schistosomiasis (freshwater)	8. Control weeds and aquatic snails. Avoiding warm, snail-infested ponds. Personal awareness raising. Information on occurrence of schistosomiasis.

[a] Numbers in parentheses refer to principal hazards (column 2) and potential risk reduction measures (column 3).

1.7.2 Integrated coastal area or river basin management

Integrated coastal area management (ICAM) and integrated river basin management (IBM) are usually initiated in response to issues relating to one or more of the following: fisheries, recreation/tourism, hazards and mangrove depletion. Therefore, recreational water hazards are just one of a wide range of issues, interests and constraints that affect the planning and management of coastal areas or river basins. Decisions relating to management of hazards should be made with reference to all relevant government policies and other factors that affect coastal/river basin amenity and use. Social, economic, aesthetic, recreational and ecological factors all need to be considered. Successful ICAM or IBM also requires "integration over time, with immediate

TABLE 1.5. HAZARDS AND MEASURES FOR REDUCING RISKS IN WHOLE-BODY CONTACT RECREATION

Examples of whole-body contact recreational activities[a]	Principal hazards	Potential risk reduction measures
Sub-aqua diving (1–12) Swimming (1–12) Surfing (1, 2, 5–9, 11, 12) Waterskiing (1–12) Whitewater canoeing, rafting (1–3, 5–7, 11, 12) Windsurfing (sailboarding) (1–12) Children's exploratory activities and paddling (1–12)	1. Drowning	1. Where appropriate: lifebelts/lifejackets, warning notices, broadcast gale warnings, education, legislation regarding use of lifejackets while boating, supervision and availability of rescue services. Personal care.
	2. Waterborne infections[b]	2. Microbial standards. Licensing, control and treatment of discharges of sewage, effluents, storm overflows. Improvements where indicated by unsatisfactory microbial quality. Personal awareness of local conditions.
	3. Leptospirosis (fresh water)	3. Bankside management to control rodents, litter collection. Treating and covering cuts and abrasions prior to exposure. Seeking medical advice if influenza-like symptoms are noticed a few days after recreation.
	4. Cyanobacterial toxicoses (fresh water)	4. Control of eutrophication, monitoring of cyanobacterial populations, curtailing recreation during blooms. Local publicity. Personal awareness raising: reporting blooms, avoiding contact, washing down body and equipment after exercise.
	5. Impact injury	5. Notices indicating hazards. Personal awareness raising and avoidance, wearing head and body protection, where appropriate. Supervision and presence of lifeguards and rescue services. Removal/mitigation of the hazard.
	6. Injury; treading on broken glass or jagged metal waste	6. Litter control, cleansing recreational area. Putting rubbish in bins or taking it away. Prohibiting use of glass on beaches.
	7. Collision with or entrapment by wrecks, piers, weirs, sluices and underwater obstructions	7. Notices to mariners, marker buoys, posting warnings. Personal awareness. Legislation requiring boater training. Rescue services to respond to accidents and mitigate injuries. Appropriate oversight (e.g., harbour patrol).
	8. Fish stings	8. Local awareness raising where problem occurs.
	9. Attack by marine animals (sharks, conger and moray eels, seals)	9. Posting warnings. Personal awareness raising and avoidance.
	10. Swimmers' itch and schistosomiasis (fresh water)	10. Control weeds and aquatic snails. Avoiding warm, snail-infested ponds. Personal awareness raising. Information on the occurrence of schistosomiasis.

TABLE 1.5. *Continued*

Examples of whole-body contact recreational activities[a]	Principal hazards	Potential risk reduction measures
	11. Bites from mosquitoes and other insect vectors of disease	11. Health warnings to travellers, anti-malarial therapy, avoidance of infested regions, application of appropriate insect repellants.
	12. Sunburn, sunstroke, skin cancer	12. General and local publicity. Use of sunscreen or sunblock, limit exposure. Wearing protective clothing.

[a] Numbers in parentheses refer to principal hazards (column 2) and potential risk reduction measures (column 3).

[b] Infections caused by pathogens derived from faecal pollution (see chapter 4).

day-to-day management objectives being co-ordinated and consistent with long-term national and international policy goals" (OECD, 1993, p. 16). It focuses on the interaction between various activities/resource demands carried out within the coastal zone or river basin as distinct from other regions.

Management should be coordinated to reconcile different, sometimes conflicting, uses:

- management of land resources for urban, industrial, mining, tourism and conservation activities;
- management of waters for recreation, aquaculture, conservation, transport and mining;
- management of living freshwater or marine resources; and
- provision of coastal and flood defences.

ICAM and IBM provide umbrellas for coordination among these areas of intervention, covering the economic, abiotic/biotic and social systems.

Current ICAM thinking encapsulates both coastal and river catchments. In the rest of this volume, therefore, only the term ICAM will be used.

1.7.3 Types of management action

Figure 1.4 (page 17) provides a management framework with different levels of health risk and accordingly suggested relevant interventions (which will have differing time frames for implementation), ordered in four major fields:

- compliance and enforcement;
- control and abatement technology;
- public awareness and information; and
- public health advice and intervention.

Clearly, however, there are linkages between these, with, for example, public health advice having an important input into public awareness.

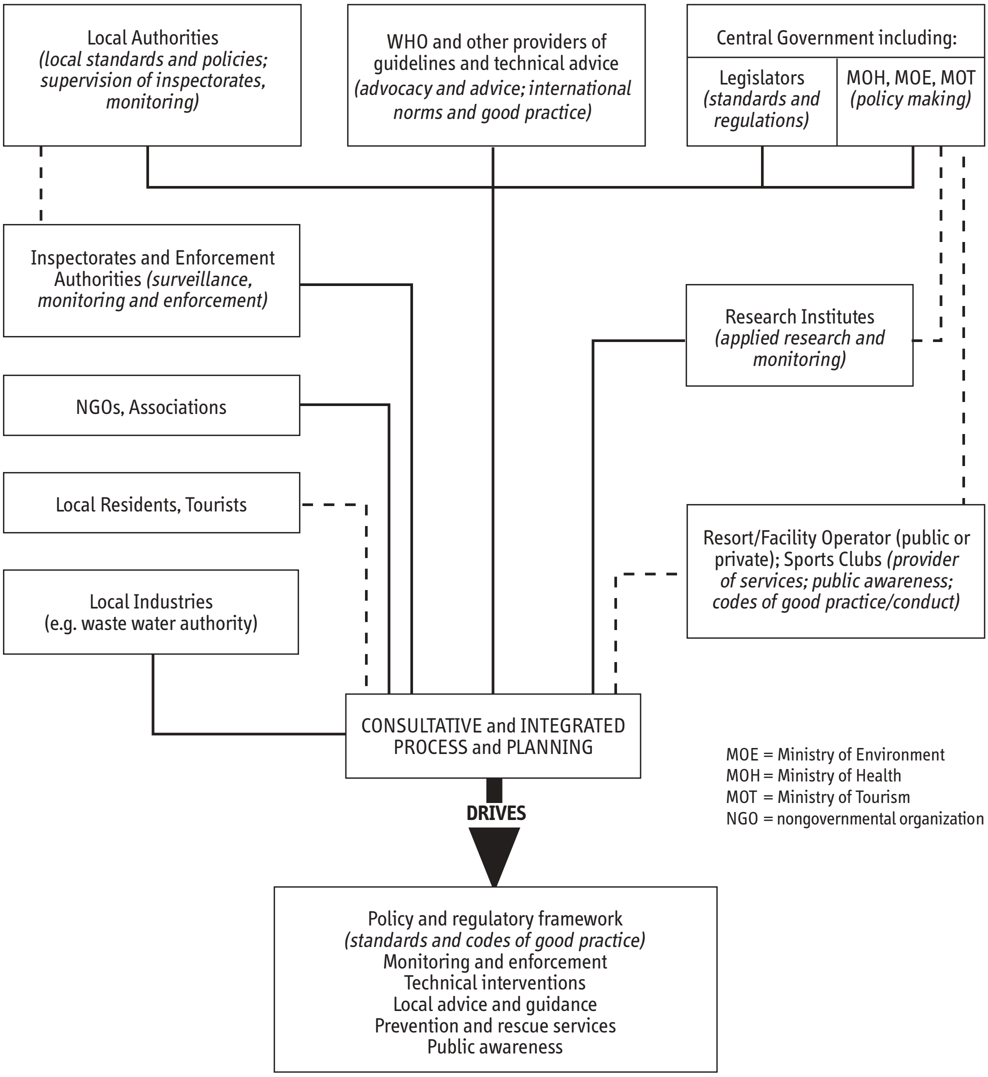

FIGURE 1.3. SOME STAKEHOLDERS IN RECREATIONAL WATER ENVIRONMENTS

The scheme shown in Figure 1.4 has general relevance and can be applied to all areas covered by the various chapters in this volume. The management interventions outlined in Figure 1.4 are discussed in more detail in chapter 13.

1.8 Nature of the guidelines

A guideline can be a level of management, a concentration of a constituent that does not represent a significant risk to the health of individual members of significant user groups, a condition under which such concentrations are unlikely to occur, or a combination of the last two. In deriving guidelines including guideline values, account

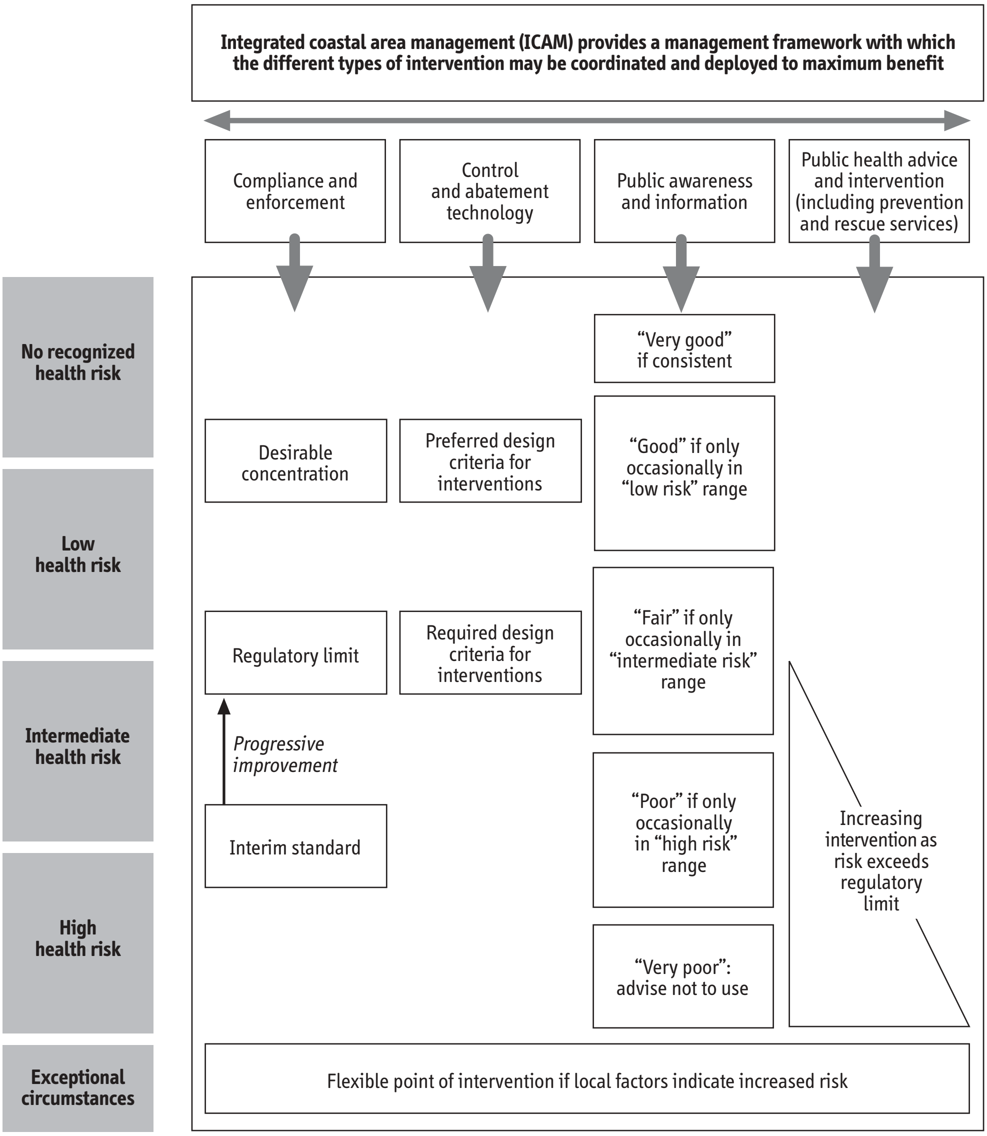

FIGURE 1.4. MANAGEMENT FRAMEWORK AND TYPES OF INTERVENTION IN RELATION TO DIFFERENT LEVELS OF RISK

is taken of both the severity and frequency of associated health outcomes. Water conforming to the guidelines may, however, present a health risk to especially susceptible individuals or to certain user groups.

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

For most parameters, there is no clear cut-off value at which health effects are excluded, and the derivation of guideline values and their conversion to standards therefore include an element of valuation addressing the frequency, nature and severity of associated health effects. This valuation process is one in which societal values play an important role, 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 degraded to this level. Indeed, a continuous effort should be made to ensure that recreational water environments are of the highest attainable quality.

Many of the hazards associated with recreational use of the water environment are of an instantaneous nature: accidents and exposures to infectious doses of microorganisms may occur in very short periods of time. Short-term deviations above guideline values or conditions are therefore of importance 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.

This volume of the *Guidelines for Safe Recreational Water Environments* does not address:

- exposures associated with foodstuffs, in particular water products such as shellfish;
- protection of aquatic life or the environment;
- occupational exposures of individuals working in recreational water environments;
- especially susceptible individuals (or population groups);
- waters afforded special significance for religious purposes and which are therefore subject to special cultural factors;
- risks associated with ancillary facilities that are not part of the recreational water environment; for example, beach sand is addressed, while toilet facilities in adjacent areas are not considered beyond assertion of the need for them in order to minimize soiling of the recreational environment;
- guideline values for aesthetic aspects, since their valuation is one of societal and cultural values, which cannot be expressed solely in quantitative terms, and their control will not reduce adverse health effects; on the other hand, the importance of aesthetic factors in ensuring maximum benefit for well-being from recreational use of the water environment is discussed;
- seasickness;
- the "bends" decompression sickness and other phenomena restricted to subaqua and deep-sea diving;
- guidance on rescue, resuscitation or treatment; and
- therapeutic uses of waters (thalassotherapy, spas).

Swimming pools, spas and similar recreational water environments are addressed in the companion volume, *Guidelines for Safe Recreational Water Environments Volume 2: Swimming Pools, Spas and Similar Recreational Water Environments.*

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CHAPTER 2

Drowning and injury prevention

A number of injury-related health outcomes may arise through the recreational use of water and adjacent areas. Prominent among them are:

- drowning and near-drowning;
- major impact injuries (including spinal injuries resulting in various degrees of paraplegia and quadriplegia; and head injuries resulting in concussion, brain injury and loss of memory and motor skills);
- slip, trip and fall injuries (including bone fractures/breaks/dislocations resulting in temporary or permanent disability; facial injuries resulting in nose and jaw dislocations and scarring; and abrasions); and
- cuts, lesions and punctures

This chapter discusses these adverse health outcomes and their contributory factors, along with possible preventive measures. Bites, stings and so on from aquatic organisms are addressed in chapter 11.

2.1 Drowning

Drowning, which can be defined as death arising from impairment of respiratory function as a result of immersion in liquid, is a major cause of death worldwide. It has been estimated that, in 2000, 449 000 people drowned worldwide, with 97% of drownings occurring in low- and middle-income countries (Peden & McGee, 2003). It is the third leading cause of death in children aged 1–5 and the leading cause of mortality due to injury, with the mortality rates in male children being almost twice as high as those in female children (Peden & McGee, 2003). Not all drownings are related to recreational water use and the percentage that is attributable to recreational water is likely to vary from country to country. A study in the USA found that 50–75% of all drownings there occurred in natural waters (oceans, lakes, rivers, etc.), with both children and adults being victims (Dietz & Baker, 1974). Brenner et al. (2001) examined the location of drownings in children in the USA. They reported that for children aged between 1 and 4, 56% of drownings were in artificial pools and 26% were in other bodies of freshwater, while among older children 63% of drownings were in natural bodies of freshwater. In Australia, between 1992 and 1997, 17% of drownings occurred in non-tidal lagoons and lakes and 10% occurred at surf beaches (Mackie, 1999). In Uganda, drowning has been shown to be responsible for 27% of all injury fatality. Most of the drowning victims were young males who drowned in lakes and rivers during transportation or on fishing trips (Kobusingye, 2003). Data on drowning in many countries is inadequate, especially in terms of the location of the incident, and this can hamper the evaluation of interventions and prevention and rescue techniques.

Death by drowning is not the sole outcome of distress in the water. Near-drowning is also a serious problem. One study (Wintemute et al., 1988) found that for every 10 children who die by drowning, 140 are treated in emergency rooms and 36 are admitted to hospitals for further treatment (see also Spyker, 1985; Liller et al., 1993), although some never recover. In the Netherlands, it has been reported that on average there are about 300 drowning fatalities a year and an additional 450 cases who survive the drowning incident, of these 390 are admitted to hospital for further treatment (Bierens, 1996; Branche & Beeck, 2003).

It is possible to survive prolonged submersion in cold water (e.g., less than 21 °C). In rare cases, people have been submerged for significant periods (e.g., up to 40 min) with normal neurological recovery (Spyker, 1985; Winegard, 1997; Chochinov et al., 1998; Hughes et al., 2002; Perk et al., 2002).

The recovery rate from near-drowning may be lower among young children than among teenagers and adults. Some survivors suffer subsequent anoxic encephalopathy (Pearn et al., 1976; Pearn, 1977; Patrick et al., 1979), leading to long-term neurological deficits (Quan et al., 1989). Studies show that the prognosis depends more on the effectiveness of the initial rescue and resuscitation than on the quality of subsequent hospital care (Fenner et al., 1995; Cummings & Quan, 1999). Development of effective rescue resources, with on-scene resuscitation capabilities, may be important in reducing the frequency of drowning and consequences of near-drowning.

2.1.1 Contributory factors

Both drowning and near-drowning have been associated with many contributory factors (see, for example, Poyner, 1979). Data suggest, for example, that males are more likely to drown than females (Peden & McGee, 2003). This is generally associated with higher exposure to the aquatic environment (through both occupational and recreational uses), greater consumption of alcohol (leading to decreased ability to cope and impaired judgement) and their inclination towards higher risk-taking activity (Dietz & Baker, 1974; Mackie, 1978; Plueckhahn, 1979, 1984; Nichter & Everett, 1989; Quan et al., 1989; Howland et al., 1996).

Alcohol consumption is one of the most frequently reported contributory factors associated with the greatest proportion of adolescent and adult drownings in many countries (Howland & Hingson, 1988; Levin et al., 1993; Petridou, 2003). For children, lapses in parental supervision are the most frequently cited contributory factor in drownings (Quan et al., 1989), although alcohol consumption by the parent or guardian may also play a role in the lapse of supervision (Petridou, 2003).

Drowning and near-drowning may be associated with recreational water uses involving minimal water contact. Recreational use of watercraft (yachts, boats, canoes) and fishing (from watercraft, water's edge, rocks or solid structures) have been associated with drownings (Plueckhahn, 1972; Nichter & Everett, 1989; Steensberg, 1998). Such recreational water uses may occur during cold weather, and immersion cooling may be a significant contributory factor (see section 3.2; Bierens et al., 1990, 1995; Beyda, 1998; Lindholm & Steensberg, 2000). Non-use of lifejackets, even when readily available, is frequently cited as a significant contributory factor in these cases (Plueckhahn, 1979; Patetta & Biddinger, 1988; Steensberg 1998; Quan et al., 1998). In one study in North Carolina, USA, the activities most frequently associated with drownings were (in descending order) swimming, wading and fishing (Patetta & Biddinger, 1988).

Attempted rescue represents a significant risk to the rescuer. For example, a study in North Carolina reported the death by drowning of the would-be rescuer in a significant number of cases (Patetta & Biddinger, 1988). In Australia, Mackie (1999) reported that between 1992 and 1997 there were 1551 non boating-related drownings, of which over 2% were sustained while attempting a rescue.

Hyperventilation before breath-hold swimming and diving has been associated with a number of drownings among individuals, almost exclusively males, with excellent swimming skills. Although hyperventilation makes it possible for a person to extend their time under water, it may result in a loss of consciousness by lowering the carbon dioxide level in the blood (Craig, 1976; Spyker, 1985).

At beaches with surf, rip currents can be a major cause of distress. These currents, which pull swimmers away from shore, have been found to be a factor in as many as 80% of rescues by surf lifeguards (USLA, 2002). In Australia, 35% of rescues and 18.5% of resuscitation cases, over a ten year period, from surf beaches were due to rip currents (Fenner, 1999).

The presence of pre-existing disease is a risk factor for drowning and near-drowning, and higher rates of drowning are reported among those with seizure disorders (Greensher, 1984; CDC, 1986; Patetta & Biddinger, 1988; Quan et al., 1989). Further documented contributory factors include water depth and poor water clarity (Quan et al., 1989).

2.1.2 Preventive and management actions

It has been suggested that over 80% of all drownings can be prevented and prevention is the key management intervention (World Congress on Drowning, 2002; Mackie, 2003). Surprisingly, there is no clear evidence that drowning rates are greater in poor swimmers (Brenner, 2003) and the value of swimming lessons and water safety instruction as drowning preventive measures has not been demonstrated (Patetta & Biddinger, 1988; Mackie, 2003). There is also a significant debate regarding the age at which swimming skills may be safely acquired. Although the need for adult supervision is not decreased when young children acquire increased skills, the possibility that training decreases parental vigilance has not been assessed (Asher et al., 1995).

The availability of cardiopulmonary resuscitation (CPR) (including infant and child CPR) skills (Patetta & Biddinger, 1988; Orlowski, 1989; Liller et al., 1993; Kyriacou et al., 1994; Pepe and Bierens, 2003a) and of rescue skills among witnesses (Patetta & Biddinger, 1988) have been reported to be important in determining the outcome of unintentional immersions. It has been recommended that resuscitation skills should be learned by all professionals who frequent aquatic areas (Pepe & Bierens, 2003b) as early first aid and resuscitation are important factors in survival after a drowning incident.

The Centers for Disease Control and Prevention, USA (CDC) have suggested that legal limits for blood alcohol levels during water recreation activities should be mandated and enforced, and that the availability of alcohol at water recreation facilities should be restricted (CDC, 1998). Cummings & Quan (1999) report data that supports the theory that decreasing alcohol use around water is an effective safety intervention.

Education, aimed at making both locals and tourists knowledgeable about water-based hazards (such as rip currents), can play an important role in reducing drowning. Whittaker (2003) noted that an education package, started in 1998, apparently reduced the drowning rate on beaches in Victoria (Australia) by 31% over a 4 year period.

The principal contributory factors and preventive and management actions for drowning and near-drowning are similar and are summarized in Table 2.1.

2.2 Spinal injury

Data concerning the number of spinal injuries sustained as a result of swimming or water recreation incidents are not widely available or systematically collected. In the USA, it has been found that some 10% of all spinal cord injuries (an incidence of approximately 1000 per year) are related to diving into water (Think First Foundation, 2002).

Blanksby et al. (1997) tabulated data from a series of studies concerning diving incidents as the cause of acute spinal injury in various regions of the world. In one study (Steinbruck & Paeslack, 1980), 212 of 2587 spinal cord injuries were caused by sports or diving incidents, of which 139 were associated with water sports, the majority (62%) with diving. Diving incidents were found to be responsible for 3.8–14% of traumatic spinal cord injuries in a comparison of French, Australian, English and US studies (Minaire et al., 1979), for 2.3% of spinal injuries in a South African study and for 21% in a Polish study (Blanksby et al., 1997).

In diving incidents of all types, injuries are almost exclusively located in the cervical vertebrae (Minaire et al., 1979; Blanksby et al., 1997; Watson et al., 2001). Statistics such as those cited above therefore underestimate the importance of these injuries, which typically cause quadriplegia (paralysis affecting all four limbs) or, less commonly, paraplegia (paralysis of both legs). In Australia, for example, diving incidents account for approximately 20% of all cases of quadriplegia (Hill, 1984). The financial cost of these injuries to society is high, because those affected are frequently healthy younger persons—principally males under 25 years (Blanksby et al., 1997)—and treatment of persons with spinal injuries can be very expensive.

2.2.1 Contributory factors

Data from the USA suggest that body surfing at a beach and striking the bottom was the most common cause of aquatic spinal injury. Ten per cent of spinal injuries occurred when people dived into water, particularly from high platforms, including

TABLE 2.1. DROWNING AND NEAR-DROWNING: PRINCIPAL CONTRIBUTORY FACTORS AND PREVENTIVE AND MANAGEMENT ACTIONS

Contributory factors

- Alcohol consumption
- Cold
- Current (including rip currents, river currents, and tidal currents)
- Offshore winds (especially with flotation devices)
- Ice cover
- Pre-existing disease
- Underwater entanglement
- Bottom surface gradient and stability
- Waves (coastal, boat, chop)
- Water transparency
- Impeded visibility (including coastal configuration, structures and overcrowding)
- Lack of parental supervision (infants)
- Poor or inadequate equipment (e.g. boats or lifejackets)
- Overloading of boats
- Overestimation of skills
- Lack of local knowledge

Preventive and management actions

- Public education regarding hazards and safe behaviours
- Regulations that discourage unsafe behaviours (e.g., exceeding recommended boat loadings)
- Continual adult supervision (infants)
- Restriction of alcohol provision
- Provision of properly trained and equipped lifeguards
- Provision of rescue services
- Access to emergency response (e.g., telephones with emergency numbers)
- Local hazard warning notices
- Availability of resuscitation skills/facilities
- Development of rescue and resuscitation skills among general public and user groups
- Coordination with user group associations concerning hazard awareness and safe behaviours
- Wearing of adequate lifejackets when boating

trees, balconies and other structures. Special dives such as the swan or swallow dive are particularly dangerous, because the arms are not outstretched above the head but to the side (Steinbruck & Paeslack, 1980). There is no evidence to suggest that impact upon the water surface gives rise to serious (spinal) injury (Steinbruck & Paeslack, 1980). Alcohol consumption may contribute significantly to the frequency of injury through diminished awareness and information processing (Blanksby et al., 1997).

Minimum depths for safe diving are greater than frequently perceived, but the role played by water depth has not been conclusively ascertained. Inexperienced or unskilled swimmers require greater depths for safe diving. The velocities reached from ordinary dives are such that sight of the bottom even in clear water may provide an inadequate time for deceleration response (Yanai & Hay, 1995). Most diving injuries occur in relatively shallow water (1.5 m or less) and few in very shallow water (e.g., less than 0.6 m), where the hazard may be more obvious (Gabrielsen, 1988; Branche et al., 1991). Familiarity with the water body is not necessarily protective. In a study from South Africa (Mennen, 1981), it was noted that the typical injurious dive is into a water body known to the individual.

Data from the Czech Republic suggest that spinal injuries are more frequently sustained in open freshwater recreational water areas than in supervised swimming areas, although the number of injuries sustained in freshwater areas in this country appears to be declining (EEA/WHO, 1999).

A proportion of spinal injuries will lead to death by drowning. While data on this are scarce, it does not appear to be a common occurrence (see, for example, EEA/WHO 1999 regarding Portugal). In other cases, the act of rescue from drowning may give rise to spinal cord trauma after the initial impact (Mennen, 1981; Blanksby et al., 1997).

2.2.2 Preventive and management actions

Technique and education appear to be important in injury prevention (Perrine et al., 1994; Blanksby et al., 1997), as are preventive programmes. In Ontario, Canada, for example, preventive programmes established by Sportsmart Canada and widespread education decreased the incidence of water-related injuries substantially between 1989 and 1992 (Tator et al., 1993).

Because of the young age of many injured persons, awareness raising and education regarding safe behaviours are required early in life. Many countries have school-age swimming instruction that may inadequately stress safe diving, but which may also provide a forum for increasing public safety (Damjan & Turk, 1995). Education and awareness raising appear to offer the best potential for diving injury prevention, in part because people have been found to take little notice of signs and regulations (Hill, 1984). This is not to suggest that signs should not be utilized, but that both education and signage may provide significant benefits.

The principal contributory factors and preventive and management actions for spinal cord injury are summarized in Table 2.2.

TABLE 2.2. SPINAL CORD INJURY: PRINCIPAL CONTRIBUTORY FACTORS AND PREVENTIVE AND MANAGEMENT ACTIONS

Contributory factors
• Alcohol consumption • Diving into water of unknown depth • Bottom surface type • Water depth • Lack of adult supervision • Conflicting uses in one area • Diving into water from trees/balconies/structures • Poor underwater visibility
Preventive and management actions
• Local hazard warnings and public education • General public (user) awareness of hazards and safe behaviours, including use of signs • Early education in diving hazards and safe behaviours • Restriction of alcohol provision • Use separation • Lifeguard supervision • Emergency services, access

2.3 Brain and head injuries

Concussions, brain injury and skull/scalp abrasions have occurred through beach and aquatic recreational activities such as diving into shallow water. The contributory factors and preventive and management actions are similar to those for spinal injuries and for limb and minor impact injuries and are summarized in Table 2.2 and Table 2.3.

TABLE 2.3. FRACTURES, DISLOCATIONS AND OTHER IMPACT INJURIES: CONTRIBUTORY FACTORS AND PRINCIPAL MANAGEMENT ACTIONS

Contributory factors
• Diving into shallow water • Underwater objects (walls, piers) • Poor underwater visibility • Adjacent surface type (e.g., of water fronts and jetties) • Conflicting uses in one area
Preventive and management actions
• General user awareness of hazards and safe behaviours • Appropriate surface type selection • Adjacent fencing (e.g., of docks and piers) • Use separation • Lifeguard supervision • Warning signs

2.4 Fractures, dislocations and other impact injuries

Recreational water users have experienced injuries to the nose and jaw areas when swimming underwater, shallow diving or hitting underwater objects such as walls and piers or even other water users (depending upon the nature of the activity). These and other injuries have also been reported as a result of slipping, tripping or falling while entering or leaving the water. Injuries involving limb fractures or breaks of different types have many causes and may occur in a variety of settings in or around water. Broken bones (along with scarring, significant blood loss and amputation) have been reported as a result of injuries sustained from boat propellers (CDC, 2002), although it is not clear whether these were sustained from the boat or while in the water. The principal contributory factors and preventive and management actions associated with fractures, dislocations and other impact injuries are summarized in Table 2.3.

2.5 Cuts, lesions and punctures

There are many reports of injuries sustained as a result of stepping on glass, broken bottles and cans. Discarded syringes and hypodermic needles may present more serious risks (Philipp et al., 1995). Cuts and related injuries can also result from contact with shells, corals and so on. In the case of injury from such objects, wound infection from, for example, *Vibrio* spp. or *Aeromonas* spp. may be an additional problem (see chapter 5). The use of footwear on beaches should be encouraged. Adequate litter bins and beach cleaning operations contribute to prevention. In some areas, syringe/sharp objects disposal bins may be appropriate. Education policies to encourage users to take their litter home are a key remedial measure (see Table 2.4). Banning the possession of glass containers (bottles, jars, etc.) in some beach areas has been found to reduce the likelihood of injuries from broken glass.

2.6 Interventions and control measures

The majority of injuries can be prevented by appropriate measures especially at a local level. A relatively low cost way of promoting aquatic safety is through public education before the visitor even sets foot on the beach. Once the visitor arrives at the beach, additional public education efforts can further enhance public safety. A variety of measures to increase public awareness can be employed and these are reviewed in Chapter 13 (see 13.5).

At the beach, physical hazards should be removed or mitigated if possible, or measures should be taken to prevent or reduce human exposure. Physical hazards that cannot be completely dealt with in this way should be the subject of additional preventive or remedial measures—for example, open or rough water, rough waves, rip currents and bottom debris could all be the subject of general education, general warning notices or special warnings, especially at times of increased risk. It may be possible to rate recreational water areas according to certain characteristics, in order to provide objective, easily understandable information to the public. For example, a beach with a small tidal range, no sudden changes in water depth and so on might be rated as 'family friendly'. A river that is used for white water canoeing might be rated as 'suitable for beginners' under certain conditions or for 'experienced canoeists'

TABLE 2.4. CUTS, LESIONS AND PUNCTURES: PRINCIPAL CONTRIBUTORY FACTORS AND PREVENTIVE AND MANAGEMENT ACTIONS

Contributory factors
• Presence of broken glass, bottles, cans, medical wastes • Walking and entering water barefoot
Preventive and management actions
• Beach cleaning • Solid waste management • Provision of litter bins • Regulation (and enforcement) prohibiting glass containers • General public awareness regarding safe behaviours (including use of footwear) • General public awareness regarding litter control • Local first aid availability

in spate (flood) conditions. Such as system could complement the hazard ranking system outlined in section 2.7.1.

The term hazard is generally used in relation to the capacity of a substance or event to adversely affect human health (see 1.5). In this context, the absence of appropriate control measures may be treated as a component in the chain of causation. For example, the lack of lifeguards, rescue equipment, signs and other remedial actions can contribute to a variety of negative health outcomes.

2.6.1 Lifeguarding

At many coastal and fresh water beaches, people known as lifeguards or lifesavers protect recreational water users from injury and drowning. Depending upon local practice they may be volunteers or paid, or both. Here, the term "lifeguard" is used to refer to people trained and positioned at recreational water sites to protect the water user. Lifeguards, when adequately staffed, qualified, trained and equipped, seem to be an effective measure to prevent drowning. The report of a working group convened by the Centers for Disease Control and Prevention, USA states that "One effective drowning prevention intervention is to provide trained, professional lifeguards to conduct patron surveillance and supervision at aquatic facilities and beach areas" (Branche & Stewart, 2001).

Lifeguards can also assist in injury prevention (e.g., advising users not to enter dangerous areas, such as where a rip current is forming) and by playing a more general educational role (concerning water quality hazards and exposure to heat, cold or sunlight, for example). It has been estimated that lifeguards take 49 preventive actions for every rescue from drowning that they effect (USLA, 2002). According to Branche & Stewart (2001), "the presence of lifeguards may deter behaviours that could put swimmers at risk for drowning, such as horseplay or venturing into rough or deep water, much like increased police presence can deter crime". Further details on lifeguarding can be found in Appendix A.

2.6.2 Use separation

The waterfront may be used for diverse purposes, such as transit (pedestrian, vehicular), sunbathing, swimming, surfing, paddling, watercraft (yachts, powerboats, canoes, personal watercraft) and as a route of access, and the water itself may be used by both swimmers and non-swimmers. As a result of multiple and often dense use, conflicts may emerge, and in many cases zoning or other restrictions on certain uses may become necessary.

Use separation is a measure for minimizing risk where different user groups use the water in different ways within a confined area. Different zones are established for incompatible activities, including for example swimming, diving, sailboarding or powerboating, as well as for conservation and naturalist activities. Specific regulations may be identified for the use of surfboards or similar apparatus. For example, these may be banned within a distance of 70 m of any fishing pier or within 50 m of any swimmer, although this may be difficult to enforce.

At flat water beaches, lines, buoys and markers may be useful in limiting the water recreation area and separating different activities. Lines can also be used to prevent swimmers from entering dangerous areas, to warn of changing conditions or to indicate separation of shallow and deep areas, underwater obstructions, radical changes in slope, etc. The anchoring rope for buoys and markers should not create any risk of entanglement. The buoys are not intended as rest areas.

At coastal beaches where tide, current and wave action typically prevent the use of perimeter devices such as these, lifeguards may patrol and issue warnings or visual reference points onshore may help to keep activities in their proper areas.

It is of particular importance to separate boats from other water users, especially motorboats. If boat launching is to be permitted, special areas should be established that effectively separate it from zones for other uses. At the beachside warning signs and/or buoys should be provided. Boat lanes are generally perpendicular to the shoreline and delimited by floating lines. Boats should launch through this lane at a specified low speed—for example, not more than 3 knots. If boating areas are not delimited for all kind of boats (sailboats, powercraft and jet skis included), an exclusion zone may be defined—for example, in the 200-m zone.

2.6.3 Infrastructure and planning

Waterfront areas are accessed for a variety of purposes, some of which affect safety. Routes used for emergency access—for instance, during launching of rescue craft or to provide access to ambulances—should be suitably maintained, and continuous accessibility should be assured.

Ready access to telephones or other means of communication with emergency services may contribute to speed of rescue or resuscitation. Telephones should ideally be readily accessible and clearly visible, marked on local maps and posted with numbers of key emergency services.

In many recreational water use areas, certain locations or subareas may present significant continuous hazards to human health—for example, due to currents, weirs or rocks. Access to such areas may be discouraged or prevented by a combination of one or more interventions, such as signing, fencing and lifeguard supervision. In some instances, caution lines are used to discourage access, intentional or otherwise, by water users.

In areas with or without lifeguards, rescue equipment may be provided that is accessible for public use. All such safety equipment should be clearly visible from a distance and kept in good repair. Location intervals should be determined according to the response required for a given water recreation area. Public rescue equipment should normally be kept in place year-round.

2.6.4 Beach capacity

It has been suggested that recreational water areas should have an estimated load (number of bathers/visitors) that they may carry safely. While overcrowding may impede effective lifeguarding and therefore contribute to drowning, in practice this is difficult to enforce, and user needs and perceptions vary considerably between areas. Of more importance is the adequate management of the recreational water use area in order to minimize risk.

2.7 Monitoring and assessment

2.7.1 Assessing hazards

Physical characteristics that may present hazards to recreational water users consist of five interrelated phenomena, four of which are common to most coastal beaches:

- water depth, particularly when greater than chest deep;
- variable beach and surf zone topography, such as tides, bars, channels and troughs;
- breaking waves;
- surf zone currents, particularly rip currents; and
- localized hazards, such as reefs, rocks, offshore platforms, inlets, offshore winds, tidal currents, cold water, kelp beds, weirs and locks. The construction of jetties, piers, wharfs and other artificial structures can also contribute to the hazard.

The assessment of hazards in a beach or water environment is critical to ensuring safety. The assessment should take into account several key considerations, including:

- the presence and nature of natural or artificial hazards;
- the severity of the hazard characteristic as related to health outcomes;
- the ease of access to the recreational water area;
- the availability and applicability of remedial actions;
- the frequency and density of use; and
- the level of development for recreational use.

As outlined in chapters 1 and 4, health risks that might be tolerated for an infrequently used and undeveloped recreational area may result in immediate remedial measures at other areas that are widely used or highly developed.

Potential health outcomes associated with various hazards are summarized in Tables 2.1–2.4. The severity of the outcomes associated with a hazard can be related to the relative risk in Figure 1.2 and can serve as a tool to highlight or emphasize priority protective or remedial management measures and to initiate further research or investigation into the reduction of risk.

The hazard assessment could lead to a 'hazard rating'. Short (2003) outlines a beach hazard rating based on the physical characteristics of a beach (i.e., whether they are wave dominated, tide-modified or tide dominated). The resulting classification consists of a general beach hazard rating and a prevailing beach hazard rating, which depends on prevailing wave, tide and wind conditions. Such as rating could be expanded to include other hazards. This could form the basis for developing a safety plan, detailing the level of resources required to reduce the level of risk.

2.7.2 *Inspection programmes and protocols*

Inspection of a site for existing and new hazards should be undertaken on a regular basis in order to promote remedial action if required.

The inspection protocol for a recreational area, in terms of injury hazards may comprise the following:

1. Determining what is to be inspected and how frequently.
2. Monitoring changing hazards and use patterns periodically.
3. Establishing a regular pattern of inspection of conditions and controls.
4. Developing a series of checklists suitable for easy application. Checklists should reflect national and local standards where they exist.
5. Establishing a method for reporting faulty equipment and maintenance problems.
6. Developing a reporting system that will allow easy access to statistics regarding "when", "where", "why" and "how" questions needing answers.
7. Motivating and informing participants in the inspection process through in-service training.
8. Use of outside experts to critically review the scope, adequacy and methods of the inspection programme.

The frequency of inspection will vary according to the size of the recreational water area, the number of features, the density of use, the speed of change in both the hazards encountered and the remedial actions in place at a specific location, and the extent of past incidents or injuries. Timing of inspections should take account of periods of maximum use (e.g., inspection in time to take remedial action before major use periods) and periods of increased risk.

The criteria for inspections and investigations may vary from country to country. In some countries, there might be legal requirements and/or voluntary standard-setting organizations.

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CHAPTER 3

Sun, heat and cold

The recreational use of water environments may be associated with extreme temperature conditions. People may be unintentionally exposed to cold water (<15°C) which can result in a debilitating shock response. Or, at the other extreme, high air temperatures may result in heat stroke. As people engage in outdoor activities and recreation by the side of a lake or at a beach, they are often exposed to high levels of ultraviolet radiation (UVR) from the sun for prolonged periods of time. UVR can cause both acute and long-term damage to health. UVR and temperature deserve particular attention, as global climate change and ozone depletion are likely to aggravate existing health risks.

3.1 Exposure to ultraviolet radiation

3.1.1 UVR and ozone depletion

Everybody is exposed to UVR from the sun, and an increasing number of people are exposed to artificial sources used in industry, commerce and recreation. Emissions from the sun include visible light, heat and UVR. The UVR region covers the wavelength range 100–400 nm and consists of three bands—UVA (315–400 nm), UVB (280–315 nm) and UVC (100–280 nm). As sunlight passes through the atmosphere, all UVC and approximately 90% of UVB is absorbed by ozone, water vapour, oxygen and carbon dioxide. UVA is less affected by the atmosphere, and almost 70% of the solar emission in this band reaches the Earth's surface. Therefore, the UVR reaching the Earth's surface is largely UVA, with a small UVB component (usually less than 3%).

The amount of UVR at the Earth's surface is influenced by:

- *sun height*: The higher the sun in the sky, the higher the UVR level. Thus, UVR levels vary with time of day and time of year, with maximum levels occurring when the sun is directly overhead. Outside the tropics, the highest levels occur when the sun is at its maximum elevation, at around midday (solar noon) during the summer months.
- *latitude*: The closer the equator, the higher the UVR levels.
- *cloud cover*: UVR levels are highest under cloudless skies. Even with some cloud cover, UVR levels can be high as long as the solar disc is unobscured.
- *altitude*: At higher altitudes, a thinner atmosphere scatters and absorbs less UVR. With every 1000-m increase in altitude, UVR levels increase by approximately 14% (Blumthaler et al., 1994).

- *ground reflection*: UVR is reflected or scattered to varying extents by different surfaces. For example, fresh snow can reflect as much as 80% of UVR, sea foam about 25%, water up to about 15% (depending on the elevation of the sun) and dry beach sand about 15%.

As the ozone layer becomes depleted, the protective filter provided by the atmosphere is progressively reduced. Consequently, human beings and the environment are exposed to higher UVR levels, in particular higher UVB levels. Within the UV region, UVB has the greatest impact on human health, animals, marine organisms and plant life. International treaties to protect the ozone layer, such as the Vienna Convention (1985) and the Montreal Protocol on Substances That Deplete the Ozone Layer (1987), have gradually phased out the production of ozone-depleting substances; their ozone-depleting potential is expected to reach its maximum between 2000 and 2010. Due to the time delays in atmospheric processes, stratospheric ozone depletion will persist for many years (EEA, 1998), and the corresponding increases in UVR reaching the Earth's surface will exacerbate adverse health effects in all populations of the world. Computational models predict that a 10% decrease in stratospheric ozone could cause an additional 300 000 non-melanoma skin cancers (NMSCs), 4500 melanomas and between 1.6 and 1.75 million cataracts worldwide every year (UNEP, 1991).

3.1.2 Health outcomes

Overexposure to solar UVR may result in acute and chronic health effects on the skin, eye and immune system. Chronic effects include two major public health problems: skin cancers and cataracts. Furthermore, a growing body of evidence suggests that current environmental levels of UVR may increase the risk of infectious diseases and limit the efficacy of vaccinations (Halliday & Norval, 1997; Duthie et al., 1999). A comprehensive review and summary of UVR-related health effects can be found in the WHO Environmental Health Criteria monograph *Ultraviolet Radiation* (WHO, 1994) and in the United Nations Environment Programme report *Environmental Effects of Ozone Depletion* (UNEP, 1998).

1. Beneficial effects of UVR

Exposure to UVB stimulates the production of vitamin D in the skin. It has been estimated that more than 90% of vitamin D requirement is satisfied by this exposure and less than 10% from diet. Vitamin D has an important function in increasing calcium and phosphorus absorption from food and plays a crucial role in skeletal development, immune function and blood cell formation. Vitamin D deficiency is unlikely for most people, as, for example, a 10- to 15-min daily exposure of face, forearms and hands to normal northern European summer sun is sufficient to maintain vitamin D levels (McKie, 2000). An exception to this would be for people residing at high latitudes, where UVB levels in winter would be very low.

UVR from artificial sources is used to treat several diseases and dermatological conditions, including rickets, psoriasis, eczema and jaundice. While sunbed use for cosmetic purposes is not recommended (EUROSKIN, 2000), therapeutic treatment takes place under medical supervision, and the beneficial effects of therapeutic UVR exposure usually outweigh the harmful side-effects.

2. *Adverse effects of UVR on the skin*

The widespread perception that a tan is healthy and beautiful has led many people to actively seek a tan and expose their skin to excessive levels of UVR. This attitude, changed clothing habits, the popularity of outdoor activities and frequent holidays in sunny locations seem to be the major causes for the dramatic rise in skin cancer rates in all fair-skinned populations. Between 2 and 3 million NMSCs (WHO, Department of Evidence and Information for Policy, unpublished data) and 132 000 melanoma skin cancers (Ferlay et al., 2001) occur globally each year, according to WHO estimates. Since the early 1960s, the incidence of skin cancers has increased by between 3% and 7% in most fair-skinned populations (Armstrong & Kricker, 1994).

The sensitivity of skin to UVR is usually defined by six phototypes (Fitzpatrick et al., 1974). A more recent classification scheme relates skin type to short-term and long-term effects of UVR, based on the finding that 85–90% of registered skin cancers are found in the melano-compromised skin types I and II, while most of the remaining skin cancers are found in the melano-competent skin types III and IV (Fitzpatrick & Bolognia, 1995). These categories relate to the presence of melanin pigment in the epidermis, which determines human skin colour. Melanin absorbs UVR and in this way provides protection against exposure to UVR. Both classification schemes are depicted in Table 3.1.

TABLE 3.1. CLASSIFICATION OF SKIN TYPES[a]

Skin type classification		Burns in the sun	Tans after having been in the sun
I	Melano-compromised	Always	Seldom
II		Usually	Sometimes
III	Melano-competent	Sometimes	Usually
IV		Seldom	Always
V	Melano-protected	Naturally brown skin	
VI		Naturally black skin	

[a] Adapted from Fitzpatrick & Bolognia, 1995.

Many believe that only fair-skinned people need to be concerned about overexposure to the sun. Darker skin has more protective melanin pigment, and the incidence of skin cancer is lower in dark-skinned people. Nevertheless, skin cancers do occur and are often detected at a later, more dangerous stage. The risk of UVR-related health effects on the eye and immune system (see below) is independent of skin type (Vermeer et al., 1991).

Children are at a higher risk of suffering damage from exposure to UVR than adults, in particular because of the following:

- A child's skin is thinner and more sensitive, and even a short time outdoors in the midday sun can result in serious burns.
- Epidemiological studies demonstrate that frequent sun exposure and sunburn in childhood set the stage for high rates of melanoma in later life (IARC, 1992).
- Children have more time to develop diseases with long latency, more years of life to be lost and more suffering to be endured as a result of impaired health. Increased life expectancy further adds to people's risk of developing skin cancers.
- Children are more exposed to the sun. Estimates suggest that up to 80% of a person's lifetime exposure to UVR is received before the age of 18 (Marks et al., 1990; Wakefield & Bonett, 1990).
- Children love playing outdoors but usually are not aware of the harmful effects of UVR.

The most noticeable acute effect of excessive UVR exposure is erythema, the familiar inflammation of the skin commonly termed sunburn. The symptoms of a mild sunburn are reddening of the skin caused by vascular dilatation and some swelling, while in severe cases the skin will blister. In addition, most people will tan from darkening of existing melanin or through the UVR stimulation of melanin production, which occurs within a few days following exposure. A further, less obvious adaptive effect is the thickening of the outermost layers of the skin that attenuates UVR and decreases the penetration to the deeper layers in the skin. Current estimates suggest that a suntan can offer a sun protection factor (SPF) of between 2 and 3 (Young & Sheehan, 2001). Depending on their skin type, individuals vary greatly in their skin's initial threshold for erythema and their ability to adapt to UVR exposure (see Table 3.1).

Chronic exposure to UVR also causes a number of degenerative changes in the cells, fibrous tissue and blood vessels of the skin. These include freckles, naevi (moles) and lentigines, which are pigmented areas on the skin, and diffuse brown pigmentation. UVR accelerates skin aging, and the gradual loss of the skin's elasticity results in wrinkles and dry, coarse skin.

NMSCs comprise basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). BCC is the commonest but rarely fatal, while SCC can metastasize and be fatal if left untreated. Surgical treatment for NMSC can be painful and is often disfiguring. The temporal trends of NMSC incidence are difficult to determine, because registration of these cancers has not been achieved. However, specific studies carried out in the USA, Australia and Canada indicate that between the 1960s and the 1980s, the prevalence of NMSC has increased by a factor of more than two.

Malignant melanoma (MM), although far less prevalent than NMSC, is the major cause of death from skin cancer and is more likely to be reported and accurately diagnosed than NMSC. Since the early 1970s, MM incidence has increased significantly—for example, an average 4% every year in the USA (American Cancer Society, 2000). A large number of studies indicate that the risk of MM correlates with genetic and personal characteristics and a person's UVR exposure behaviour. The following is a summary of the main human risk factors (WHO, 1994):

- A large number of atypical naevi (moles) is the strongest risk factor for MM in fair-skinned populations.
- MM is more common among people with a pale complexion, blue eyes and red or fair hair. Experimental studies have demonstrated a lower minimum erythema dose and more prolonged erythema in melanoma patients than in controls.
- High, intermittent exposure to solar UVR appears to be a significant risk factor for the development of MM.
- The incidence of MM in white populations generally increases with decreasing latitude, with the highest recorded incidence occurring in Australia, where the annual rates are 10 and over 20 times the rates in Europe for women and men, respectively.
- Several epidemiological studies support a positive association with history of sunburn, particularly sunburn at an early age.
- The role of cumulative sun exposure in the development of MM is equivocal. However, MM risk is higher in people with a history of NMSC and of solar keratoses (areas of skin marked by overgrowth of horny tissue), both of which are indicators of cumulative UVR exposure.

3. *UVR effects on the eye*

The eye is recessed within the anatomy of the head and shielded by the brow ridge, the eyebrows and the eyelashes. Bright visible light activates the constriction of the pupil and the squinting reflex to minimize the penetration of the sun's rays into the eye. However, the effectiveness of these natural defences in protecting against UVR exposure is limited under certain conditions, such as sunbed use or strong ground reflection from fresh snow and sometimes sand and water.

Acute effects of UVR exposure on the eye include photokeratitis and photoconjunctivitis. These inflammatory reactions are comparable to a sunburn of the very sensitive skin-like tissues of the eyeball and eyelids and usually appear within a few hours of exposure. Both can be very painful but are reversible and do not result in any long-term damage to the eye or vision. An extreme form of photokeratitis is snow blindness.

Sun exposure, in particular exposure to UVB, also appears to be a major risk factor for cataract development, although cataracts appear to different degrees in most individuals as they age. Cataracts occur when proteins in the eye's lens unravel, tangle and accumulate pigments that cloud the lens and eventually lead to blindness. They are the leading cause of blindness in the world, affecting some 12–15 million people. According to WHO (1994) estimates, up to 20% of cases of cataract-related blindness may be caused or enhanced by sun exposure, especially in India, Pakistan and other countries of the "cataract belt" close to the equator. As the world's population ages, cataract-induced visual dysfunction and blindness are on the increase; reducing ocular exposure to UVR and smoking prevention are the only interventions that can reduce risk of developing cataracts (Brian & Taylor, 2001).

4. *UVR effects on the immune system*

The immune system is the body's defence mechanism against infections and cancers and is normally very effective at recognizing and responding to an invading microorganism or the onset of a tumour. Although the data remain preliminary, there is increasing evidence for an immunosuppressive effect of both acute high-dose and chronic low-dose UVR exposure on the human immune system (Duthie et al., 1999).

Animal experiments have demonstrated that UVR can modify the course and severity of skin tumours (Fisher & Kripke, 1977). Also, people treated with immunosuppressive drugs have a greater incidence of SCC than the normal population. Consequently, beyond its role in the initiation of skin cancer, sun exposure may reduce the body's defences, which normally limit the progressive development of skin tumours.

Several studies have demonstrated that exposure to current environmental levels of UVR alters the activity and distribution of some of the cells responsible for triggering immune responses in humans. Consequently, sun exposure may enhance the risk of disease resulting from viral, bacterial, parasitic or fungal infections and may modify the course of disease progression in both animals and humans (Halliday & Norval, 1997; Yamamoto et al., 1999, 2000). Furthermore, especially in countries of the developing world, high UVR levels may reduce the effectiveness of vaccines.

3.1.3 Interventions and control measures

Damage from UVR to the skin, eyes and immune system is mostly preventable. Reducing both the occurrence of sunburn and cumulative UVR exposure can decrease harmful health effects and significantly reduce health care costs.

Spending a sunny day at the beach, sunbathing by the side of a lake or engaging in different kinds of water sports frequently lead to prolonged exposure to UVR, often including the time of day when UVR levels are highest. This can be exacerbated by the lack of shade and reflection of the sun's rays by water and sand—both can reflect up to about 15% of incident UVR. Sun protection consideration should take these particular environmental conditions into account.

1. *Personal protection against UVR*

It is the individual's choice as to whether to adopt sun protection or not. Simple protective measures are available and should be adopted to avoid adverse health effects on the skin, eyes and immune system caused by sun exposure (Box 3.1).

Children require special protection, as they are at a higher risk of suffering damage from exposure to UVR than adults. Encouraging children to take simple precautions will prevent both short-term and long-term damage while still allowing them to enjoy the time they spend outdoors. Shade, clothing and hats provide the best protection

BOX 3.1 EXAMPLE OF ACTION STEPS FOR SUN PROTECTION (US EPA, 2000)

LIMIT TIME IN THE MIDDAY SUN

The sun's UV rays are the strongest between 10 a.m. and 4 p.m. To the extent possible, limit exposure to the sun during these hours.

WATCH FOR THE UV INDEX

This important resource helps you plan your outdoor activities in ways that prevent overexposure to the sun's rays. While you should always take precautions against overexposure, take special care to adopt sun safety practices when the UV index predicts exposure levels of moderate or above.

USE SHADE WISELY

Seek shade when UV rays are the most intense, but keep in mind that shade structures such as trees, umbrellas or canopies do not offer complete sun protection. Remember the shadow rule: "Watch your shadow—No shadow, seek shade!"

WEAR PROTECTIVE CLOTHING

A hat with a wide brim offers good sun protection for your eyes, ears, face and the back of your neck. Sunglasses that provide 99–100% UVA and UVB protection will greatly reduce eye damage from sun exposure. Tightly woven, loose-fitting clothes will provide additional protection from the sun.

USE SUNSCREEN

Apply a sunscreen of SPF 15 or more liberally and reapply every 2 h, or after working, swimming, playing or exercising outdoors.

for children; applying sunscreen becomes necessary on those parts of the body that remain exposed, like the face and hands. Infants of less than 12 months should always be kept in the shade.

2. *Information and education*

   Information should be provided to the public on UVR and variation in UVR levels with time of day, time of year and geographical location; health effects of sun exposure on the skin, eyes and immune system; and available protective measures (see Box 3.1).

   The global solar UV index (International Commission on Non-Ionizing Radiation Protection, 1995; WHO, 2002) is an important vehicle to raise public awareness of UVR and the risks of excessive UVR exposure and to alert people about the need to adopt protective measures (see Box 3.2). The UV index describes the level of solar UVR at the Earth's surface. The values of the index range from zero upward. The higher the index value, the greater the potential for skin and eye damage following exposure to UVR, and the less time it takes for harm to occur.

   A standard graphic representation of UV index has been proposed (WHO, 2002) in order to promote consistency in reporting and improve understanding of the

BOX 3.2 GLOBAL SOLAR UV INDEX (WHO, 2002)

UV index values are grouped into exposure categories:

UV index values	Exposure category	Level of sun protection required	'Sound bite' messages
≤2	Low	None required	You can safely stay outside
3–5	Moderate	Protection required	Seek shade during midday hours. Slip on a shirt, slop on sunscreen and slap on a hat.
6–7	High		
8–10	Very high	Extra protection required	Avoid being outside during midday hours. Make sure you seek shade. Shirt, sunscreen and hat are a must
11+	Extreme		

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

concept. Ready made materials, such as those shown in Figure 3.1, are available from WHO.

The levels of UVR and therefore the values of the index vary throughout the day. In reporting the UV index, most emphasis is placed on the maximum UVR level on a given day. This generally occurs during the 4-h period around solar noon. Depending on geographical location and whether daylight saving time is applied, solar noon takes place between noon and 2 p.m. The media usually present a forecast of the maximum UVR level for the following day. In many countries, the UV index is reported along with the weather forecast in newspapers, on TV and on the radio. However, this reporting usually occurs during the summer months only, unless the location lies within or close to the tropics.

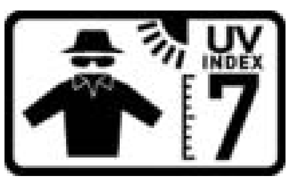

FIGURE 3.1. UVI GRAPHIC REPRESENTATION (WHO, 2002)

Information relating to the UV index should be especially targeted at vulnerable groups within the population, such as children and tourists, and should inform people about the range of UVR-induced health effects, including sunburn, skin cancer and skin aging and effects on the eye and immune system. Daily UV index levels can easily be presented on signboards and signposts on beaches or by the side of lakes and should be accompanied by a simple message encouraging people to adopt sensible sun behaviour. Furthermore, simple flyers could be made available free of charge at the entrance, at cashiers or at kiosks. Lifeguards, first aid providers and other employees should be educated about UVR and sun protection and trained to act as role models for the users of recreational water environments, in particular children. They may help to disseminate information about the dangers of UVR and could be important partners for organizations that are planning to hold educational events or skin cancer screening initiatives. Further information can be found on the website of WHO's INTERSUN Programme (http://www.who.int/peh/uv/).

Public education aims to improve people's knowledge about the health risks of excessive sun exposure and to achieve a change in attitudes and behaviour. Educational activities in the context of recreational water environments should mainly address children, adolescents and their parents. The best way of generating interest is through activities and games. The main message should be that the enjoyment of outdoor sport and recreation activities should not be compromised, but can even be enhanced by sun-protective behaviour. Sensible behaviour is relatively simple to incorporate and can eliminate sunburn and heat stroke, which are often associated with being in the sun for prolonged periods of time.

Reducing the occurrence of sunburn and cumulative UVR exposure during childhood and over a lifetime will eventually cause skin cancer rates to decline. It has been estimated that four out of five cases of skin cancer could be prevented by sensible behaviour (Stern et al., 1986). An effective campaign can have an enormous impact on public health: it has been estimated that the regular use of sunscreen with SPF 15+ up to the age of 18 could decrease the frequency of skin cancer in Australia by more than 70% (Stern et al., 1986).

The SunSmart Campaign of the Anti-Cancer Council of Victoria, Australia (Anti-Cancer Council of Victoria, 1999b), has made significant achievements in raising awareness of the issues of sun protection and skin cancer as well as encouraging changes in sun-related behaviour. Evaluations of the programme show that fewer people see tanning as desirable or attractive and more people wear hats, use sunscreen and cover up to avoid the sun. Most significantly, research during the 1990s revealed an 11% decrease in the incidence of common skin cancers in 14- to 50-year-old people (Staples et al., 1998).

Low-cost interventions can significantly decrease costs to the healthcare system. Skin cancer is the most costly of all cancers to the Australian health system. The direct costs of treatment have been estimated at US$5.70 per head per annum, while the cost of prevention campaigns has been calculated at US$0.08 per head per annum. Assuming that a 20-year prevention campaign costing US$0.17 per head per annum reduced UVR exposure by 20%, that melanoma rates began to fall after a 5-year lag and that NMSCs and solar keratoses began to fall after a 15-year lag, the predicted annual saving would be US$0.17 per person (Carter et al., 1999). This would mean that every dollar spent would save a dollar.

In order to change people's sun exposure habits and the societal view that associates a tan with good health and beauty, long-term strategies are required. To create a supportive environment for the integration of sun protection considerations in the use of recreational water environments, it is important to establish working relationships with authorities and organizations such as community health services, sporting clubs, skin cancer associations, and the service and tourism sector, including public transport services and restaurants. Efforts should be made to learn from and integrate existing community initiatives to promote sun protection in the planning and implementation process.

3. *Infrastructure and planning*

While it is the decision of the individual as to whether to adopt sensible sun behaviour or not, the management of recreational water environments has the responsibility to facilitate a positive choice through adequate structural and policy measures. One important infrastructural consideration is the provision of shade structures and the integration of shaded areas in the vicinity of recreational water bodies. This is especially important in areas where a lot of people congregate—e.g., at a snack stand where people may queue for prolonged periods of time. Shade can be either permanent or portable and can come from natural sources such as trees or hedges or from artificial structures such as gazebos, canopies or shelter sheds. An inexpensive means of shade provision is to give users of recreational water environments the opportunity to hire portable parasols at low cost.

An example of a guide for local government is shown in Table 3.2.

3.2 Exposure to cold

Cold water removes heat from the body 25 times faster than cold air. The immediate effects of sudden immersion in cold water (<15 °C) can be a debilitating, short duration (approximately 2–3 minutes), reflex response called cold shock. This response includes life-threatening respiratory and cardiovascular effects. The respiratory effect involves quick onset (less than 30 seconds) uncontrollable rapid breathing, which impairs breath-holding and facilitates aspiration of water (which can lead to drowning). The cardiovascular response involves an immediate constriction (closure) of the blood vessels near the surface of the body, an increase in heart rate and a surge in blood pressure. These factors may lead to incapacitation from a cardiovascular incident, such as heart attack or stroke and/or death from drowning following aspiration (Golden & Tipton, 2002; International Life Saving Federation, 2003).

If sudden immersion in cold water does not cause death immediately, the related effects will impair swimming ability. Research has shown that even strong swimmers can experience difficulty and drown within minutes of cold-water immersion unless they are habituated to cold (Golden & Hardcastle, 1982). These initial responses occur long before body temperature begins to fall and are believed to be responsible for the majority of sudden cold-water immersion deaths.

TABLE 3.2. AN EXAMPLE OF A RECREATIONAL FACILITY SUN PROTECTION GUIDE FOR LOCAL GOVERNMENT[a]

SunSmart components	Desirable actions/outcomes
Education	• Erect signage about the importance of sun protection • Ensure that employees are role models for users of facilities • Conduct sun protection information sessions for employees • Ensure that sun protection information is available to patrons and clients
Clothing	• Ensure that employees wear broad-brimmed hats, sunglasses and long-sleeved shirts on patrol • Sell broad-brimmed hats in kiosks
Sunscreen	• Sell low-priced (or subsidized) SPF 30+[b] broad-spectrum, waterproof sunscreen • Provide employees with SPF 30+ broad-spectrum sunscreen
Shade	• Review available shade at local government recreational facilities • Ensure that sufficient shade, either natural or built, is available or planned for when developing new recreational facilities or centres • Investigate the opportunities to make available portable shade structures to schools and organizations using local government-controlled facilities
Schedules	• Allow users to leave in the middle of the day and then return without extra cost
Policy guidelines	• Change any rules (e.g., clothing restrictions for employees or patrons) that prevent people from being adequately protected • Adopt the SunSmart Sport or Pool Policy available from the Anti-Cancer Council of Victoria, Australia • Promote and encourage schools or sporting clubs using local government facilities to introduce a sun protection policy of their own • Ensure that no facilities that increase the risk of skin cancer operate within local government recreation facilities (e.g., solariums)

[a] Source: Anti-Cancer Council of Victoria (1999a).

[b] IARC (2001) recommends the use of sunscreen with an SPF of 15 or higher. In geographical locations where UVR levels are always high, such as Australia, a sunscreen with SPF 30+ may be necessary.

After about three minutes, the initial effects of sudden cold-water immersion decline. Thereafter, progressive whole-body cooling occurs, leading to a gradual fall in deep body temperature—hypothermia. Before a significant level of hypothermia develops, however, there is a progressive cooling of the muscles and joints in the exposed limbs resulting in shivering and stiffening. This impairs locomotion and thus swimming performance (Tipton et al., 1999), which will likely lead to drowning before a life-threatening level of hypothermia develops—unless the victim is wearing a lifejacket or personal flotation device (PFD) capable of keeping the airway clear of the water. This impairment of locomotion also impedes the person's ability to assist in his or her own rescue effort.

For those wearing a proper lifejacket, drowning may be prevented; however, without timely rescue, hypothermia will eventually lead to loss of consciousness and death from cardiac arrest (Golden, 1973). Time to death in such victims will be influenced by body insulation (thickness of clothing worn and the amount of body fat, with men generally having less than women), age (young and elderly fair less well), water state (breaking waves increase the chances of water aspiration) and time to rescue. A person who has consumed alcohol will succumb to the effects of hypothermia more rapidly (Haight & Keatinge, 1973).

One very rare complication of contact with cold water is cold urticaria. This condition is an allergy-like reaction to contact with cold water, as well as other sources of cold (Bentley, 1993). Within minutes, the skin may become itchy, red and swollen. Fainting, very low blood pressure and shock-like symptoms can present.

Prevention is the best cure. Attempts should not be made to swim in cold water unless habituated to it or wearing suitable protective garments (such as a wet suit or survival suit). If at risk of immersion, precautions should be taken against becoming immersed (such as by use of a safety line). On boats, suitable clothing and a proper lifejacket (with sufficient buoyancy to keep the airway clear of the water even when unconscious) should be worn.

3.3 Exposure to heat

Human body temperature is maintained within a narrow range, despite extremes in environmental conditions and physical activity. In healthy individuals, an efficient heat regulatory system will normally enable the human body to cope effectively with a moderate rise in ambient temperature. Within certain limits of mild heat stress and physical activity, thermal comfort can be maintained. In extreme temperatures, the human body is able to react with a series of adaptation mechanisms. The most significant are sweating, dilatation of the peripheral blood vessels, an increase in some hormones (antidiuretic hormone and aldosterone) and an increase in respiratory rate and pulse. In the meantime, the body tries to lose as few salts as possible and decreases the blood flow to the kidney.

Heat acclimatization usually takes from 7 to 14 days, but complete acclimatization to an unfamiliar thermal environment may take several years (Babayev, 1986; Frisancho, 1991). Acclimatization lowers the threshold for sweating, which is the most effective natural means of combating heat stress and can occur with little or no change in the body core temperature. As long as sweating is continuous, people can withstand remarkably high temperatures, provided water and sodium chloride (the most important physiological constituents of sweat) are replaced.

Disorders due to heat most frequently occur with rapid changes in thermal conditions, especially in low latitudes and in densely populated urban areas (Weiner, 1984; WHO, 1990). This was well illustrated by the 1980, 1983, 1988 and 1995 heat waves in the USA (CDC, 1995) and the 1987 heat wave in Athens, Greece (Katsouyanni et al., 1988, 1993). The following population groups seem to be disproportionally affected by such weather extremes, probably because they have a lesser physiological coping ability (CDC, 1995):

- the elderly;
- the very young (0–4 years);
- persons with impaired mobility;

- persons suffering from pre-existing chronic diseases (such as arteriosclerosis, previous heart failures, diabetes and congenital absence of sweat glands); and
- frequent consumers of alcohol (Schuman, 1964; Kilbourne, 1982).

A comfortable temperature for most people is around 20–28 °C. Factors influencing thermal comfort include air temperature, humidity, wind speed and fluxes in shortwave and longwave radiation. Under normal conditions, recreational water bodies may influence people's perception of ambient temperature conditions, such that a middle-aged person walking on the beach at midday copes better with heat exposure than the same person walking on an urban road at midday (Jendritzky et al., 1997).

In recreational water areas, steps that can be taken to reduce body temperature are similar to those for reducing exposure to sun and include wearing lightweight clothing and broad-brimmed hats, seeking shady areas and swimming in cool water. Other initiatives to help cope with exposure to heat include ensuring an adequate supply of safe drinking-water and replenishing any salt loss. Educating people with increased susceptibility to heat exposure (e.g., the elderly) would also be useful.

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CHAPTER 4
Faecal pollution and water quality

Faecal pollution of recreational water can lead to health problems because of the presence of infectious microorganisms. These may be derived from human sewage or animal sources.

This chapter relates to recreational water activities where whole-body contact takes place (i.e., those in which there is a meaningful risk of swallowing water).

4.1 Approach

Water safety or quality is best described by a combination of sanitary inspection and microbial water quality assessment. This approach provides data on possible sources of pollution in a recreational water catchment, as well as numerical information on the actual level of faecal pollution. Combining these elements provides a basis for a robust, graded, classification as shown in Figure 4.1.

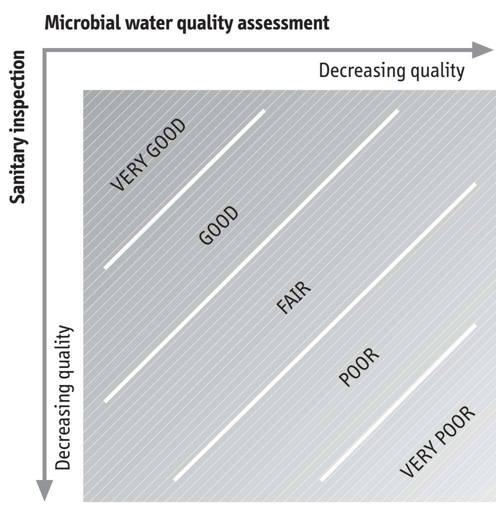


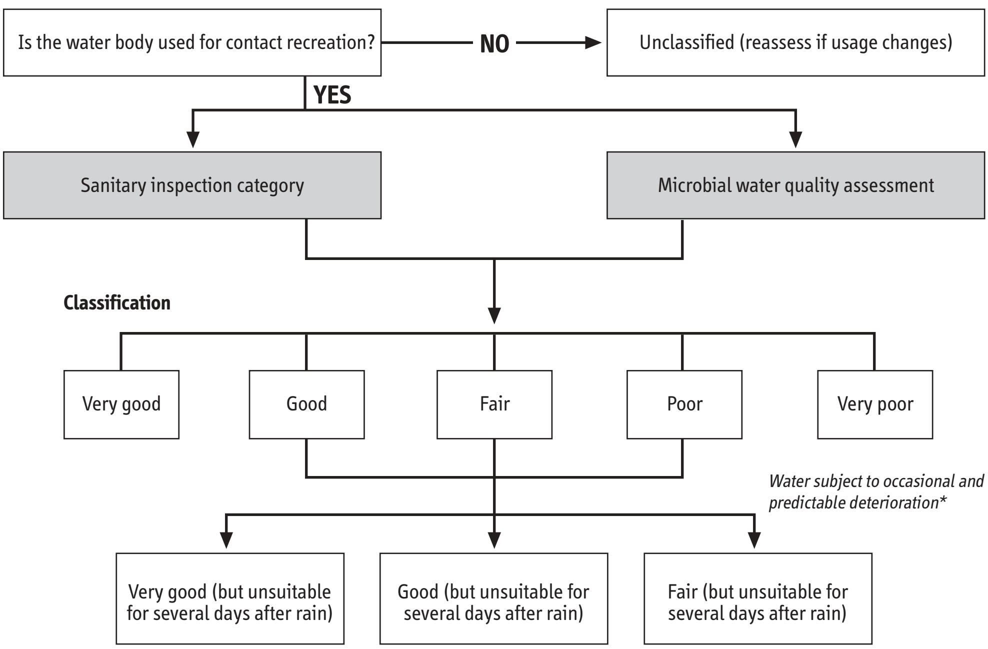
FIGURE 4.1. SIMPLIFIED CLASSIFICATION MATRIX

The results of the classification can be used to:

- grade beaches in order to support informed personal choice;
- provide on-site guidance to users on relative safety;
- assist in the identification and promotion of effective management interventions; and
- provide an assessment of regulatory compliance.

In some instances, microbial water quality may be strongly influenced by factors such as rainfall leading to relatively short periods of elevated faecal pollution. Experience in some areas has shown the possibility of advising against use at such times of increased risk and, furthermore, in some circumstances that individuals respond to such messages. Where it is possible to prevent human exposure to pollution hazards in this way this can be taken into account in both grading and advice. Combining classification (based on sanitary inspection and microbial quality assessment) with prevention of exposure at times of increased risk leads to a framework for assessing recreational water quality as outlined in Figure 4.2.

The resulting classification both supports activities in pollution prevention (e.g., reducing stormwater overflows) and provides a means to recognise and account for local cost-effective actions to protect public health (e.g., advisory signage about rain impacts).



* where users can be shown to be effectively discouraged from entering the water following occasional and predictable water quality deteriorations (linked to, for example, rainfall), the area may be upgraded to reflect the water quality that users are exposed to, but only with the accompanying explanatory material.

FIGURE 4.2. SIMPLIFIED FRAMEWORK FOR ASSESSING RECREATIONAL WATER ENVIRONMENTS

4.2 Health effects associated with faecal pollution

Recreational waters generally contain a mixture of pathogenic and non-pathogenic microorganisms. These microorganisms may be derived from sewage effluents, the recreational population using the water (from defecation and/or shedding), livestock (cattle, sheep, etc.), industrial processes, farming activities, domestic animals (such as dogs) and wildlife. In addition, recreational waters may also contain free-living pathogenic microorganisms (chapter 5). These sources can include pathogenic organisms that cause gastrointestinal infections following ingestion or infections of the upper respiratory tract, ears, eyes, nasal cavity and skin.

Infections and illness due to recreational water contact are generally mild and so difficult to detect through routine surveillance systems. Even where illness is more severe, it may still be difficult to attribute to water exposure. Targeted epidemiological studies, however, have shown a number of adverse health outcomes (including gastrointestinal and respiratory infections) to be associated with faecally polluted recreational water. This can result in a significant burden of disease and economic loss.

The number of microorganisms (dose) that may cause infection or disease depends upon the specific pathogen, the form in which it is encountered, the conditions of exposure and the host's susceptibility and immune status. For viral and parasitic protozoan illness, this dose might be very few viable infectious units (Fewtrell et al., 1994; Teunis, 1996; Haas et al., 1999; Okhuysen et al., 1999; Teunis et al., 1999). In reality, the body rarely experiences a single isolated encounter with a pathogen, and the effects of multiple and simultaneous pathogenic exposures are poorly understood (Esrey et al., 1985).

The types and numbers of pathogens in sewage will differ depending on the incidence of disease and carrier states in the contributing human and animal populations and the seasonality of infections. Hence, numbers will vary greatly across different parts of the world and times of year. A general indication of pathogen numbers in raw sewage is given in Table 4.1.

In both marine and freshwater studies of the impact of faecal pollution on the health of recreational water users, several faecal index bacteria, including faecal streptococci/intestinal enterococci (see Box 4.1), have been used for describing water quality. These bacteria are not postulated as the causative agents of illnesses in swimmers, but appear to behave similarly to the actual faecally derived pathogens (Prüss, 1998).

Available evidence suggests that the most frequent adverse health outcome associated with exposure to faecally contaminated recreational water is enteric illness, such as self-limiting gastroenteritis, which may often be of short duration and may not be formally recorded in disease surveillance systems. Transmission of pathogens that can cause gastroenteritis is biologically plausible and is analogous to waterborne disease transmission in drinking-water, which is well documented. The association has been repeatedly reported in epidemiological studies, including studies demonstrating a dose–response relationship (Prüss, 1998).

TABLE 4.1. EXAMPLES OF PATHOGENS AND INDEX ORGANISM CONCENTRATIONS IN RAW SEWAGE[a]

Pathogen/index organism	Disease/role	Numbers per 100 ml
Bacteria		
Campylobacter spp.	Gastroenteritis	10^4–10^5
Clostridium perfringens spores	Index organism	$6 \times 10^4 - 8 \times 10^4$
Escherichia coli	Index organism (except specific strains)	10^6–10^7
Faecal streptococci/intestinal enterococci	Index organism	$4.7 \times 10^3 - 4 \times 10^5$
Salmonella spp.	Gastroenteritis	0.2–8000
Shigella spp.	Bacillary dysentery	0.1–1000
Viruses		
Polioviruses	Index organism (vaccine strains), poliomyelitis	180–500 000
Rotaviruses	Diarrhoea, vomiting	400–85 000
Adenoviruses	Respiratory disease, gastroenteritis	not enumerated[b]
Norwalk viruses	Diarrhoea, vomiting	not enumerated[b]
Hepatitis A	Hepatitis	not enumerated[b]
Parasitic protozoa[c]		
Cryptosporidium parvum oocysts	Diarrhoea	0.1–39
Entamoeba histolytica	Amoebic dysentery	0.4
Giardia lamblia cysts	Diarrhoea	12.5–20 000
Helminths[c] **(ova)**		
Ascaris spp.	Ascariasis	0.5–11
Ancylostoma spp. and *Necator* sp.	Anaemia	0.6–19
Trichuris spp.	Diarrhoea	1–4

[a] Höller (1988); Long & Ashbolt (1994); Yates & Gerba (1998); Bonadonna et al. 2002.

[b] Many important pathogens in sewage have yet to be adequately enumerated, such as adenoviruses, Norwalk-like viruses, hepatitis A virus.

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

A cause–effect relationship between faecal or bather-derived pollution and acute febrile respiratory illness (AFRI) and general respiratory illness is also biologically plausible. A significant dose–response relationship (between AFRI and faecal streptococci) has been reported in Fleisher et al. (1996a). AFRI is a more severe health outcome than the more frequently assessed self-limiting gastrointestinal symptoms (Fleisher et al., 1998). When compared with gastroenteritis, probabilities of contacting AFRI are generally lower and the threshold at which illness is observed is higher.

A cause–effect relationship between faecal or bather-derived pollution and ear infection has biological plausibility. However, ear problems are greatly elevated in bathers over non-bathers even after exposure to water with few faecal index organisms (van Asperen et al., 1995). Associations between ear infections and microbiological indices of faecal pollution and bather load have been reported (Fleisher et al., 1996a). When compared with gastroenteritis, the statistical probabilities are generally lower and are associated with higher faecal index concentrations than those for gastrointestinal symptoms and for AFRI.

BOX 4.1 FAECAL STREPTOCOCCI/INTESTINAL ENTEROCOCCI

Faecal streptococci is a bacterial group that has been used as an index of faecal pollution in recreational water; however, the group includes species of different sanitary significance and survival characteristics (Gauci, 1991; Sinton & Donnison, 1994). In addition, streptococci species prevalence differs between animal and human faeces (Rutkowski & Sjogren, 1987; Poucher et al., 1991). Furthermore, the taxonomy of this group has been subject to extensive revision (Ruoff, 1990; Devriese et al., 1993; Janda, 1994; Leclerc et al., 1996). The group contains species of two genera—*Enterococcus* and *Streptococcus* (Holt et al., 1993). Although several species of both genera are included under the term enterococci (Leclerc et al., 1996), the species most predominant in the polluted aquatic environments are *Enterococcus faecalis*, *E. faecium* and *E. durans* (Volterra et al., 1986; Sinton & Donnison, 1994; Audicana et al., 1995; Borrego et al., 2002).

Enterococci, a term commonly used in the USA, includes all the species described as members of the genus *Enterococcus* that fulfil the following criteria: growth at 10 °C and 45 °C, resistance to 60 °C for 30 min, growth at pH 9.6 and at 6.5% NaCl, and the ability to reduce 0.1% methylene blue. Since the most common environmental species fulfil these criteria, in practice the terms faecal streptococci, enterococci, intestinal enterococci and *Enterococcus* group may refer to the same bacteria.

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

It may be important to identify human versus animal enterococci, as greater human health risks (primarily enteric viruses) are likely to be associated with human faecal material—hence the emphasis on human sources of pollution in the sanitary inspection categorisation of beach classification (see Table 4.12). Grant et al. (2001) presented a good example of this approach. They demonstrated that enterococci from stormwater, impacted by bird faeces and wetland sediments and from marine vegetation, confounded the assessment of possible bather impact in the surf zone at southern Californian beaches. There will, however, be cases where animal faeces is an important source of pollution in terms of human health risk.

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

Some studies have reported increased rates of skin symptoms among swimmers, and associations between skin symptoms and microbial water quality have also been reported (Ferley et al., 1989; Cheung et al., 1990; Marino et al., 1995; see also chapter 8). Controlled studies, however, have not found such association and the relationship between faecal pollution and skin symptoms remains unclear. Swimmers with exposed wounds or cuts may be at risk of infection (see also chapter 5) but there is no evidence to relate this to faecal contamination.

Most epidemiological investigations either have not addressed severe health outcomes (such as hepatitis, enteric fever or poliomyelitis) or have been undertaken in areas of low endemicity or zero reported occurrence of these diseases. Considering the strong evidence for transmission of self-limiting gastroenteritis, much of which may be of viral etiology, transmission of infectious hepatitis (hepatitis A and E viruses) and poliomyelitis is biologically plausible, should exposure of susceptible persons occur. However, poliomyelitis was not found to be associated with bathing in a 5-year retrospective study relying on total coliforms as the principal water quality index (Public Health Laboratory Service, 1959). Furthermore, sero-prevalence studies for hepatitis A among windsurfers, waterskiers and canoeists who were exposed to contaminated waters have not identified any increased health risks (Philipp et al., 1989; Taylor et al., 1995). However, there has been a documented association of transmission of *Salmonella paratyphi*, the causative agent of paratyphoid fever, with recreational water use (Public Health Laboratory Service, 1959). Also, significantly higher rates of typhoid have been observed in Egypt among bathers from beaches polluted with untreated sewage compared to bathers swimming off relatively unpolluted beaches (El Sharkawi & Hassan, 1982).

More severe health outcomes may occur among recreational water users swimming in sewage-polluted water who are short-term visitors from regions with low endemic disease incidence. Specific control measures may be justified under such circumstances.

Outbreak reports have noted cases of diverse health outcomes (e.g., gastrointestinal symptoms, typhoid fever, meningoencephalitis) with exposure to recreational water and in some instances have identified the specific etiological agents responsible (Prüss, 1998). The causative agents of outbreaks may not be representative of the "background" disease associated with swimming in faecally polluted water as detected by epidemiological studies. Table 4.2 lists pathogens that have been linked to swimming-associated disease outbreaks in the USA between 1985 and 1998.

TABLE 4.2. OUTBREAKS ASSOCIATED WITH RECREATIONAL WATERS IN THE USA, 1985–1998[a]

Etiological agent	Number of cases	Number of outbreaks
Shigella spp.	1780	20
Escherichia coli O157:H7	234	9
Leptospira sp.	389	3
Giardia lamblia	65	4
Cryptosporidium parvum	429	3
Norwalk-like viruses	89	3
Adenovirus 3	595	1
Acute gastrointestinal infections (no agent identified)	1984	21

[a] From Kramer et al. (1996); Craun et al. (1997); Levy et al. (1998).

Two pathogenic bacteria, enterohaemorrhagic *Escherichia coli* and *Shigella sonnei*, and two pathogenic protozoa, *Giardia lamblia* and *Cryptosporidium parvum*, are of special interest because of the circumstances under which the associated outbreaks occurred—i.e., usually in very small, shallow bodies of water that were frequented by children. Epidemiological investigations of these, and similar, outbreaks suggest that the source of the etiological agent was usually the bathers themselves, most likely children (Keene et al., 1994; Cransberg et al., 1996; Voelker, 1996; Ackman et al., 1997; Kramer et al., 1998; Barwick et al., 2000). Each outbreak affected a large number of bathers, which might be expected in unmixed small bodies of water containing large numbers of pathogens. Management of these small bodies of water is similar to management of swimming pools (see Volume 2 of the *Guidelines for Safe Recreational Water Environments*).

Outbreaks caused by Norwalk-like viruses and adenovirus 3 are more relevant, in that the sources of pathogens were external to the beaches and associated with faecal contamination. However, high bather density has been suggested to account for high enterovirus numbers at a Hawaiian beach (Reynolds et al., 1998). *Leptospira* sp. are usually associated with animals that urinate into surface waters, and swimming-associated outbreaks attributed to *Leptospira* sp. are rare (see chapter 5). Conversely, outbreaks of acute gastrointestinal infections with an unknown etiology are common, with the symptomatology of the illness frequently being suggestive of viral infections. The serological data shown in Table 4.3 suggest that Norwalk virus has more potential than rotavirus to cause swimming-associated gastroenteritis (WHO, 1999), although these results were based on a limited number of subjects. Application of reverse transcriptase-polymerase chain reaction technology has indicated the presence of Norwalk-like viruses in fresh and marine waters (Wyn-Jones et al., 2000).

TABLE 4.3. SEROLOGICAL RESPONSE TO NORWALK VIRUS AND ROTAVIRUS IN CHILDREN WITH RECENT SWIMMING-ASSOCIATED GASTROENTERITIS[a,b]

Antigen	Number of subjects	Age range	Number with 4-fold titre increase
Norwalk virus	12	3 months–12 years	4
Rotavirus	12	3 months–12 years	0

[a] From WHO (1999).

[b] Acute and convalescent sera were obtained from swimmers who suffered from acute gastroenteritis after swimming at a highly contaminated beach in Alexandria, Egypt. On the day after the swimming event and about 15 days later sera were obtained from 12 subjects, all of whom were less than 12 years old.

4.3 Approaches to risk assessment and risk management

Regulatory schemes for the microbial quality of recreational water have been largely based on percentage compliance with faecal index organism counts (EEC, 1976; US EPA, 1998). Constraints to these approaches include the following:

- Management actions are retrospective and can be deployed only after human exposure to the hazard.
- In many situations, the risk to health is primarily from human excreta, yet the traditional indices of faecal pollution are also derived from other sources. The response to non-compliance, however, typically concentrates on sewage treatment or outfall management as outlined below.

- There is poor interlaboratory comparability of microbiological analytical data.
- Beaches are classified as either safe or unsafe, although there is, in fact, a gradient of increasing variety and frequency of health effects with increasing faecal pollution of human and animal origin.

Traditionally, regulation tends to focus response upon sewage treatment and outfall management as the principal, or only, interventions. Due to the high costs of these measures coupled with the fact that local authorities are generally not the sewerage undertaker, local authorities may be relatively powerless, and few options may be available for effective local interventions in securing water user safety from faecal pollution. The limited evidence available from cost–benefit studies of point source pollution control suggests that direct health benefits alone may often not justify the proposed investments which may also be ineffective in securing regulatory compliance, particularly if non-human, diffuse faecal sources and/or stormwaters are major contributor(s) (Kay et al., 1999). Furthermore, the costs may be prohibitive or may divert resources from greater public health priorities, such as securing access to a safe drinking-water supply, especially in developing regions. Lastly, considerable concern has been expressed regarding the burden (cost) of monitoring, primarily but not exclusively to developing regions, especially in light of the precision with which the monitoring effort assesses the risk to the health of water users and effectively supports decision-making to protect public health.

These limitations may largely be overcome by a monitoring scheme that combines microbial testing with broader data collection concerning sources and transmission of pollution. There are two outcomes from such an approach—one is a recreational water environment classification based on long-term analysis of data, and the other is immediate actions to reduce exposure, which may work from hour to hour or from day to day.

4.3.1 Harmonized approach and the "Annapolis Protocol"

A WHO expert consultation in 1999 formulated a harmonized approach to assessment of risk and risk management for microbial hazards across drinking, recreational and reused waters. Priorities can therefore be addressed across all water types or within a type, when using the risk assessment/risk management scheme illustrated in Figure 4.3 (Bartram et al., 2001).

The "Annapolis Protocol" (WHO, 1999; Bartram & Rees, 2000—chapter 9) represents an adaptation of the "harmonized approach" to recreational water and was developed in response to concerns regarding the adequacy and effectiveness of approaches to monitoring and management of faecally polluted recreational waters.

The most important developments recommended in the Annapolis Protocol were:

- the move away from the reliance on numerical values of faecal index bacteria as the sole compliance criterion to the use of a two component qualitative ranking of faecal loading in recreational water environments, supported by direct measurement of appropriate faecal indices; and

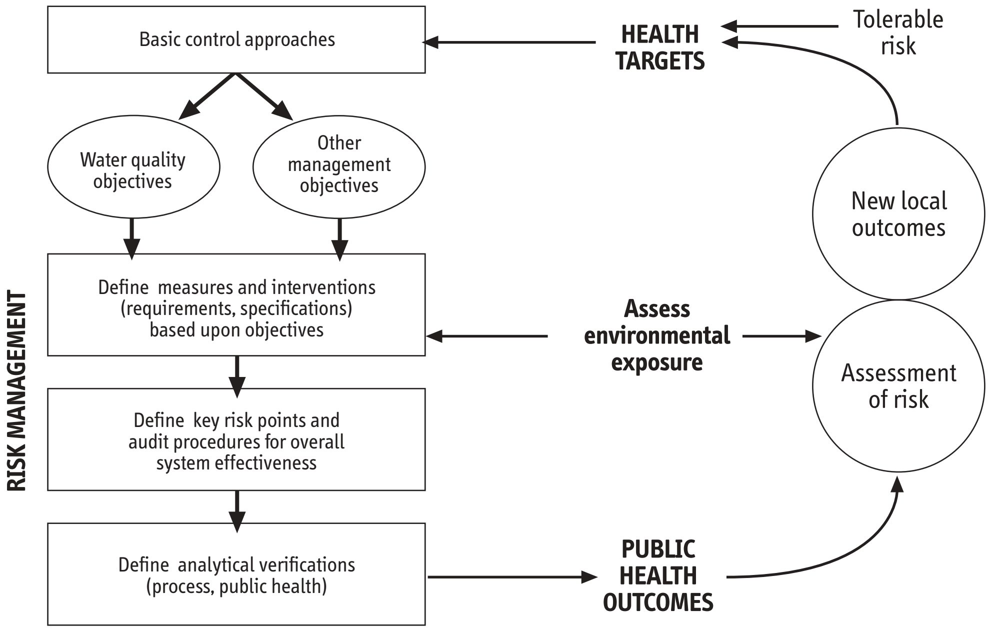


FIGURE 4.3. HARMONIZED APPROACH TO ASSESSMENT OF RISK AND RISK MANAGEMENT FOR WATER-RELATED EXPOSURE TO PATHOGENS (ADAPTED FROM BARTRAM ET AL., 2001)

- provision to account for the impact of actions to discourage water use during periods, or in areas, of higher risk.

The protocol has been tested in various countries, and recommendations resulting from these trials have been included in the Guidelines described here. These include the classification scheme that results from application of the Annapolis Protocol to the development of *Guidelines for safe Recreational Water Environments*, which is described in sections 4.5 and 4.6.

4.3.2 Risk assessment

Assessing the risk associated with human exposure to faecally polluted recreational waters can be carried out directly via epidemiological studies or indirectly through quantitative microbial risk assessment (QMRA). Both methods have advantages and limitations.

Epidemiological studies have been used to demonstrate a relationship between faecal pollution (using bacterial index organisms) and adverse health outcomes (see section 4.2 and Prüss, 1998). Some types of epidemiological studies are also suitable to quantify excess risk of illness attributable to recreational exposure. The problems and biases in a range of epidemiological studies of recreational water and the suitability of studies to determine causal or quantitative relationships have been reviewed by Prüss (1998).

From a review of the literature, one (or more) key epidemiological study may be identified that provides the most convincing data with which to assess quantitatively the relation between water quality (index organism) data and adverse health outcomes. The series of randomized epidemiological investigations, conducted in the United Kingdom, provide such data for gastroenteritis (Kay et al., 1994), AFRI and ear ailments associated with marine bathing (Fleisher et al., 1996a). These studies are described in more detail in section 4.4.1.

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

These factors suggest a general screening-level risk assessment (SLRA) as the first step to identify where further data collection and quantitative assessment may be most useful. However, caution is required in interpretation because the risk of infection or illness from exposure to pathogenic microorganisms is fundamentally different from the risk associated with other contaminants, such as toxic chemicals. Several of the key differences between exposure to pathogens and toxic chemicals are:

- exposure to chemical agents occurs via an environment-to-person pathway. Exposure to pathogens can occur via an environment-to-person pathway, but can also occur due to person-to-person contact (secondary spread);
- whether a person becomes infected or ill after exposure to a pathogen may depend on the person's pre-existing immunity. This condition implies that exposure events are not independent;
- infectious individuals may be symptomatic or asymptomatic;
- different strains of the same pathogen have a variable ability to cause disease (differing virulence);
- this virulence can evolve and change as the pathogen passes through various infected individuals; and
- pathogens are generally not evenly suspended in water.

Although the differences between exposure to chemical agents and pathogenic microorganisms are widely acknowledged, the conceptual framework for chemical risk assessment (Table 4.4) has been commonly employed for assessing the risk associated with exposure to pathogenic microorganisms. Frameworks have been developed specifically to assess the risks of human infection associated with exposure to pathogenic microorganisms and to account for some of the perceived shortcomings of the chemical risk framework with respect to properties unique to infectious microorganisms. However, to date, these frameworks have not been widely adopted.

In employing the chemical risk framework to carry out a SLRA, a representative pathogen is used to conservatively characterize its microbial group. For example, the occurrence of adenovirus, with its associated dose–response curve, may be used as a predictor for enteric viruses. Conservative estimates of exposure to each pathogen group (viruses, bacteria, parasitic protozoa and helminths) may be used to characterize "total" risks from each of the groups of pathogens. The results of the SLRA should then indicate an order of magnitude estimate of risk, whether or not further data are required and if risks are likely to be dominated by a single class of pathogen or source (potentially defining options for risk management). It should be emphasized that this SLRA approach presumes that little net error is made by not accounting for either person-to-person transmission of disease or immunity.

TABLE 4.4. RISK ASSESSMENT PARADIGM FOR ANY HUMAN HEALTH EFFECT[a]

Step	Aim
1. Hazard identification	To describe acute and chronic human health effects (toxicity, carcinogenicity, mutagenicity, developmental toxicity, reproductive toxicity and neurotoxicity) associated with any particular hazard, including pathogens.
2. Exposure assessment	To determine the size and nature of the population exposed and the route, amount and duration of the exposure.
3. Dose–response assessment	To characterize the relationship between various doses administered and the incidence of the health effect.
4. Risk characterization	To integrate the information from exposure, dose–response and hazard identification steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty.

[a] Adapted from NRC, 1983.

Given the somewhat limited array of microorganisms for which a dose–response relationship has been estimated, SLRAs are currently limited to a few microorganisms, such as rotavirus, adenovirus, *Cryptosporidium parvum*, *Giardia lamblia* and *Salmonella* spp. (Haas et al., 1999). A screening-level QMRA approach is outlined for a recreational water example in Box 4.2 (adapted from Ashbolt et al., 1997).

A more comprehensive alternative to the SLRA approach is to employ a population based disease transmission model to assess the risks of human disease associated with exposure to pathogenic microorganisms. In this population-based approach, the potential for person-to-person transmission and immunity are accounted for (Eisenberg et al., 1996; Soller, 2002), however, the models require substantially more epidemiological and clinical data than SLRA models. Application of the disease transmission modelling approach may, therefore, be more limited than the SLRA approach.

The primary advantages of QMRA studies are that the potential advantages and limitations of risk management options may be explored via numerical simulation to examine their potential efficacy, and that risk below epidemiologically detectable levels may be estimated under certain circumstances. The limitations of QMRA studies, as noted earlier, are that limited data are available to carry out these assessments and, in many cases, the data that are available are highly uncertain and variable. Nevertheless, it may be inferred from several of the available QMRA studies

(Sydney and Honolulu) (Mamala Bay Study Commission, 1996; Ashbolt et al., 1997) that they provide supporting evidence for the results of various epidemiological studies.

BOX 4.2 SCREENING-LEVEL QMRA APPROACH FOR BATHER RISK (ADAPTED FROM ASHBOLT ET AL., 1997)

For a predominantly sewage-impacted recreational water, the concentration of pathogens in waters may be estimated from the mean pathogen densities in sewage and their dilution in recreational waters (based on the numbers of index organisms; see Table 4.5 below). As an initial conservative approximation of pathogen numbers in recreational waters, enterococci may be used as an index for the dilution of sewage-associated bacterial pathogens (e.g., *Shigella*) and spores of *Clostridium perfringens* or enterococci for the enteric viruses and parasitic protozoa. Alternatively, direct presence/absence measurement of pathogens in large volumes of recreational waters may be attempted (Reynolds et al., 1998). Next, a volume of recreational water ingestion is required to determine the pathogen dose, in this instance 20–50 ml of water per hour of swimming has been assured.

TABLE 4.5. GEOMETRIC MEAN INDEX ORGANISMS AND VARIOUS PATHOGENS IN PRIMARY SEWAGE EFFLUENT IN SYDNEY, AUSTRALIA[a]

Thermotolerant coliforms (cfu/100 ml)	*Clostridium perfringens* spores (cfu/100 ml)	*Cryptosporidium* (oocysts/litre)	*Giardia* (cysts/litre)	Rotavirus (pfu/litre)[b]
1.33×10^7	7.53×10^4	24	14 000	470

[a] Index bacteria and parasite data are from Long & Ashbolt (1994).

[b] Total enteric virus estimate of 5650 for raw sewage is from Haas (1983). Long & Ashbolt (1994) quoted a 17% reduction for adenoviruses, enteroviruses and reoviruses by primary treatment (discharge quality), and rotavirus was assumed to be 10% of total virus estimate.

After the general concentrations of pathogens from the three microbial groups have been determined, selected representatives are used for which dose–response data are available (e.g., *Shigella*, *Cryptosporidium*, *Giardia*, rotavirus and adenoviruses). Note that these specific pathogens may not necessarily be the major etiological agents, but are used as health protective representatives characteristic of the likely pathogens. Risks from viral, bacterial and protozoan pathogens can then be characterized per exposure by applying published dose–response models for infection and illness (Haas et al., 1999). Employing the framework described above for chemical agents, risks experienced on different days are assumed to be statistically independent, and the daily risks are assumed to be equal. According to Haas et al. (1993), the annual risk can be calculated from a daily risk as follows:

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

where:

- P_{ANNUAL} is the annual risk of a particular consequence;
- P_{DAILY} is the daily risk of the same consequence; and
- N is the number of days on which exposure to the hazard occurs within a year.

Thus, QMRA can be a useful tool for screening the risk to public health at recreational water sites and for determining the potential efficacy of management alternatives through the integration of a wide array of disparate data. Finally, QMRA provides credible scientific analysis that can be used in conjunction with or, at times, in lieu of epidemiological investigations to assess risk to human health at recreational water sites.

4.3.3 Risk management

To meet health targets ultimately based on a tolerable risk of illness (see section 4.4), achievable objectives need to be established for water quality and associated management. Hazard analysis and critical control point (HACCP) provides an example of a possible approach. It is a risk management tool that promotes good operational/management practice and is an effective quality assurance (QA) system that is used in the food and beverage industry (Deere et al., 2001). It has become the benchmark means to ensure food and beverage safety since its codification in 1993 by the Food and Agriculture Organization of the United Nations and WHO Codex Alimentarius Commission. Water Safety Plans (WSP) for drinking-water have been developed from the HACCP approach (WHO, 2003).

For recreational waters, the HACCP approach has been interpreted as described in Table 4.6. This risk management procedure should be approached in an iterative manner, with increasing detail proportional to the scale of the problem and resources available. By design, HACCP addresses principally the needs for information for immediate management action; when applied to recreational water use areas, however, its information outputs are also suitable for use in longer-term classification.

Variation in water quality may occur in response to events (such as rainfall) with predictable outcomes, or the deterioration may be constrained to certain areas or subareas of a single recreational water environment. It may be possible to effectively discourage use of areas that are of poor quality or discourage use at times of increased risk. Since measures to predict times and areas of elevated risk and to discourage water contact during these periods may be inexpensive (especially where large point sources are concerned), greater cost effectiveness and improved possibilities for effective local management intervention are possible.

4.4 Guideline values

In many fields of environmental health, guideline values are set at a level of exposure at which no adverse health effects are expected to occur. This is the case for some chemicals in drinking-water, such as DDT (*p,p′*-dichlorodiphenyl trichloroethane) and copper.

For other chemicals in drinking-water, such as genotoxic carcinogens, there is no "safe" level of exposure. In these cases, guidelines (including WHO guideline values; WHO, 1996) are generally set at the concentration estimated to be associated with a certain (low) excess burden of disease. A frequent point of reference is a 1 in

TABLE 4.6. IMPLEMENTATION OF HACCP APPROACH FOR RECREATIONAL WATER MANAGEMENT

Initial steps	**Implementation**
Assemble HACCP team	• The team is formed to steer the overall process. Composition of the team should be such as to represent all stakeholders and cover all fields of expertise as much as possible. Representatives of health agencies, user groups, tourism industry, water and sewage industry, communities, competent authorities, potential polluters, experts in hazard and risk analysis, etc., should all therefore be considered.
Collate historical information	• Summarize previous data from sanitary surveys, compliance testing, utility maps of sewerage, water and stormwater pipes and overflows. • Determine major animal faecal sources for each recreational water catchment. • Reference development applications and appropriate legal requirements. • If no (historical) data are available, collect basic data to fill data gap/deficiency.
Produce and verify flow charts	• Produce and verify flow charts for faecal pollution from source(s) to recreational exposure area(s) for each recreational water catchment. This may require a new sanitary survey. • The series of flow charts should illustrate what happens to water between catchment and exposure in sufficient detail for potential entry points of different sources of faecal contaminants to be pinpointed and any detected contamination to be traced.
Core principles	
Hazard analysis	• Identify human versus different types of animal faecal pollution sources and potential points of entry into recreational waters. • Determine significance of possible exposure risks (based on judgement, quantitative and qualitative risk assessment, as appropriate). • Identify preventive measures (control points) for all significant risks.
Critical control points	• Identify those points or locations at which management actions can be applied to reduce the presence of, or exposure to, hazards to acceptable levels. Examples include municipal sewage discharge points, treatment works operation, combined sewer overflows, illegal connections to combined sewers, etc.
Critical limits	• Determine measurable control parameters and their critical limits. Ideally, assign target and action limits to pick up trends towards critical limits (e.g., >10–20 mm rainfall in previous 24-h period or notification of sewer overflow by local agency).
Monitoring	• Establish a monitoring regime to give early warning of exceedances beyond critical limits. Those responsible for the monitoring should be closely involved in developing monitoring and response procedures. Note that monitoring is not limited to water sampling and analysis, but could also include, for example, visual inspection of potential sources of contamination in catchment or flow/overflow gauges.
Management actions	• Prepare and test actions to reduce or prevent exposure in the event of critical limits being exceeded. Examples include building an appropriate treatment and/or disposal system, training personnel, developing an early warning system, issuing a media release and (ultimately) closing the area for recreational use.
Validation/ verification	• Obtain objective evidence that the envisaged management actions will ensure that the desired water quality will be obtained or that human recreational exposures will be avoided. This would draw from the literature and in-house validation exercises. • Obtain objective data from auditing management actions that the desired water quality or change in human exposure is in fact obtained and that the good operational practices, monitoring and management actions are being complied with at all times.
Record keeping	• Ensure that monitoring records are retained in a format that permits external audit and compilation of annual statistics. These should be designed in close liaison with those using the documents and records.

100 000 excess incidence of cancer over a lifetime of exposure. Such levels may be termed tolerable risk levels.

Guideline values and standards for microbial water quality were originally developed to prevent the occurrence of outbreaks of disease. However, there was limited information available concerning the degree of health protection they provided. In the case of recreational waters, the quantitative epidemiological studies published in recent years enable the estimation of the degree of health protection (or, conversely, burden of disease) associated with any given range of water quality. Further information on this is available in section 4.4.1, which illustrates the association of gastrointestinal illness and respiratory illness with microbial water quality.

In setting guidelines for recreational water quality, it would be logical to ensure that the overall levels of health protection were comparable to those for other water uses. This would require comparison of very different adverse health outcomes, such as cancer, diarrhoea, etc. Significant experience has now been gained in such comparisons, especially using the metric of disability-adjusted life years (DALYs).[1] When this is done for recreational waters, it becomes clear that typical standards for recreational water would lead to "compliant" recreational waters associated with a health risk very significantly greater than that considered acceptable, or tolerable, in other circumstances (such as carcinogens in drinking-water). However, setting recreational water quality standards at water qualities that would provide for levels of health protection similar to those accepted elsewhere would lead to standards that would be so strict as to be impossible to implement in many parts of the developing and developed world and would detract from the beneficial effects of recreational water use.

The approach adopted here therefore recommends that a range of water quality categories be defined and individual locations be classified according to these (see sections 4.4.3 and 4.6). The use of multiple categories provides incentive for progressive improvement throughout the range of qualities in which health effects are believed to occur.

4.4.1 Selection of key studies

Numerous studies have shown a causal relationship between gastrointestinal symptoms and recreational water quality as measured by index bacteria numbers (Prüss, 1998). Furthermore, a strong and consistent association has been reported with temporal and dose–response relationships, and the studies have biological plausibility and analogy to clinical cases from drinking contaminated water, although various biases can occur with all epidemiological studies (Prüss, 1998).

[1] A DALY expresses years of life lost to premature death (i.e., a death that occurs before the age to which the dying person could have been expected to survive if s/he were a member of a standardized model population with a life expectancy at birth equal to that of the world's longest-living population—Japan) and years lived with a disability of specific severity and duration. Thus, one DALY is one lost year of healthy life.

In 19 of the 22 studies examined in Prüss's (1998) review, the rate of certain symptoms or symptom groups was significantly related to the count of faecal index bacteria in recreational water. Hence, there was a consistency across the various studies, and gastrointestinal symptoms were the most frequent health outcome for which significant dose-related associations were reported.

The randomized controlled trials conducted in marine waters in the United Kingdom (Kay et al., 1994; Fleisher et al., 1996a; Kay et al., 2001) provide the most convincing data. These studies give the most accurate measure of exposure, water quality and illness compared with observational studies where an artificially low threshold and flattened dose–response curve (due to misclassification bias) were likely to have been determined.

These trials therefore form the key studies for derivation of guideline values for recreational waters (Box 4.3). However, it should be emphasized that they are primarily indicative for healthy adult populations in sewage impacted marine waters in temperate climates. Studies that reported higher thresholds and case rate values (for adult populations or populations of countries with higher endemicities) may suggest increased immunity, which is a plausible hypothesis but awaits empirical confirmation. Most studies reviewed by Prüss (1998) suggested that symptom rates were higher in lower age groups, and the UK studies may therefore systematically underestimate risks to children.

BOX 4.3 KEY STUDIES FOR GUIDELINE VALUE DERIVATION

The randomized trials reported by Kay et al. (1994) and Fleisher et al. (1996a) were designed to overcome significant "misclassification" (e.g., attributing a daily mean water quality to all bathers) and "self-selection" (e.g., the exposed bathers may have been more healthy at the outset) biases present in earlier studies. Both effects would have led to an underestimation of the illness rate.

This was done by recruiting healthy adult volunteers in urban centres during the four weeks before each of the four studies (i.e., the volunteers may not represent the actual population at a beach as well as did participants in the earlier prospective studies), conducted from 1998 to 1992 at United Kingdom beaches that were sewage impacted but passed existing European Union "mandatory" standards. Volunteers reported for an initial interview and medical examination 1–3 days prior to exposure. They reported to a beach on the study day and were informed of their randomization status into the "bather" or "non-bather" group (i.e., avoiding "self-selection" bias). Bathers were taken by a supervisor to a marked section of beach, where they bathed for a minimum period of ten min and immersed their heads three times during that period. The water in the recreational area was intensively sampled during the swimming period to give a spatial and temporal pattern of water quality, which allowed a unique water quality to be ascribed to each bather derived from a sample collected very close to the time and place of exposure (i.e., minimizing "misclassification" bias). Five candidate bacterial faecal indices were measured synchronously at three depths during this process. Enumeration of indices was completed using triplicate filtration to minimize bias caused by the imprecision of index organism measurement in marine waters. All volunteers were interviewed on the day of exposure and at one week post-exposure, and they completed a postal questionnaire at three weeks post-exposure. These questionnaires collected data on an extensive range of potential confounding factors, which were examined in subsequent analyses. Bathers and all subsequent interviewers were blind to the measure(s) of exposure used in statistical analysis, i.e., faecal index organism concentration encountered at the time and place of exposure.

Gastroenteritis rates in the bather group were predicted by faecal streptococci (i.e., intestinal enterococci) measured at chest depth (with gastroenteritis being based on accepted definitions in Europe and North America such as loose bowel motions, fever and vomiting). This relationship was observed at three of the four study sites; at the fourth, very low concentrations of this index organism were observed.

Only faecal streptococci, measured at chest depth, showed a dose–response relationship for both gastrointestinal illness (Kay et al., 1994) and AFRI (Fleisher et al., 1996a) in marine waters. Bathers had a statistically significant increase in the occurrence of AFRI at levels at or above 60 faecal streptococci/100 ml. While a significant dose–response relation with gastroenteritis was identified when faecal streptococci concentrations exceeded approximately 32/100 ml. No dose–response relationships with other illnesses were identified.

Faecal index organism concentrations in recreational waters vary greatly. To accommodate this variability, the disease burden attributable to recreational water exposure was calculated by combining the dose–response relationship with a probability density function (PDF) describing the distribution of index bacteria. This allows the health risk assessment to take account of the mean and variance of the bacterial distribution encountered by recreational water users.

The maximum level of faecal streptococci measured in these trials was 158 faecal streptococci/100 ml (Kay et al., 1994). The dose–response curve for gastroenteritis derived from these studies, and used in deriving the guidelines below, is limited to values in the range commencing where a significant effect was first recorded, 30–40 faecal streptococci/100 ml, to the maximum level detected. The probability of gastroenteritis or AFRI at levels higher than these is unknown. In estimating the risk levels for exposures above 158 faecal streptococci/100 ml, it is assumed that the probability of illness remains constant at the same level as exposure to 158 faecal streptococci/100 ml (i.e., an excess probability of 0.388), rather than continuing to increase. This assumption is likely to underestimate risk and may need review as studies become available that clarify the risks attributable to exposures above these levels.

Discussion has arisen concerning the steep dose–response curve reported in these studies, compared with previous studies. The best explanation of the steeper curve appears to be that with less misclassification and other biases, a more accurate measure of the association between index organism numbers and illness rates was made. In addition, the key studies examined beaches with direct sewage pollution, and it is possible that other pollution risks may result in a different (lower) risk. A reanalysis of these data (Kay et al., 2001) using a range of contemporary statistical tools has confirmed that the relationships originally reported are robust to alternative statistical approaches. The slopes of the dose–response curves for gastrointestinal illness and AFRI are also broadly consistent with the dose–response models used in QMRA (Ashbolt et al., 1997).

4.4.2 *The 95th percentile approach*

Many agencies have chosen to base criteria for recreational water compliance upon either percentage compliance levels, typically 95% compliance levels (i.e., 95% of the sample measurements taken must lie below a specific value in order to meet the standard), or geometric mean values of water quality data collected in the bathing zone. Both have significant drawbacks. The geometric mean is statistically a more stable measure, but this is because the inherent variability in the distribution of the water quality data is not characterized in the geometric mean. However, it is this variability that produces the high values at the top end of the statistical distribution that are of greatest public health concern. The 95% compliance system, on the other hand, does reflect much of the top-end variability in the distribution of water quality data and has the merit of being more easily understood. However, it is affected by greater statistical uncertainty and hence is a less reliable measure of water quality, thus requiring careful application to regulation. When calculating percentiles it is important to note that there is no one correct way to do the calculation. It is therefore desirable to know what method is being used, as each will give a different result (see Box 4.4).

4.4.3 *Guideline values for coastal waters*

The guideline values for microbial water quality given in Table 4.7 are derived from the key studies described above. The values are expressed in terms of the 95th percentile of numbers of intestinal enterococci per 100 ml and 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 are recommended for use in the recreational water environment classification scheme discussed in section 4.6.

4.4.4 *Guideline values for fresh water*

Dufour (1984) discussed the significant differences in swimming-associated gastrointestinal illness rates in seawater and freshwater swimmers at a given level of faecal index organisms. The illness rate in seawater swimmers was about two times greater than that in freshwater swimmers. A similar higher illness rate in seawater swimmers is observed if the epidemiological study data of Kay et al. (1994) and Ferley et al. (1989) are compared, although it should be noted that the research groups used very different methodologies. At the same intestinal enterococci densities, the swimming-associated illness rate was about five times higher in seawater bathers (Kay et al., 1994) than in freshwater swimmers (Ferley et al., 1989). This difference may be due to the more rapid die-off of index bacteria than pathogens (especially viruses) in seawater compared with fresh water (Box 4.5). This relationship would result in more pathogens in seawater than in fresh water when index organism densities are identical, which would logically lead to a higher swimming-associated gastrointestinal illness rate in seawater swimmers.

BOX 4.4 PERCENTILE CALCULATION

Individual regulatory authorities should decide on the most appropriate percentile calculation approach, based on data availability, statistical considerations and local resources. Two main approaches can be used. In the parametric approach it is assumed that the samples have been drawn from a particular distribution. This is typically the $\log_{10}$ normal distribution for microbiological data and so one uses the 95 percentile of that distribution, calculated from the mean and standard deviation of the logarithms of the data. The nonparametric approach does not assume any particular distribution and uses data ranking.

The parametric approach is outlined in Bartram & Rees (2000). This approach requires sufficient data to define the mean and standard deviations of the $\log_{10}$ bacterial enumerations. It also assumes that the dilution policy applied by the microbiology laboratories has been applied so as to not produce data items reported as, for example, <100 per 100 ml. For data sets with sufficient entries and appropriate dilution policy, the 95 percentile point of the probability density function (PDF) is defined as follows:

$$\text{Log}_{10}\ 95\%\text{ile} = \text{Arithmetic mean } \log_{10} \text{ bacterial concentration} + (1.6449 \times \text{standard deviation of } \log_{10} \text{ bacterial concentration})$$

In calculating this statistic for a column of bacterial data acquired from one beach, all enumerations should be converted to $\log_{10}$ values and the calculations of mean and standard deviation should be completed on the $\log_{10}$ transformed data.

Sample percentiles can also be calculated by a two-step non-parametric procedure. Firstly the data are ranked into ascending order and then the "rank" of the required percentile calculated using an appropriate formula—each formula giving a different result. The calculated rank is seldom an integer and so in the second step an interpolation is required between adjacent data using the following formula:

$$X_{0.95} = (10 - r_{\text{frac}})X_{r_{\text{int}}} + r_{\text{frac}}X_{r_{\text{int}}+1}$$

where $X_{0.95}$ is the required 95 percentile, $X_1, X_2, \ldots, X_n$ are the n data arranged in ascending order and the subscripts r_{frac} and r_{int} are the fractional and integer parts of r.

RANKING FORMULAE

Three formulae are in use in the water industry (Ellis 1989), covering the range of estimates that may be made: Weibull, Hazen and Excel™. Their formulae are: $r_{\text{Weibull}} = 0.95(n + 1)$, $r_{\text{Hazen}} = \frac{1}{2} + 0.95n$, and $r_{\text{Excel}} = 1 + 0.95(n - 1)$. An example calculation using the Weibull formula is presented in Bartram & Rees (2000, Table 8.3). It needs at least 19 samples to work, and always gives the highest result. The Hazen formula needs only 10 samples to work, while the Excel™ formula needs only one sample and always gives the lowest result.

EXAMPLE CALCULATION

Say that we have 100 data of which the six highest are: 200, 320, 357, 389, 410, 440. Then we have $r_{\text{Hazen}} = 95.5$ and so the 95 percentile estimated by the Hazen formula is $X_{0.95} = (0.5 \times 200) + (0.5 \times 320) = 260$.

Note that using the Weibull formula we have $r_{\text{Weibull}} = 95.95$ and so the 95 percentile estimated by the Weibull formula is $X_{0.95} = (0.05 \times 200) + (0.95 \times 320) = 314$, while for the method used in Excel™ we have $r_{\text{Excel}} = 95.05$ and so the 95 percentile estimated by the Excel formula is $X_{0.95} = (0.95 \times 200) + (0.05 \times 320) = 206$—much lower than the Weibull result.

TABLE 4.7. GUIDELINE VALUES FOR MICROBIAL QUALITY OF RECREATIONAL WATERS

95th percentile value of intestinal enterococci/100 ml (rounded values)	Basis of derivation	Estimated risk per exposure
≤40 **A**	This range is below the NOAEL in most epidemiological studies.	**<1% GI illness risk** **<0.3% AFRI risk** The upper 95th percentile value of 40/100 ml relates to an average probability of less than one case of gastroenteritis in every 100 exposures. The AFRI burden would be negligible.
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 of 200/100 ml relates to an average probability of one 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 in the range of 19–39 per 1000 exposures, or a range of approximately 1 in 50 to 1 in 25 exposures.
>500 **D**	Above this level, there may be a 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 point of >500/100 ml would be greater than 39 per 1000 exposures, or greater than approximately 1 in 25 exposures.

Notes:

1. Abbreviations used: A–D are the corresponding microbial water quality assessment categories (see section 4.6) used as part of the classification procedure (Table 4.12); AFRI = acute febrile respiratory illness; GI = gastrointestinal; LOAEL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect level.
2. The "exposure" in the key studies was a minimum of 10 min of swimming involving three head immersions. It is envisaged that this is equivalent to many immersion activities of similar duration, but it may underestimate risk for longer periods of water contact or for activities involving higher risks of water ingestion (see also note 8).
3. The "estimated risk" refers to the excess risk of illness (relative to a group of non-bathers) among a group of bathers who have been exposed to faecally contaminated recreational water under conditions similar to those in the key studies.
4. The functional form used in the dose–response curve assumes no further illness outside the range of the data (i.e., at concentrations above 158 intestinal enterococci/100 ml; see Box 4.3). Thus, the estimates of illness rate reported above this value are likely to be underestimates of the actual disease incidence attributable to recreational water exposure.
5. The estimated risks were derived from sewage-impacted marine waters. Different sources of pollution and more or less aggressive environments may modify the risks.
6. This table is derived from risk to healthy adult bathers exposed to marine waters in temperate north European waters.

TABLE 4.7. *Continued*

7. This table may not relate to children, the elderly or the immunocompromised, who could have lower immunity and might require a greater degree of protection. There are presently no adequate data with which to quantify this, and no correction factors are therefore applied.
8. Epidemiological data on fresh waters or exposures other than swimming (e.g., high-exposure activities such as surfing, dinghy boat sailing or whitewater canoeing) are currently inadequate to present a parallel analysis for defined risks. Thus, a single series of microbial values is proposed, for all recreational uses of water, because insufficient evidence exists at present to do otherwise. However, it is recommended that the length and frequency of exposure encountered by special interest groups (such as bodysurfers, board riders, windsurfers, sub-aqua divers, canoeists and dinghy sailors) be taken into account (chapter 1).
9. Where disinfection is used to reduce the density of index organisms in effluents and discharges, the presumed relationship between intestinal enterococci (as an index of faecal contamination) and pathogen presence may be altered. This alteration is, at present, poorly understood. In water receiving such effluents and discharges, intestinal enterococci counts may not provide an accurate estimate of the risk of suffering from gastrointestinal symptoms or AFRI.
10. Risk attributable to exposure to recreational water is calculated after the method given by Wyer et al. (1999), in which a $\log_{10}$ standard deviation of 0.8103 for faecal streptococci was assumed. If the true standard deviation for a beach is less than 0.8103, then reliance on this approach would tend to overestimate the health risk for people exposed above the threshold level, and vice versa.
11. Note that the values presented in this table do not take account of health outcomes other than gastroenteritis and AFRI. Where other outcomes are of public health concern, then the risks should also be assessed and appropriate action taken.
12. Guideline values should be applied to water used recreationally and at the times of recreational use. This implies care in the design of monitoring programmes to ensure that representative samples are obtained.

BOX 4.5 DIFFERENTIAL DIE-OFF OF INDEX BACTERIA AND PATHOGENS IN SEAWATER AND FRESH WATER

Salinity appears to accelerate the inactivation of sunlight-damaged coliforms in marine environments, such that coliforms are appreciably less persistent than intestinal enterococci in seawater. Cioglia & Loddo (1962) showed that poliovirus, echovirus and coxsackie virus were inactivated at approximately the same rate in marine and fresh waters (Table 4.8), but it is important to note that other factors, such as water temperature, are more important than salinity for virus inactivation (Gantzer et al., 1998).

TABLE 4.8. SURVIVAL OF ENTEROVIRUSES IN SEAWATER AND RIVER WATER[a]

	Die-off rates (in days)[b]	
Virus strain	**Seawater**	**River water**
Polio I	8	15
Polio II	8	8
Polio III	8	8
Echo 6	15	8
Coxsackie	2	2

[a] Adapted from Cioglia & Loddo (1962).

[b] Maximum number of days required to reduce the virus population by 3 logs (temperature and sunlight effects not provided, but critical; Gantzer et al., 1998).

It appears likely that bacterial index organisms have different die-off characteristics in marine and fresh waters, while human viruses are inactivated at similar rates in these environments.

Thus, application of the guideline values derived above for seawaters (Table 4.7) to fresh waters would 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.

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

Studies using a randomized trial design have been conducted in Germany at freshwater sites. These have yet to be reported in the peer-reviewed literature. Initial reports (Wiedenmann et al., 2002) suggest that these studies have identified similar thresholds of effect to those reported in Kay et al. (1994). Until the full results of these investigations become available, there is inadequate evidence with which to directly derive a water quality guideline value for fresh water.

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

4.4.5 *Adaptation of guideline values to national/local circumstances*

There is no universally applicable risk management formula. "Acceptable" or "tolerable" excess disease rates are especially controversial because of the voluntary nature of recreational water exposure and the generally self-limiting nature of the most studied health outcomes (gastroenteritis, respiratory illness). Therefore, assessment of recreational water quality should be interpreted or modified in light of regional and/or local factors. Such factors include the nature and seriousness of local endemic illness, population behaviour, exposure patterns, and sociocultural, economic, environmental and technical aspects, as well as competing health risk from other diseases including those that are not associated with recreational water. From a strictly health perspective, many of the factors that might be taken into account in such an adaptation would often lead to the derivation of stricter standards than those presented in Table 4.7. What signifies an acceptable or tolerable risk is not only a regional or local issue, however, as even within a region or locality children, the elderly and people from lower socioeconomic areas would be expected to be more at risk (Cabelli et al., 1979; Prüss, 1998).

The guideline values given in Table 4.7 were derived from studies involving healthy adult bathers swimming in sewage impacted marine waters in a temperate climate. Thus, the Guidelines do not relate specifically to children, the elderly or immunocompromised, who may have lower immunity and might require a greater degree of protection. If these are significant water user groups in an area, local authorities may want to adapt the Guidelines accordingly.

In areas with higher carriage rates or prevalence of diseases potentially transmitted through recreational water contact, risks are likely to be greater (in response to greater numbers of, or different, pathogens), and stricter standards may be judged appropriate by local authorities.

If a region is an international tourist area, other factors that need to be taken into consideration in applying the guideline values include the susceptibility of visiting populations to locally endemic disease, such as hepatitis A, as well as the risk of introduction of unfamiliar pathogens by visitors to the resident population.

The guideline values were derived from studies in which the "exposure" was a minimum of ten minutes of swimming involving three head immersions. They may therefore underestimate risk for activities involving higher risks of water ingestion or longer periods of water contact. Recreational water uses involving lesser degrees of water contact (such as windsurfing and sea canoeing) will usually result in less water ingestion and thus may require less stringent guideline values to achieve equivalent health protection.

When information on "typical" swimmers (e.g., age, number of swimming events per swimming season per swimmer, average amount of water swallowed per swimming event) is known, local authorities can adapt the guideline values to their own circumstances, expressing the health risk in terms of the rate of illness affecting a "typical" swimmer over a fixed period of time.

Use of a range of categories, rather than a simple pass/fail approach, supports the principle of informed personal choice. It also allows achievable improvement targets to be set for high-risk areas, rather than an "across the board" target which may result in less overall health gain.

Pathogens and faecal index organisms are inactivated at different rates, dependent on physicochemical conditions. Therefore, any one index organism is, at best, only an approximate index of pathogen removal efficacy in water (Davies-Colley et al., 2000; Sinton et al., 2002; Box 4.5). This suggests that factors influencing faecal index organism die-off should be taken into consideration when applying the guideline values in Table 4.7, depending on local circumstances. This is particularly true where sewage is disinfected prior to release, as this will markedly affect the pathogen/index organism relationship.

Objective input for the adaptation of guidelines to standards may be informed by quantitative microbial risk assessment (QMRA), as outlined in section 4.3.2. Thus, a screening-level QMRA is recommended where differential persistence of faecal index organisms and pathogens compared with the United Kingdom studies may occur. Examples of such circumstances include higher water temperatures, higher sunlight (UV) intensity and possibly different rates of microbial predation, along with different endemic disease(s) or where there is further treatment of sewage effluent (such as disinfection) prior to discharge.

Adaptation of guideline values to national or local circumstances may be informed by reference levels of risk using, for example, disability adjusted life years per person per year, comparing risks considered tolerable for drinking-water, for example, with risks from recreational water use. Alternatively, exposure to recreational waters has been considered tolerable when gastrointestinal illness is equivalent to that in the background unexposed population. Background rates have been given as, for example, 0.9–9.7% from a range of marine and freshwater studies (Cabelli et al., 1982; Kay et al., 1994; van Asperen et al., 1998). Based on the key studies of coastal bathers in the United Kingdom, Wyer et al. (1999) provided an example of tolerable risk in terms of faecal index bacteria (faecal streptococci) equivalent to "background" or non-water-related gastrointestinal disease. Published or site-specific dose–response curves of the probability of illness over increasing index organism exposure can then be used in conjunction with the distribution of faecal index bacteria in recreational water to yield prospective microbial water quality criteria or actual expected disease burden at a particular recreational water location.

The guideline values, defined in Table 4.7, were derived using an average value for the standard deviation of the PDF for faecal streptococci of 0.8103 (as a $\log_{10}$ faecal streptococci/100 ml value), calculated from a survey of 11 000 European recreational waters (Kay et al., 1996). Local variations in the standard deviation would affect the shape of the PDF (higher standard deviation values would give a broader spread of values, while smaller standard deviation values would produce a more narrow spread of values). Thus, the effect of using a fixed standard deviation for all recreational water environments is variable.

The adaptation of guidelines to form national standards, for example, and the subsequent regulation of recreational waters is also examined in section 4.7.3 and chapter 13.

4.4.6 Regulatory parameters of importance

For any microorganism to be used as a regulatory parameter of public health significance for recreational waters, it should ideally:

- have a health basis;
- have adequate information available with which to derive guideline values (e.g., from epidemiological investigations);
- be sufficiently stable in water samples for meaningful results to be obtained from analyses;
- have a standard method for analysis;
- be low cost to test;
- make low demands on staff training; and
- require basic equipment that is readily available.

Microorganisms commonly used in regulation include the following:

- **Intestinal enterococci** meet all of the above.
- ***E. coli*** is intrinsically suitable for fresh waters but not marine water; however, as discussed in section 4.4.4, there are currently insufficient data with which to develop guideline values using this parameter in fresh water.
- **Total coliforms** are inadequate for the above criteria, in particular as they are not specific to faecal material.

- **Thermotolerant coliforms**, although a better index than total coliforms, include non-faecally derived organisms (e.g., *Klebsiella* can derive from pulp and paper mill effluents). As there are no adequate studies on which to base guideline values, thermotolerant coliforms are unsuitable as regulatory parameters.
- **Salmonellae** have been used for regulatory purposes. Their direct health role has not been supported by outbreak data. They are unlikely to contribute significantly to the transmission of disease via the recreational water route because of their low infectivity and typically relatively low numbers in sewage, which, when combined with their rapid inactivation in waters, particularly seawaters, suggest limited biological plausibility.
- **Enteroviruses** have been used for regulatory purposes. They are costly to assay and require specialized methods that include a concentration step for their analysis, which is imprecise. Although enteroviruses are always present in sewage and there are standard methods, their numbers are variable and not related to health outcome (Fleisher et al., 1996a,b). Hence, there are insufficient data with which to develop guideline values. Their direct health significance varies from negligible (e.g., vaccine strains) to very high.

4.5 Assessing faecal contamination of recreational water environments

The two principal components required for assessing faecal contamination of recreational water areas are:

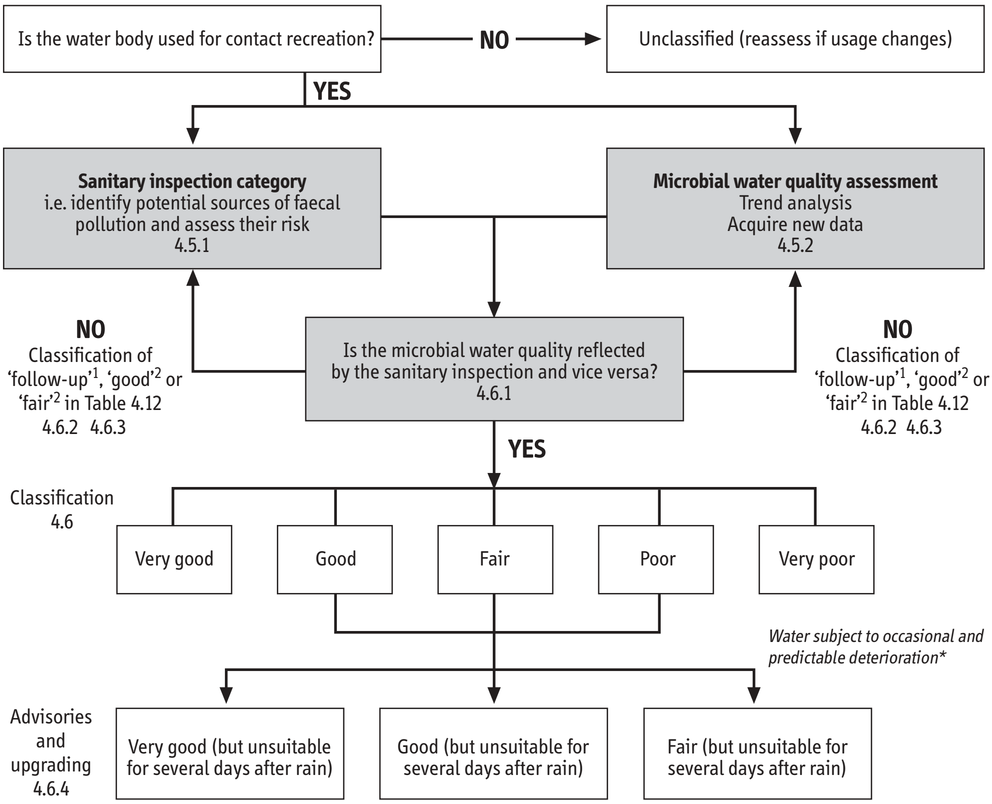
- assessment of evidence for the degree of influence of faecal material (i.e., derivation of a sanitary inspection category); and
- counts of suitable faecal index bacteria (a microbial water quality assessment).

These would be done for the purposes of classification only where a recreational water is used for whole-body contact recreation (i.e., where there is a meaningful risk of swallowing water). The two components are combined (as outlined in section 4.6 and Figure 4.4) in order to produce an overall classification.

4.5.1 Sanitary inspection category

Sources of faecal pollution have been outlined in section 4.2. The sanitary inspection should aim to identify all sources of faecal pollution, although human faecal pollution will tend to drive the overall sanitary inspection category for an area.

The three most important sources of human faecal contamination of recreational water environments for public health purposes are typically sewage, riverine discharges (where the river is a receiving water for sewage discharges and either is used directly for recreation or discharges near a coastal or lake area used for recreation) and contamination from bathers (including excreta). Other sources of human faecal contamination include septic tanks near the shore (leaching directly into groundwater seeping into the recreational water environment) and shipping and local boating (including moorings and special events such as regattas).



* where users can be shown to be effectively discouraged from entering the water following occasional and predictable water quality deteriorations (linked to, for example, rainfall), the area may be upgraded to reflect the water quality that users are exposed to, but only with the accompanying explanatory material.

FIGURE 4.4. FRAMEWORK FOR ASSESSING RECREATIONAL WATER ENVIRONMENTS (NUMBERS REFER TO SECTIONS IN CHAPTER)

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

- Sewage outfalls, combined sewer overflows, stormwater discharges
  - Presence/absence (each is considered to be of equal human faecal load unless otherwise determined)
  - Type of sewage treatment
  - Effectiveness of outfall type
- Riverine discharges
  - Presence/absence
  - Type of sewage treatment
  - Population size from which sewage originates
  - River flow in the bathing season

- Bather shedding
  —Bather density in the swimming season
  —Dilution (mixing of water in recreational water area)

Additional information that may assist in assessing the safety of recreational waters and in controlling associated risks is often readily available and may concern, for example:

- rainfall (duration and quantity);
- wind (speed and direction);
- tides and currents or water release (e.g., dam-controlled rivers); and
- coastal physiography.

Index organism densities in recreational waters can be increased to high levels following rainfall because treatment plants may be overwhelmed (causing sewage to bypass treatment) or because of animal wastes washed from forestland, pastureland and urban settings. Resuspension of sediment-trapped pathogens is another factor influenced by rainfall, particularly in freshwater river catchments. In all these cases, the effect of rainfall on recreational water quality can be highly variable, yet characteristic for each recreational water area.

The relative risks to human health through direct sewage discharge, riverine discharge contaminated with sewage and bather contamination have been ranked in this chapter (see below). In doing so, account is taken of the likelihood of human exposure and the degree of treatment of sewage. In taking sewage and riverine discharges to recreational areas into consideration, account is also taken of the pollutant load, using population as an index. In adapting guidelines, information on local circumstances needs to be taken into account and may lead to variation. For example, sewage being discharged in an estuary with small tidal interchanges may have an effect different to that of the same quantity of sewage discharged in an estuary with large tidal interchanges. Similarly, a river discharging in an enclosed bay can be considered to present a higher risk than one discharging directly into the open sea.

While in many circumstances several contamination sources would be significant at a single location, a recreational water environment may be most readily categorized, in terms of its sanitary inspection, according to the single most significant source of pollution.

The following subsections assist in placing recreational water environments into an appropriate sanitary inspection category indicative of susceptibility to human faecal pollution, but cannot account fully for local and regional factors.

1. Sewage discharges (including combined sewer overflows and stormwater discharges)

Sewage-related risk arises from a combination of the likelihood of pollution and, where pollution occurs, the degree of inactivation through treatment.

Sewage discharges, or outfalls, may be readily classified into three principal types:

- those where the discharge is directly onto the beach (above low water level in tidal areas);
- those where discharge is through "short" outfalls, where discharge is into the water but sewage-polluted water is likely to contaminate the recreational water area; and
- those where discharge is through "long" outfalls, where the sewage is diluted and dispersed and the design criteria for the outfall should ensure that sewage does not pollute recreational water areas.

While the terms "short" and "long" are often used, outfall length is generally less important than proper location and effective diffusion, which should ensure that pollution is unlikely to reach recreational areas.

Direct discharge of crude, untreated sewage (for instance, through short outfalls or combined sewer overflows, which contain a mixture of raw sewage and stormwater) into recreational areas presents a serious risk to public health. Public health authorities should take measures to protect public health where this occurs and cooperate with appropriate authorities to eliminate this practice or to minimize recreational use of affected areas. For short outfalls, the relative risk is increased based upon the size of the contributing population. An effective outfall is assumed to be properly designed, with sufficient length and diffuser discharge depth to ensure low probability of the sewage reaching the recreational area.

In public health terms, it is generally assumed that the processes of dispersion, dilution, sedimentation and inactivation (through sunlight, predation, natural die-off, etc.) following discharge into the aquatic environment from a piped outfall will lead to a certain degree of safety. A number of confounding factors reduce the efficiency of this in practice. Most important are those that lead to the rapid movement of sewage into recreational areas. For example, where sewage is relatively warm and of low salinity when compared with the receiving water, it may mix poorly and form a floating slick. Such slicks should not form where properly designed and operated diffusers are in place on the outfall. Where slicks form, they will be readily influenced by wind and may therefore pollute (even distant) recreational water environments severely. While not providing long-term security for public health, periods of high risk (such as during onshore winds) may be recognized on such beaches and action, such as advisory notices (sections 4.6.4 and 4.7.1), zoning or banning of swimming and other water contact activities, taken as appropriate. Coastal currents and tides may give rise to similar problems and may be recognized and dealt with in a similar manner.

Control of sewage pollution by holding sewage in storage for varying periods of time is practised in some countries. Where sewage is retained throughout the swimming season, water users are effectively protected from the source of pollution. Such an approach is of limited applicability for practical reasons and will be fully effective only where there is a strict cut-off in recreational activity at the end of the swimming season. The efficacy of shorter-term retention—such as retention during the day and discharge at night—is less certain and is strongly influenced by the nature of the discharge, the geographical configuration of the area and environmental factors as discussed above.

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

- no treatment (discharge of raw, untreated sewage);
- "preliminary" treatment (screening with milli- or microscreens to remove large solids);
- primary treatment (physical sedimentation or settling);
- secondary treatment (primary sedimentation plus high-rate biological processes, such as trickling filter/activated sludge);
- secondary treatment plus disinfection (chlorination, peracetic acid, UV or ozone);
- tertiary treatment (advanced wastewater treatment, including primary sedimentation, secondary treatment plus, for example, coagulation–sand filtration, UV, microfiltration);
- tertiary treatment plus disinfection; and
- lagooning (low-rate biological treatment).

Of these, lagooning, primary plus secondary treatment, tertiary treatment and disinfection will effect a significant reduction in index organism and pathogen contamination. Some treatments, notably disinfection (in particular, chlorination), may affect the validity of the microbial water quality assessment due to differential attenuation of index and pathogenic organisms. This will tend to lead to underestimates of risk, particularly with disinfection-resistant enteric viruses and chlorine-resistant *Cryptosporidium*. Where the principal human faecal pollution source is disinfected sewage, it is suggested that supplementary investigations be undertaken because of the likely underestimate of health risk based on Table 4.7.

Urban stormwater runoff and outputs from combined sewer overflows are included under the category of direct beach outfalls. Septic systems and stormwater/combined sewers are assumed to be equivalent to primary treatment.

The classification is based upon a qualitative assessment of risk of contact/exposure under "normal" conditions with respect to the operation of sewage treatment works, hydrometeorological and oceanographic conditions. The potential risk to human health through exposure to sewage through outfalls can be categorized as shown in Table 4.9.

2. *Riverine discharges*

Rivers discharging into recreational water areas may carry a heavy load of microorganisms from diverse sources, including municipal sewage (treated or otherwise) and animal husbandry. Following rainfall, microbial loads may be significantly increased due to surface runoff, urban and rural stormwater overflows (including natural water courses - torrents - that only drain storm water) and resuspension of sediments. Coastal pollution levels may therefore be elevated following rainfall and periods of high risk in some coastal areas may be found to correlate with such climatological data. Once

TABLE 4.9. RELATIVE RISK POTENTIAL TO HUMAN HEALTH THROUGH EXPOSURE TO SEWAGE THROUGH OUTFALLS (INCLUDING STORMWATER RUNOFF AND COMBINED SEWER OVERFLOWS)

	Discharge type		
Treatment	**Directly on beach**	**Short outfall**[a]	**Effective outfall**[b]
None[c]	Very high	High	NA[d]
Preliminary	Very high	High	Low
Primary (including septic tanks)	Very high	High	Low
Secondary	High	High	Low
Secondary plus disinfection[e]	—	—	—
Tertiary	Moderate	Moderate	Very low
Tertiary plus disinfection[e]	—	—	—
Lagoons	High	High	Low

[a] The relative risk is modified by population size. Relative risk is increased for discharges from large populations and decreased for discharges from small populations.

[b] This assumes that the design capacity has not been exceeded and that climatic and oceanic extreme conditions are considered in the design objective (i.e., no sewage on the beach zone).

[c] Includes combined sewer overflows if active during the bathing season (a history of total non-discharge during the bathing season can be treated as “Low”).

[d] NA = not applicable

[e] Additional investigations recommended to account for the likely lack of prediction with faecal index organisms as outlined in Table 4.7.

the hazard is recognized and characterized, simple advisory measures may be taken prospectively to alert water users of such risks and/or prevent recreational use during such periods (see sections 4.6.4 and 4.7.1).

Recreational areas on rivers will be subject to influences similar to those indicated above. In addition, where water flow is managed either for recreation (such as where water is impounded before discharge) or for other purposes, the act of impoundment and discharge may itself lead to elevated microbial levels through resuspension of sediment. Rivers may be receiving environments for sewage effluents which may be treated to varying degrees. Much lower levels of effluent dilution may occur in riverine environments than in their coastal equivalents, and differential pathogen–index organism relationships may exist between saline and non-saline waters (see section 4.4.4, Box 4.5).

Riverine discharges may be categorized with respect to the sewage effluent load and the degree of dilution in a manner similar to that described in Table 4.10. Where human faecal waste is not present but animal waste from, for example, animal husbandry is present this should be taken into account.

3. *Bather shedding*

Bathers themselves can influence water quality directly (Eisenberg et al., 1996). For example, Papadakis et al. (1997) collected water and sand samples from two beaches, counted the swimmers present on the beaches and conducted microbiological tests for counts of coliforms, thermotolerant coliforms, enterococci, *Staphylococcus aureus*, yeasts and moulds. There was a significant correlation between the number of swimmers present on the beach and *S. aureus* counts in water samples, the correlation being more pronounced on the more popular of the two beaches. Yeasts of human origin in water samples also were correlated with the number of swimmers on the more popular beach.

TABLE 4.10. RELATIVE RISK POTENTIAL TO HUMAN HEALTH THROUGH EXPOSURE TO SEWAGE THROUGH RIVERINE FLOW AND DISCHARGE

	Treatment level				
Population and flow characteristics[a,b]	**None**	**Primary**	**Secondary**	**Secondary plus disinfection**[c]	**Lagoon**
High population with low river flow	Very high	Very high	High	—	Moderate
Low population with low river flow	Very high	High	Moderate	—	Moderate
Medium population with medium river flow	High	Moderate	Low	—	Low
High population with high river flow	High	Moderate	Low	—	Low
Low population with high river flow	High	Moderate	Very low	—	Very low

[a] The population factor includes, in principle, all the population upstream from the recreational water environment to be classified and assumes no in-stream reduction in hazard factor used to classify the recreational water environment.

[b] Stream flow of primary concern is the lowest typical flow during the bathing season (excluding combined sewer overflow and stormwater; see Table 4.9).

[c] Additional investigations recommended to account for the likely lack of prediction with faecal index organisms as outlined in Table 4.7.

The effect of bathers on water quality is most commonly seen as microbial buildup during the day, such that peak levels are reached by the afternoon. In circumstances of limited dispersion, bather-derived faecal pollution may present a significant health risk, as evidenced by epidemiological studies (Calderon et al., 1991), several outbreaks of disease (see section 4.2) and by analogy to swimming pools and spas (see Volume 2 of the Guidelines). There is insufficient evidence to judge the contribution that bather-derived pollution makes in other circumstances.

TABLE 4.11. RELATIVE RISK POTENTIAL TO HUMAN HEALTH THROUGH EXPOSURE TO SEWAGE FROM BATHERS

Bather shedding	**Category**
High bather density, high dilution[a]	Low
Low bather density, high dilution	Very low
High bather density, low dilution[a,b]	Moderate
Low bather density, low dilution[b]	Low

[a] Move to next higher category if no sanitary facilities available at beach site.

[b] If no water movement.

The two principal factors of importance in relation to bathers are bather density and degree of dilution (Table 4.11). Low dilution is assumed to represent no water movement (e.g., lakes, lagoons, coastal embayments). The likelihood of bathers defecating or urinating into the water is substantially increased if toilet facilities are not readily available. Under high bather density, the classification should therefore be increased to the next higher class if no sanitary facilities are available at the beach.

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

4. *Animal inputs*

Although the sanitary inspection category is principally driven by human faecal inputs, it is important to determine major sources of animal faecal pollution. These will often be less important in terms of human health risk than human pollution, although in some instances they can have a significant impact on microbial water quality and health risk (see 4.6.2).

4.5.2 Microbial water quality assessment

The various stages involved in an assessment of the microbial quality of a recreational water environment are described elsewhere (Bartram & Rees, 2000 chapter 9) and are summarized as follows:

- **Stage 1:** Initial sampling to determine whether significant spatial variation exists. Sampling at spatially separated sampling sites should be carried out during the initial assessment on different days. Timing of samples should take into account the likely period of maximum contamination from local sewage discharges and maximum bather shedding (e.g., the afternoon or day of peak bather numbers).
- **Stage 2:** Assessment of spatial variation based on data from the above.
- **Stage 3:** Intensive sampling (if no significant spatial variation) and assessment of results. If there is no evidence of spatial variation, the initial classification is determined from results of the sanitary inspection category and microbial water quality assessment (section 4.6). It is suggested that microbial water quality for all recreational waters is classified into four categories (A–D) using the 95th percentile of the intestinal enterococci distribution as shown in Table 4.7.
- **Stage 4:** Definition, separate assessment and management of impacted areas if spatial variation 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 (section 4.6, Table 4.12) is 'very good' or 'very poor', less frequent monitoring can be justified (Table 4.13).

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

It is important that sufficient samples are collected to enable an appropriate estimation of the index organism densities to which recreational water users are exposed. Previous recommendations based on 20 or fewer samples are considered to be inappropriate given the usual variation in faecal index organisms as the precision of the estimate of the 95th percentile is low. Increasing sample numbers, for instance towards 100 samples, would increase precision.

The number of results available can be increased significantly—with no additional cost—by pooling data from multiple years. This practice is justified unless there is reason to believe that local (pollution) conditions have changed, causing the results to deviate from established behaviour. For practical purposes, it is suggested that data from 100 samples from a 5-year period and a rolling 5-year data set be used for microbial water quality assessment purposes. In many situations, a much shorter period will be required, where, for example, more extensive sampling is undertaken. In some circumstances, fewer samples may be required—for instance, where the water quality is very poor, however, it is suggested that 60 samples from a 3-year period should be the minimum considered.

Data sets that contain numerous values below the limit of detection can be difficult to manage. Where the use of such data is unavoidable, the Hazen method (Box 4.4) is a robust method for calculating the 95^{th} percentile. It should be the preferred method as it gives very close estimates of the actual 95^{th} percentile whether or not there are results that fall below the limit of detection (Hunter, 2002). In subsequent analyses, however, appropriate dilutions should be employed to ensure that non-detects are rare or completely avoided.

Various index bacteria, including *E. coli*, thermotolerant coliforms and intestinal enterococci, are used for the monitoring of recreational waters (see section 4.4.6). Several methods are available for estimating bacterial numbers at recreational water areas (outlined in Bartram & Rees, 2000). Where a change is made between index organisms (e.g., from thermotolerant coliforms to intestinal enterococci, or a change in the microbiological method employed), a limited number of data may be available in the initial years of implementation. In order to overcome this, correction factors appropriate to local conditions may be applied to historical records to enable their use. Such conversion factors would normally be driven by comparative studies of the results of local analyses. Another strategy that has been employed is to collect both old and new index organism data during a transition period. Although costs are increased this does provide a 'break-in' period.

4.6 Classification of recreational water environments

Classification of recreational water is achieved by combining the sanitary inspection category and the microbial water quality assessment using a matrix such as that shown in Table 4.12. The overall approach is summarized in Figure 4.4 (see section 4.5).

The classification emphasizes faecal contamination from humans, with lesser importance placed on faecal contamination from other sources, such as drainage from areas of animal pasture and intensive livestock rearing, the presence of gulls or the use of the beach for dogs or horses. Due to the "species barrier," the density of pathogens of public health importance is generally assumed to be less in aggregate in animal excreta than in human excreta which may therefore represent a significantly lower risk to human health. As a result, the use of faecal bacteria alone as an index of risk to human health may significantly overestimate risks where the index organisms derive from sources other than human excreta. Nevertheless, there are human health risks associated with pollution of recreational waters from animal excreta, and some pathogens, such as *Cryptosporidium parvum*, *Campylobacter* spp. and *E. coli* O157:H7 can be transmitted through this route. Thus, local knowledge of possible sources and environmental pathways of animal pathogens to humans should form part of the sanitary inspection.

The assessment framework (Figure 4.4) enables local management to respond to sporadic or limited areas of pollution and thereby upgrade a recreational water's classification provided appropriate and effective management action is taken to control exposure (section 4.6.4). This form of classification (as opposed to a pass/fail

TABLE 4.12. EXAMPLE OF A CLASSIFICATION MATRIX FOR FAECAL POLLUTION OF RECREATIONAL WATER ENVIRONMENTS[3,4]

		Microbial Water Quality Assessment Category (95th percentile intestinal enterococci/100 ml)				
		A ≤40	**B** 41–200	**C** 201–500	**D** >500	**Exceptional circumstances**
Sanitary Inspection Category (susceptibility to faecal influence)	**Very low**	Very good	Very good	Follow up[1]	Follow up[1]	Action
	Low	Very good	Good	Fair	Follow up[1]	Action
	Moderate	Good[2]	Good	Fair	Poor	Action
	High	Good[2]	Fair[2]	Poor	Very poor	Action
	Very high	Follow up[2]	Fair[2]	Poor	Very poor	Action
	Exceptional circumstances	Action				

Notes:

[1] implies non-sewage sources of faecal indicators (e.g., livestock), and this should be verified (section 4.6.2).

[2] indicates possible discontinuous/sporadic contamination (often driven by events such as rainfall). This is most commonly associated with Combined Sewer Overflow (CSO) presence. These results should be investigated further and initial follow-up should include verification of sanitary inspection category and ensuring samples recorded include "event" periods. Confirm analytical results. Review possible analytical errors (see section 4.6.2).

[3] In certain circumstances, there may be a risk of transmission of pathogens associated with more severe health effects through recreational water use. The human health risk depends greatly upon specific (often local) circumstances. Public health authorities should be engaged in the identification and interpretation of such conditions (section 4.6.5).

[4] Exceptional circumstances (see section 4.6.5) relate to known periods of higher risk, such as during an outbreak with a pathogen that may be waterborne, sewer rupture in the recreational water catchment, etc. Under such circumstances, the classification matrix may not fairly represent risk/safety.

approach) therefore provides incentive to local management actions as well as to pollution abatement. It further provides a generic statement of the level of risk and is thereby supportive of informed personal choice. It assists in identifying the principal management and monitoring actions likely to be appropriate.

4.6.1 *Initial classification*

The outcome of the sanitary inspection and the microbial water quality assessment, based on Table 4.12 and Figure 4.4, 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 potential discrepancy between the results of the microbial water quality assessment and the sanitary inspection. If the assessment of spatial variation shows that higher microbial contamination levels are limited to only part of a recreational water environment, separate assessment and management are required.

In cases where multiple sources of contamination exist, the single most significant source is used to determine the susceptibility to faecal influence. Contributions from riverine discharges and bather densities need to be scaled, based on local knowledge of hydrological conditions.

A case study is provided in Box 4.6 to illustrate the approach.

BOX 4.6 CASE STUDY (PART 1)

The following is an example of how to apply the framework guideline approach to a seawater used for body contact recreation. Historical microbiological data for the recreational water were available; therefore, the last 5 years of data (in this case, more than 20 samples per year) were used to provide the microbial water quality assessment.

1 SANITARY INSPECTION CATEGORY

(following criteria described in 4.5.1)

a) Sewage discharges (if present)—based on Table 4.9

		If present:		
Outfalls	**Present? Y / N**	**Type of sewage treatment**	**Type of outfall**	**Category**
Sewage outfalls	Y	primary	effective	low
Combined sewer overflows	N			—
Stormwater	Y		direct	very high

b) Riverine discharges (if present)—based on Table 4.10
Riverine discharges on beach (where river receives sewage discharge)

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

Continued

c) Bather shedding (based on Table 4.11)

Bather density in swimming 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

d) Physical characteristics of the beach
Provide a scale sketch map of the beach 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

2 MICROBIAL WATER QUALITY ASSESSMENT

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

Sample volume = 100 ml
Tested for thermotolerant coliforms 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 index 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
Microbial Water Quality Assessment Category = C

3 COMBINED SANITARY AND MICROBIAL WATER QUALITY ASSESSMENT AND OVERALL CLASSIFICATION

This beach is rated as "poor":
Sanitary Inspection Category—Very low
Microbial Assessment Category—C

		Microbial Water Quality Assessment Category (intestinal enterococci/100 ml)				
		A ≤40	**B** 41–200	**C** 201–500	**D** >500	**Exceptional circumstances**
Sanitary Inspection Category (susceptibility to faecal influence)	Very low	Very good	Very good	Follow up[1]	Follow up[1]	Action
	Low	Very good	Good	Fair	Follow up[1]	
	Moderate	Good[2]	Good	Fair	Poor	
	High	Good[2]	Fair[2]	Poor	Very poor	
	Very high	Follow up[2]	Fair[2]	**Poor**	Very poor	
	Exceptional circumstances	Action				

Notes: See Table 4.12

4.6.2 *Follow-up of initial classification*

Where the sanitary inspection and water quality data inspection result in a potentially incongruent categorization in Table 4.12, further assessment will be required. This could include reassessing the sanitary inspection (i.e., identifying further potential sources in the catchment and assessing their risk) and additional analysis of water quality, with specific consideration given to the sampling protocol and analytical methodology.

Examples of situations that may lead to potentially incongruent assessments include the following:

- analytical errors;
- where the importance of non-point sources is not appreciated in the initial survey;
- where the sampling points are not representative of sewage influence;
- where CSOs are present on the beach but it is not appreciated that they do not discharge during the bathing season;
- where the assessment is based on insufficient or unrepresentative data; and
- where extreme events, whether anthropogenic or natural in origin, arise from damaged infrastructure and/or inappropriate sewage disposal practices, e.g., shipping damage to marine outfalls or connections to surface water of foul drains from domestic and other properties.

Where sanitary inspection indicates low risk but microbial water quality assessment data inspection 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 non-human contamination (e.g., analysis of appropriate biomarkers, surveys of mammal and bird numbers etc.) may be appropriate. Confirmation that contamination is primarily from non-human sources may allow reclassification (see 4.6.4) to a more favourable grading, although care is needed here as risk will depend on the type of non-human pollution as it may still be a source of a number of important pathogens (section 4.6.5). Similarly, where microbial water quality assessment indicates a very low risk that is not supported by the sanitary inspection, consideration should be given to the sampling design, the analytical methodology used and the possibility that the sanitary inspection may have been incomplete.

4.6.3 *Provisional classification*

There will be occasions when there is a pressing need to issue advice on the classification of a recreational water environment, even though the information required in Figure 4.4 for moving to the classification (or reclassification) step is incomplete. Three scenarios may be envisaged:

- where there are no data of any kind available as to the microbial water quality of the water body or its susceptibility to faecal influence (such as new developments);

- where the data available are incomplete, in respect of either the microbial water quality assessment or the sanitary inspection or both; and
- where there is reason to believe that the existing classification no longer accords with changed circumstances, but the data required for completing classification are insufficient.

In these circumstances, it may be necessary to issue a provisional classification (see Box 4.7). When such a step is taken, it should be made clear that the advice is provisional and subject to change. A provisional classification should be time-limited, and there should be a commitment to obtaining the necessary data to follow the steps described in Figure 4.4 to provide a definite classification as soon as possible.

BOX 4.7 EXAMPLE ACTIONS FOR PROVISIONAL CLASSIFICATION

NO HISTORICAL DATA OR ASSESSMENT

Examples of recreational water environments for which no sanitary inspection information and no water quality data are available include a newly used beach or a part of a long beach that becomes "popular."

The first step is to identify the extent of the water body or beachfront requiring classification. Urgent microbial water quality assessment will be required; if the sampling and analytical capacities are insufficient, the most intensively used recreational water area should be selected for initial study.

At the first opportunity and in any event during the "bathing" season, take a minimum of 8–12 samples across the selected transect, ideally at about 50-m intervals (depending upon the length of the beach), but in any case not more than 200 m apart.

At the time of initial sampling, conduct a limited sanitary inspection, for the purpose of identifying possible pollution sources in the immediate vicinity of the area that will require further evaluation. While laboratory results are awaited, the sanitary inspection should be completed as far as possible and arrangements made to obtain maps, plans, information on the sewer 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 these 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 category A or D. For example, if almost all the samples have values over 500 enterococci/100 ml, then the 95th percentile will clearly exceed 500, thus provisionally placing the water in category D. Consequently, 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, then the recreational water should be provisionally classified at the appropriate level.

If the results are not so clear-cut, a second round of sampling will be needed. This should be conducted as soon as possible, providing it is during the "bathing" season.

On the basis of the sanitary inspection and microbial water quality assessment data available after the second round of sampling, an early assessment should be made, and, if judged 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 Figure 4.4 and Table 4.12 as soon as possible.

INCOMPLETE DATA

Where the data available are insufficient, in respect of either the microbial water quality assessment or the sanitary inspection or both, the first step is to review the data carefully to see whether it is possible to reach any provisional conclusions. It may turn out that this is relatively easy to do at the extreme ends of the classification spectrum. For example, a major sewage discharge point in the immediate vicinity of the recreational water area or a set of analytical results with a strong trend to very high or very low values may enable a provisional classification to be made. If it is not possible to make a provisional classification, the review may make it apparent where the key deficiencies in the data lie and so point the way to what additional information is most critically needed.

In the absence of past intestinal enterococci data it may be necessary to make use of historical records relating to another index organism, such as thermotolerant coliforms. The issue of conversion factors that may be applied for that purpose is dealt with in section 4.5.2.

If the data are insufficient to allow any conclusion to be drawn as to the appropriate classification of the recreational water environment, a complete or virtually complete application of the data-gathering process in Figure 4.4 may need to be embarked upon. In the event that it is necessary for beach classification to be urgently undertaken (in the absence of sufficient data), 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, sufficient data need to be collected before completing the reclassification or, as in the above, it will be necessary to carry out a careful review of the existing data to see whether it is possible to reach any provisional conclusions.

If this review shows an incongruity between the sanitary inspection data and the microbial water quality assessment data, steps should be taken, as set out (in section 4.6.2), to understand this. Should both the sanitary inspection data and the microbial water quality data point to a similar change in beach classification, a provisional conclusion should be drawn, but steps should be taken to obtain sufficient data for proper beach classification.

4.6.4 Reclassification, including advisories and upgrading

As water contamination may be triggered by specific and predictable conditions (e.g., rainfall), local management actions can be employed to reduce or prevent exposure at such times. Provided the effectiveness of such actions can be demonstrated, the recreational water environment 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 (e.g., advisories) is subsequently verified during the following bathing season, if the reclassification is not confirmed it will automatically revert to the original classification. This is illustrated, in Box 4.8, by a continuation of the case study introduced in Box 4.6.

BOX 4.8 CASE STUDY (PART 2)

Initial classification (see Box 4.6), on the basis of a sanitary inspection category of 'very high' and a microbial water quality assessment of 'C', was:

'Poor'.

The initial classification, however, appeared to be driven principally by the presence of occasional stormwater overflows. Subsequent investigation found that the stormwater overflow events were predictable and signage was introduced to warn bathers not to swim during rainfall and for up to 2 days following heavy rainfall. The beach was 'posted' whenever heavy rainfall had occurred.

Exclusion of the stormwater overflow changes the sanitary inspection category from 'very high' to 'low', which results in a provisional upgrading of:

'Fair (but unsuitable for 2 days after heavy rain)'.

Monitoring of the recreational water over a bathing season revealed that bathers complied with the notices not to bathe. Water quality sampling showed that after 2 days 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 in the expectation that on completion the advisory can be removed and the beach classified as:

'Good'.

Some of the events triggering water contamination can be measured by simple means, such as rainfall gauges, detectors on stormwater overflows, etc. More sophisticated approaches involving modelling may be appropriate under some circumstances. The real-time prediction of faecal index organism concentrations at recreational compliance points has been achieved using two principal approaches. The first uses background conditions to calibrate a statistical model, typically based on the relationships of multiple predictor variables, such as:

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

The alternative approach is the construction of a nearshore hydrodynamic model linked to a water quality model predicting concentrations of faecal index organisms (Falconer et al., 1998). Both approaches offer potential for real-time prediction of faecal pollution changes for protection of public health through timely management interventions. As such, some of these parameters could be considered for analysis at control points (see Table 4.6). Control points are those points that can be monitored to provide information to management so that management actions can have an impact on risk (section 4.3.3).

4.6.5 Exceptional circumstances

While no general guidance concerning risks during exceptional circumstances is provided here (for instance as guideline values), there is a need to make provisions to enable their identification and management (see Chapter 13 and Table 13.3). Examples could include sewer breaks, extreme floods or rainfall events with a return period of more than five years. Public health authorities should be engaged in the definition of water quality standards or appropriate action triggers relevant to specific circumstances. This will normally require provision for responsibility and authority to act in response to such risks/circumstances.

While interpretation of the public health significance of specific conditions will generally require the participation of the public health authority, initial identification of a potential problem may arise from (human) disease surveillance, authorities responsible for wastewater treatment and management or veterinary authorities. Furthermore, while the public health authorities bear responsibility for assessing public health risk, determining and implementing appropriate actions will require intersectoral action and will also often include local government, facility operators, user groups and so on. Public health authorities may be required to interpret the relevance of specific pathogens or outbreak events, examples of relevance may include:

- *E. coli* O157. This pathogen arises primarily from livestock rearing. It has a low infectious dose, causes a severe dysentery-like illness and may be associated with haemolytic uraemic syndrome. The disease is associated with significant mortality and morbidity. To date, there has been one documented report of transmission of *E. coli* O157 through recreational waters (Ackman et al., 1997). In catchment areas impacted by livestock excreta, there is a potential risk of transmission to humans. The carriage rate among cattle varies from 1 to 15% in the United Kingdom, and higher rates have been reported in the USA (Jones, 1999). Where effluent from dairies or intensive grazing is a significant proportion of the faecal load in recreational waters, public health authorities should be informed.
- Enteric hepatitis viruses (HAV, HEV). Infection with HAV is typically mild when first acquired early in life but is severe when first acquired in adulthood. It is a recognized problem among susceptible travellers to areas of high endemicity. Although there are no documented cases of transmission through swimming, such transmission is biologically plausible.
- Typhoid and paratyphoid (enteric) fevers. *Salmonella typhi* and *S. paratyphi*, the causative agents of typhoid and paratyphoid fevers, respectively, can be transmitted by the waterborne route. *S. typhi* has a low infectious dose. There has been a documented association of *S. paratyphi* transmission with recreational water use (Public Health Laboratory Service, 1959). The only source of the

agents is human excreta; therefore, in areas with outbreaks or high endemicity of the diseases, a risk of transmission exists. The one documented study found no transmission in water containing less than 10 000 total coliforms/100 ml (approximately equivalent to 1000 intestinal enterococci/100 ml).

- Cholera. While the infectious dose for cholera is generally considered high, it is variable, and the causative agent may be excreted in large numbers when an outbreak occurs. The causative bacteria, *Vibrio cholerae*, may also establish itself in local ecosystems in some conditions, and the significance of this for human health is poorly understood. Where *V. cholerae* occurs, the significance of this for human health should be specifically assessed.
- Outbreaks of disease among human populations. When there is an outbreak of certain diseases among a population, there may be a significant increase in the occurrence of the causative agent in the faeces of the affected person and in turn in sewage and sewage-polluted recreational waters. However, in many circumstances, the overall public health risk is modest because the number of infected/excreting persons is a small proportion of the total.

Exceptional circumstances requiring re-evaluation of risk also include those circumstances leading to increased pollution and, by inference, increased risk to bathers. Thus, failure in sewage treatment or fracture of a long sea outfall would imply the need to immediately reassess safety.

Results of microbial water quality testing should be monitored on a "control chart", and deviation from established behaviour should be one trigger for investigation and assessment of public health risk.

4.6.6 Monitoring and auditing

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

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

For recreational water areas where no change to the sanitary inspection category has occurred over several years, the sanitary inspection category was "Very low" or "Low" and the microbial water quality assessment is stable and based on at least 100 samples, microbiological sampling can be reduced to a minimum of five samples per year to ensure that no major changes go unidentified. For beaches 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 ("Moderate" and "High"), a greater annual microbiological sampling programme is recommended (Table 4.13).

TABLE 4.13. RECOMMENDED MONITORING SCHEDULE

Risk category identified by sanitary inspection	Microbial water quality assessment	Sanitary inspection
Very low	Minimum of 5 samples per year	Annual
Low	Minimum of 5 samples per year	Annual
Moderate	Annual low-level sampling 4 samples *x* 5 occasions during swimming season Annual verification of management effectiveness Additional sampling if abnormal results obtained	Annual
High	Annual low-level sampling 4 samples *x* 5 occasions during swimming season Annual verification of management effectiveness Additional sampling if abnormal results obtained	Annual
Very high	Minimum of 5 samples per year	Annual

4.7 Management action

There are two main elements to consider in respect of management actions, classification of recreational water locations and short-term information that reflects changes in conditions. Good-quality public information in near-real time about the recreational water environment, through, for example, public health advisories, is particularly important to enable the public to make informed choices about if and where to use recreational water areas. Long-term management, on the other hand, might also be aimed at encouraging pollution abatement and prevention.

4.7.1 Public health advisories and warnings

Recreational water managers may take steps to identify periods when water quality is poor, issue advisory notices warning the public of increased risk and assess the impact of those advisories in discouraging water contact. This approach has the benefit of protecting public health and, in many circumstances, provides potential both to improve the classification of a location through low-cost measures and to enable safe use of areas for long periods that might otherwise be considered inappropriate for recreational use (see section 4.6.4).

Some locations will consistently have very poor water quality due to the proximity of sewage discharges; others will have intermittently poor water quality due to pollution that may be rare or impossible to predict. Still other sites will have episodic, but possibly predictable, deterioration in water quality, such as that driven by weather conditions, particularly rainfall. In any of these circumstances, local public health agencies may wish to issue an advisory notice or other form of public notification. The level at which an advisory might be issued depends on local circumstances, which include levels and type of endemic illness prevalent in the population and outbreaks or endemic occurrence of potentially serious illness that may be spread by recreational water exposure (see section 4.6.5 and Table 13.3). In cases where locations are known to have consistently very poor microbial water quality, an appropriate management action may be to permanently discourage its use as a recreational water area by, for example, fencing, signposting, moving the location of car parks, bus stops and toilets, and so on (Bartram & Rees, 2000 chapter 9).

4.7.2 Pollution prevention

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

1. Direct point source pollution abatement

Effective outfalls with sufficient length and diffuser discharge depth are designed to ensure a low probability of sewage reaching the designated recreational water environment. Therefore, the premise is to separate the bather from contact with sewage, and, as such, long outfalls can be an effective means of protecting public health. Pre-treatment with milli-screens is considered to be the minimum treatment level.

For nearshore discharges of large urban communities, where effluent may come into contact with recreational water users, tertiary treatment with disinfection will provide the greatest health benefits and a sanitary inspection category of 'very low' (see Table 4.9), although public health risks will vary depending on the operation and reliability of the plant and the effectiveness of disinfection.

2. Intermittent pollution abatement

Runoff via drainage ditches, combined sewer overflows, etc. is predominantly "event-driven" pollution that may affect recreational water areas for relatively short periods after rainfall. Combined sewer and stormwater overflows, which are built into most sewerage systems where the effluent "combines" with rainfall, may present the greater health risk, because water users may be exposed to diluted untreated sewage. Where the sewer does not receive surface water after rainfall, the "uncombined" raw sewage overflows present a direct health risk, contact with which should be avoided.

The best option is to have separate collection systems for sewage and rain/stormwater. Although treatment is an option for combined sewer overflows often the treatment plant cannot cope with the quantity of the sewage, or the effectiveness of the treatment is lowered due to a change in the "quality" of the sewage.

Other pollution abatement alternatives for CSOs include:

- retention tanks that discharge during non-recreational water use periods. These are costly and may be impractical for large urban areas, although examples do exist (e.g., Barcelona);
- transport to locations distant from recreational areas via piped collection systems or effective outfalls; and

- disinfection (ozone, chlorine, peracetic acid or UV), which may be not be effective against all hazards.

The above pollution abatement alternatives usually require major capital expenditures for event-driven pollution episodes and, as such, may not be readily justifiable, especially in developing countries. An alternative adopted is the development and application of management programmes that minimize recreational use during event-driven pollution episodes.

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

3. *Catchment pollution abatement*

Upstream diffuse pollution, point source discharges, pathogen accumulation and remobilization from stream sediments and riverine discharges to coastal recreational areas may be significant pollution sources that present a challenge to pollution abatement (Kay et al., 1999). Major sources of pollution should be identified and a catchment-wide pollution abatement programme developed. Multi-agency and interdisciplinary cooperation among health and environmental control agencies, local authorities, users, polluters, etc. assist in effective programme development (integrated management approaches are outlined in 1.7.2). The role of the agricultural sector in generation and remediation of pollution loadings is often crucial.

4.7.3 Enforcement of regulatory compliance

Regulatory compliance enforcement has limitations as the principal tool for the protection and improvement of microbial quality of recreational waters, although the power of closure or threat of closure may be a powerful driver for improvement. The two principal limitations concern responsibility for cause of failure and the nature of intervention.

Where a recreational water use location fails a regulatory standard, it may be difficult to define responsibility for failure. In many locations, a number of sources will contribute to overall pollution, and the relative importance of different sources may vary greatly with time. Rivers often function as major sources of microbial loads and will in turn be affected greatly by, for instance, rainfall. They may themselves be recipients of multiple pollution loads. Approaches to regulatory compliance enforcement that depend upon identifying and requiring change of a single discharge/pollution source "responsible" for failure may therefore be problematic.

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 on detection of conditions 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, with measures to be taken in order to improvement classification, including pollution control.

4.8 References

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CHAPTER 5

Free-living microorganisms

In addition to microorganisms introduced to recreational waters through human or animal faecal contamination (see chapter 4), a number of pathogenic microorganisms are indigenous to such areas or, (like the leptospires) once introduced are capable of colonizing the environment. This chapter describes the principal free-living microorganisms of concern; the diseases that they may cause associated with recreational water use; and potential control measures.

5.1 Human pathogenic Vibrio species

Vibrio species are motile, non-spore-forming, slightly curved Gram-negative rods with a single polar flagellum. They are both aerobic and facultatively anaerobic. Vibrios require, or their growth is stimulated by, sodium chloride, and they are capable of respiratory and fermentative metabolism, with only a single species (*V. furnissii*) producing gas. All human pathogenic *Vibrio* species except *V. metschnikovii* reduce nitrate and are oxidase positive.

Substantial evidence has been provided showing that *Vibrio* species are natural inhabitants of marine aquatic environments in both temperate and tropical regions, with most infections acquired by exposure to such environments or to foods derived from them (Kelly et al., 1991; Oliver & Kaper, 1997). *Vibrio* species have been isolated from a variety of environmental samples, including water, sediment, plankton, shellfish and finfish. Several studies suggest that the occurrence of vibrios does not correlate with the occurrence of the traditionally used faecal index organisms, although a positive correlation may be found in waters receiving human wastes from disease outbreaks (mainly cholera). There appears to be a positive correlation between water temperature and the numbers of human pathogenic vibrios isolated, as well as the number of reported infections. Seasonality is especially noted for *V. vulnificus* and *V. parahaemolyticus* (Oliver & Kaper, 1997). *Vibrio* species have been isolated in waters showing a broad range of salinities and varying pH values. *V. cholerae* and *V. mimicus* are the only species found in fresh water. Thus, due to the ubiquitous nature of *Vibrio* species in the aquatic environment, the presence of *Vibrio* species in bathing water cannot be controlled by water quality control measures such as wastewater treatment and disinfection. Human carriers and shedding appear to be of only limited importance in the epidemiology of *Vibrio* infections associated with recreational water use.

While there exists considerable variation in the severity of the various *Vibrio*-associated diseases, the most severely ill patients generally suffer from pre-existing illnesses, with chronic liver disease being one of the most common. An exception to this generalization is *V. cholerae* serogroups O1 and O139, the causes of cholera, which can readily cause disease in non-compromised individuals.

The *Vibrio* species of medical importance grow well on common media, including blood, chocolate and Mueller-Hinton agars. A more thorough search for *Vibrio* species can be done by culture on a selective-differential plating medium, such as thiosulfate–citrate–bile salts–sucrose (TCBS) medium. However, not all *Vibrio* species of medical importance grow well on TCBS agar (Kelly et al., 1991). In fact, different brands of TCBS can select different species of vibrios and be less selective for the target microorganisms. Increased yields of vibrios from environmental samples may be obtained by enrichment in alkaline peptone water before subculture on plating media. Since *Vibrio* species vary considerably in pathogenicity and epidemiological significance, isolates should be identified to species level. Such identification should be performed by reference laboratories. Although commercial systems for the identification of *Vibrio* species have improved, misidentifications remain a problem.

Currently, 12 *Vibrio* species are known to cause or to be associated with human infections: *V. alginolyticus*, *V. carchariae*, *V. cholerae*, *V. cincinnatiensis*, *V. damsela*, *V. fluvialis*, *V. furnissii*, *V. hollisae*, *V. metschnikovii*, *V. mimicus*, *V. parahaemolyticus* and *V. vulnificus* (Kelly et al., 1991). The infections can be classified as intestinal or extraintestinal, although this division is not absolute (Table 5.1).

Studies of the infectious dose for vibrios able to cause gastrointestinal disease have been carried out mainly for *V. cholerae*, where the infectious dose appears high. For *V. cholerae*, 10^6 organisms or more are needed to cause cholera. In hypochlorhydric persons, the infectious dose is reduced to 10^4–10^5 organisms (Oliver & Kaper, 1997). Thus, it is unlikely that persons bathing or involved in other recreational water

TABLE 5.1. *VIBRIO* SPECIES THAT MAY BE FOUND IN HUMAN CLINICAL SPECIMENS[a]

	Occurrence in human clinical specimens[b]	
Species	**Intestinal**	**Extraintestinal**
V. alginolyticus	–	++
V. carchariae	–	+
V. cholerae 01	++++	+
Non-01	++	+
V. cincinnatiensis	–	++
V. damsela	–	+
V. fluvialis	++	–
V. furnissii	++	–
V. hollisae	++	–
V. metschnikovii	+	+
V. mimicus	++	+
V. parahaemolyticus	++++	+
V. vulnificus	+	+++

[a] Modified from Kelly et al. (1991)

[b] The symbols +, ++, +++ and ++++ give the relative frequency of each organism in specimens from implicated infections; – = not found.

activities would ingest vibrios in numbers high enough to cause gastrointestinal disease in the absence of extreme contamination. However, the risk of extraintestinal infections associated with human pathogenic *Vibrio* species, especially wound and ear infections, during recreational activities in water is of health importance, although the infectious doses for such infections are unknown.

5.1.1 V. alginolyticus

V. alginolyticus is very common in the marine environment. The organism does not cause diarrhoea but may cause soft tissue infections following exposure to seawater (Kelly et al., 1991). Ear, wound and eye infections have been reported most often. It appears that a majority of patients with otitis associated with *V. alginolyticus* have predisposing conditions, including chronic otitis media and rupture or tubulation of the tympanic membrane. Infections are usually self-limiting and of moderate severity and short duration, and antibiotic treatment is only occasionally necessary.

5.1.2 V. cholerae

Among the vibrios, special attention has focused on the identity of those causing cholera. *V. cholerae* has been divided into more than 150 serological types on the basis of the O or somatic antigens.

Numerous outbreaks of cholera involving drinking-water and foods have been documented. Although *V. cholerae* O1 and O139 are occasionally isolated from the aquatic environment, especially in areas with cholera outbreaks, no confirmed cholera cases caused by activities in recreational waters, including bathing, seem to have been reported. Thus, probably because of the high infectious dose required to cause cholera, it appears that the isolation of *V. cholerae* O1 and O139 from marine waters represents a very low health risk to persons bathing or participating in other recreational activities in such waters. Other non-O1 serotypes cause gastroenteritis, with the range of symptoms found to vary, but common features include diarrhoea and occasional vomiting with abdominal cramps.

Although isolates have been recovered from wounds, ears and a variety of other sites, the clinical significance of *V. cholerae* as a cause of extraintestinal infections is uncertain, as other potential pathogens are often also isolated.

5.1.3 V. parahaemolyticus

V. parahaemolyticus is an agent of food poisoning, associated with the consumption of raw or insufficiently cooked seafood. It has also been associated with pneumonia (Yu & Uy-Yu, 1984), resulting from inhalation of contaminated aerosol, and wound infection. *V. parahaemolyticus* has been associated with severe life-threatening infections these, however, were subsequently found to be due to *V. vulnificus* (Kelly et al., 1991).

5.1.4 V. vulnificus

V. vulnificus is a foodborne pathogen, causing a rapidly fatal infection in persons with underlying liver diseases. Generally implicated is the consumption of raw or under-cooked oysters, although raw clams, octopus and other marine fish and shellfish have also been associated with the disease. In addition to being foodborne, *V. vulnificus* causes wound infections following entry into a skin lesion. Such infections are almost always associated with seawater and/or shellfish. Puncture wounds generally result from utensils used to clean shellfish or from the hard shell or fins of shellfish and fish. Symptoms, which develop after about 16 h, include intense pain, redness, swelling and rapidly developing tissue destruction. Although the pathogenesis of these infections has yet to be elucidated, it is likely that one or more of the several exoenzymes (e.g., collagenase, protease, elastase, phospholipase, cytotoxic haemolysin) produced by this species are essential for its ability to invade and cause tissue destruction. Surgical removal of tissue, skin grafting and even amputation are generally required. Mortality rates average 20–25%. Wound infections with *V. vulnificus* typically occur in healthy persons and remain localized, although the bacterium may become systemic in people with chronic liver disease, and this carries a high fatality rate. In the past, several reports of severe, life-threatening infections associated with *V. parahaemolyticus* were described; however, subsequent examination of the isolates from these cases has indicated that they were actually *V. vulnificus* (Kelly et al., 1991).

5.2 Aeromonas species

Aeromonas species are Gram-negative rod-shaped or coccoid cells that are facultative anaerobes and generally motile by a single polar flagellum (although non-motile species exist), which are currently assigned to the family Aeromonadaceae (Altwegg, 1999). They utilise carbohydrates with production of acid and gas, and the metabolism of glucose is both fermentative and respiratory. They are oxidase and catalase positive and reduce nitrates to nitrites.

Aeromonas spp. are considered autochthonous inhabitants of aquatic environments and are ubiquitous in surface fresh and marine waters, with high numbers occurring during the warmer months of the year (Ashbolt et al., 1995; Holmes et al., 1996). Clinical isolation of these microbes presents the same seasonal distribution (Joseph, 1996). Numbers may be high in both polluted and unpolluted habitats with densities ranging from <1 to 1000 cells per ml (Holmes et al., 1996; Borrell et al., 1998; Altwegg, 1999). A significant correlation has been reported between aeromonads and the trophic state of freshwater (Rippey & Cabelli, 1989; Ashbolt et al., 1995). Other authors, however, were unable to predict the trophic status of several lakes in relation to these microorganisms (Rhodes & Kator, 1994). Sewage can also contain elevated numbers (10^6–10^8 cells per ml) of aeromonads (Ashbolt et al. 1995; Holmes et al., 1996). In marine bathing waters they can be abundant and their presence is supported by organic matter coming from the land (Alucino et al., 2001). Study of *Aeromonas* spp. virulence factors (Chopra & Houston, 1999; Janda, 2001) in isolates recovered from bathing waters indicates the presence of potentially virulent strains (Ashbolt et al., 1995; Kingombe et al., 1999; Sechi et al., 2002; Soler et al., 2002).

The taxonomy of the genus is considered complex and has evolved rapidly since 1987 with the addition of nine new species. Presently, it includes fifteen accepted species (Altwegg, 1999). As a consequence of this difficult taxonomy, studies of environmental and clinical aeromonads have generally been limited to three species; A*eromonas hydrophila*, *Aeromonas sobria* and *Aeromonas caviae*. According to present taxonomy, however, strains under these names may belong to other species. The term *A. hydrophila* has, for example, frequently been used indistinctly to include all motile, mesophilic aeromonads, which comprise several named species (Carnahan & Altwegg 1996). The reason for such simplification is that most commercial identification systems tend to identify most of the strains as belonging to this species. This has led to an overestimation of the clinical and environmental relevance of this species and has hampered the establishment of the true incidence of the other species. When reliable identification methods are applied the most prevalent clinical species are *A. caviae, A. veronii* (correct terminology for the clinical strains referred to as *A. sobria*) and *A. hydrophila* accounting for more than 85% of all clinical isolates (Kühn et al., 1997; Janda & Abbott, 1998; Figueras et al., 2000a,b). These species have also been found to be prevalent in recreational waters (Borrell et al., 1998).

Aeromonas has been found to have a role in a number of human illnesses (Janda & Abbott, 1998). Its association with gastroenteritis has been seen both in industrialised countries and developing countries worldwide (Joseph, 1996; Janda & Abbott, 1998; Sixl et al., 1999). *Aeromonas*-associated diarrhoea is normally self-limiting and in many cases does not lead to a microbiological study of the faeces. This lack of investigation could explain why relatively few outbreaks have been identified (Montiel & Harf-Montiel, 1997). It affects mostly children under five years of age and immunocompromised adults. These are also the population groups most frequently associated with aeromonad-related septicaemia (Janda & Abbott, 1996, 1998). Underlying diseases (cancer, hepatobiliary disease and diabetes) play a major role in the acquisition and outcome of the diseases produced by *Aeromonas* (Ko & Chuang, 1995; Janda & Abbott, 1998). Although there are exceptions, *Aeromonas* sepsis normally arises secondarily to gastroenteritis or wound infections and is associated with high (30–85%) mortality rates (Janda & Abbott, 1996, 1998; Altwegg, 1999; Ko et al., 2000). The main risk of acquiring *Aeromonas*-associated infections is by water contact through open wounds. The consumption of contaminated water or food may be important (Bloom & Bottone, 1990; Joseph et al., 1991; Altwegg et al., 1991; Voss et al., 1992; Kelly et al., 1993; Krovacek et al., 1995). Cases of wound infections in healthy people associated with recreational-water have been described (Joseph et al., 1991; Voss et al., 1992; Altwegg, 1999) as have cases of pneumonia following aspiration of contaminated water (Goçalves et al., 1992; Janda & Abbott, 1998).

5.3 Free-living amoebae

Free-living amoebae are unicellular protozoa common to most soil and aquatic environments (Page, 1988). Of the many hundreds of species of free-living amoebae, only members of the genus *Acanthamoeba*, *Naegleria fowleri* and *Balamuthia mandrillaris* are known to infect humans, often with fatal consequences.

5.3.1 Acanthamoeba

Acanthamoeba is a genus of environmental free-living amoebae found in most soil and water habitats (Page, 1988). The organism can infect a variety of mammals, including humans, producing severe and often fatal consequences. The genus contains numerous species, of which *A. polyphaga*, *A. castellanii* and *A. culbertsoni* have been identified most frequently as causing human disease (Martinez, 1985; Ma et al., 1990; Kilvington & White, 1994).

Acanthamoeba is characterized by a feeding and replicating trophozoite that, under adverse conditions, can form a dormant cyst stage (Page, 1988). Trophozoites are 25–40 µm in length, depending on the species, and show numerous needle-like projections from the trophozoite body, termed acanthapodia. A central contractile vacuole is present in the trophozoite cytoplasm and is required for osmotic regulation. Cysts range in length from approximately 15 to 28 µm, depending on the species, and are double walled.

The resistance of *Acanthamoeba* cysts to extremes of temperature, disinfection and desiccation accounts for the almost ubiquitous presence of the organism in the environment (Martinez, 1985; Page, 1988; Kilvington & White, 1994). *Acanthamoeba* have been isolated from natural and artificial waters, chlorinated swimming pools and the atmosphere.

Acanthamoeba is an aerobic organism and as such cannot exist as the trophozoite stage in environments with low oxygen content. However, *Acanthamoeba* cysts have been isolated from anaerobic material such as faeces and sewage (Daggett et al., 1982; Martinez, 1985). The trophozoites are killed by saline concentrations of >1%, although the more environmentally robust cysts have been isolated from marine environments (Sawyer et al., 1982).

Acanthamoeba numbers in freshwater habitats vary according to the temperature of the water (either from seasonal variation or through thermal enrichment from industrial processes), availability of a bacterial food source and, possibly, the extent of human activity associated with the water (Daggett et al., 1982; Martinez, 1985; Kilvington & White, 1994). However, detailed ecological surveys have not been conducted. *Acanthamoeba* cysts have been isolated in significant numbers from marine sites, particularly those associated with sewage and waste effluent outlets.

Certain species of *Acanthamoeba* are pathogenic to humans and cause two clinically distinct diseases: granulomatous amoebic encephalitis (GAE) and inflammation of the cornea (keratitis) (Ma et al., 1990; Martinez, 1991; Kilvington & White, 1994). The taxonomic classification of *Acanthamoeba* is derived from microscopic observations of the trophozoite and cyst forms (Page, 1988). This is a subjective approach, and molecular typing methods have demonstrated that *Acanthamoeba* is a genetically complex group that correlates poorly with species identification based on morphological criteria (Kilvington et al., 1991a; Gast & Byers, 1995). As a consequence, the precise identity of the *Acanthamoeba* species/strains causing human infection and their possible environmental sources are unknown. However, *A. polyphaga* and *A. castellanii* are most frequently reported as causing keratitis, and *A. culbertsoni* is most frequently reported as causing GAE (Kilvington et al., 1991a; Gast & Byers, 1995).

GAE is a chronic disease of the immunosuppressed (as a result of chemotherapy or drug or alcoholic abuse) host (Martinez, 1985, 1991; Ma et al., 1990). Cases of GAE in patients with acquired immunodeficiency syndrome (AIDS) have also been reported. GAE is subacute or chronic and invariably fatal. Symptoms include fever, headache, seizures, meningitis and visual abnormalities. GAE is extremely rare, with only 60 cases reported worldwide. The route of infection in GAE is unclear, although invasion of the brain may result from the blood following a primary infection elsewhere in the body, possibly the skin or lungs (Martinez, 1985, 1991). The precise source of such infections is unknown because of the almost ubiquitous presence of *Acanthamoeba* in the environment.

Acanthamoeba keratitis affects previously healthy persons and is a severe and potentially blinding infection of the cornea (Ma et al., 1990; Kilvington & White, 1994). In the untreated state, acanthamoeba keratitis can lead to permanent blindness. Although only one eye is usually affected, cases of bilateral infection have been reported. The disease is characterized by intense pain and ring-shaped infiltrates in the corneal stroma. Contact lens wearers are most at risk from the infection and account for approximately 90% of reported cases (Kilvington & White, 1994). Poor contact lens hygiene practices (notably ignoring recommended cleaning and disinfection procedures and rinsing or storing of lenses in tap water or non-sterile saline solutions) are recognized risk factors, although the wearing of contact lenses while swimming or participating in other water sports may also be a risk factor. In non-contact lens related keratitis, infection arises from trauma to the eye and contamination with environmental matter such as soil and water (Sharma et al., 1990).

5.3.2 Naegleria fowleri

Naegleria fowleri is a free-living amoeba found in thermal freshwater habitats worldwide. The organism causes fatal primary amoebic meningoencephalitis (PAM) in humans. Infection usually results from swimming in contaminated water (John, 1982; Martinez, 1985; Warhurst, 1985).

N. fowleri is found in thermal aquatic environments and 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 by the excysted trophozoites (Warhurst, 1985). *N. fowleri* has been isolated from both natural and artificial thermally enriched habitats, such as natural hot springs, freshwater lakes, domestic water supplies, chlorinated swimming pools, water cooling towers and effluent from industrial processes (Martinez, 1985). *N. fowleri* has also been isolated from water cooling circuits of electricity power stations and thermal effluents from industrial processes in Belgium, Czechoslovakia, France, the USA and the United Kingdom (De Jonckheere, 1987; Kilvington & Beeching, 1997). In the latter study, *N. fowleri* was also isolated upstream and downstream of the river supplying the power station (Kilvington & Beeching, 1997). Also, in Belgium, *N. fowleri* has been isolated from a fish farm exploiting thermal water from a nuclear power plant (De Jonckheere, 1987). Such ecological surveys have indicated that *N. fowleri* is more likely to predominate in artificial thermal habitats compared with natural environments such as hot springs, where other, non-pathogenic, thermophilic *Naegleria* species predominate (Kilvington et al., 1991b; Kilvington & Beeching, 1997).

Primary amoebic meningoencephalitis results from the instillation of *N. fowleri* into the nasal passages, usually while swimming. Young males are most at risk from infection, probably because of their more vigorous swimming habits. From the nostrils, the organism invades the nasal epithelium and migrates along the olfactory lobes, via the cribriform plate, to infect the brain and meninges. The infectious dose of *N. fowleri* for humans is not known. PAM is usually fatal, with death occurring in 3–10 days after exposure.

Since PAM was first recognized in 1965, several hundred cases have been reported worldwide. Clustering of cases can occur when a single site is the source of infection. In Usti, Czechoslovakia, 16 cases were associated with a public swimming pool (Cerva & Novak, 1968). The source of the contamination was eventually traced to a cavity behind a false wall used to shorten the pool length. The pool took water from a local river, which was the likely source of the organism.

Cases of PAM have been reported from Belgium and Czechoslovakia in people swimming in warm effluent water from industrial processes (De Jonckheere, 1987). In south-western Australia, infections have been associated with the reticulated mains supply water. In this region, water is supplied to remote localities via over-ground steel pipes. Solar heating of the water in the system enabled *N. fowleri* to proliferate and resulted in approximately 20 cases of PAM. The installation of chlorifiers at regular intervals along the pipelines and regular monitoring of the supply eliminated the problem (Robinson et al., 1996).

One confirmed case of PAM occurred in Bath Spa, England, in 1978. The victim was a young girl who swam in a public bathing pool fed with water from the historic thermal springs that rise naturally in the City (Cain et al., 1981). Subsequent analysis confirmed the thermal springs to be the source of the infection (Kilvington et al., 1991b).

5.3.3 Balamuthia mandrillaris

In 1990, Visvesvara and colleagues described cases of fatal encephalitis in humans and other primates due to a previously undescribed free-living amoeba. By morphological appearance, the amoebae resembled members of the genus *Leptomyxa*; on closer examination, however, they were found to be sufficiently distinct to be described as a new genus and species, *Balamuthia mandrillaris* (Visvesvara et al., 1993). Using antiserum to the organism, the investigators were able to demonstrate that certain cases of GAE attributed to *Acanthamoeba* were in fact caused by *B. mandrillaris*.

Unlike *N. fowleri* and *Acanthamoeba*, *B. mandrillaris* does not grow on the standard medium for isolating free-living amoebae, plain agar seeded with the bacterium *Escherichia coli* (Page, 1988). *B. mandrillaris* has been cultured from only a few cases of infection using mammalian tissue culture cell lines (Visvesvara et al., 1990, 1993). As a consequence of the difficulties in growing the organism, there have been no reports of the isolation of *B. mandrillaris* from water or other environmental samples.

Like *Acanthamoeba* GAE, *B. mandrillaris* encephalitis is largely a disease of the immunocompromised host and infects either sex and any age (Visvesvara et al., 1990, 1993). However, cases are being recognized in persons with no underlying immunosuppression and with no history of contact or swimming in water (Martinez & Visvesvara, 2001). The clinical course of the disease in humans ranges from 14 days to 6 months, with a mean of 75 days. Infection is invariably fatal. Clinical symptoms and histopathological findings are similar to those seen in GAE, and cysts are also found in the tissues. Approximately 85 cases of *B. mandrillaris* encephalitis have been described worldwide, with some 50% coming from the USA. At least 10 cases have occurred in patients with human immunodeficiency virus (HIV). Other cases have been identified from Argentina, Australia, Canada, Czechoslovakia, Japan, Mexico and Peru (Visvesvara et al., 1996; Martinez & Visvesvara, 2001).

5.4 Leptospira species

Leptospires are motile spirochaete (helically coiled) bacteria. Traditionally, the genus *Leptospira* consists of two species, the pathogenic *L. interrogans* sensu lato and the saprophytic *L. biflexa* sensu lato. Serological tests within each species revealed many antigenic variations and, on this basis, leptospires are classified as serovars. In addition, a classification system based on DNA relatedness is used (Brenner et al., 1999). The current species determination is based on this principle. The serological and genetic taxonomies are two different systems with only little correlation (Brenner et al., 1999). Free-living strains are ubiquitous in the environment (Faine et al., 1999); the pathogenic strains, however, live in the kidneys of animal hosts.

5.4.1 L. interrogans *sensu lato*

Leptospires live in the proximal renal tubules of the kidneys of carrier animals (including rats, cows and pigs) and are excreted in the urine, which can then contaminate surface waters (ponds, lakes, streams, rivers), groundwater soil and mud. Humans and animals (humans are always incidental hosts) become infected either directly through contact with infected urine or indirectly via contaminated fresh water or soil. Virulent leptospires gain entry to the body through cuts and abrasions of the skin and through the mucosal surfaces of the mouth, nose and conjunctiva. In cases due to exposure to recreational water, the incubation period seems to vary between 2 and 30 days but generally is between 7 and 14 days (Christie, 1974).

Diseases caused by *Leptospira interrogans* sensu lato have been given a variety of names, including swineherd's disease, Stuttgart disease and Weil's syndrome, but collectively all of these infections are termed leptospirosis. The clinical manifestations of leptospirosis vary considerably in form and intensity, ranging from a mild flu-like illness to a severe and potentially fatal form of the disease, characterized by liver and kidney failure and haemorrhages (Weil's syndrome). Severity is related to the infecting serovar as well as host characteristics, such as age and underlying health and nutritional status. Specific serovars are often associated with certain hosts. For example, serovar hardjo is associated with cattle; serovar pomona is associated with pigs, cattle and rodents; and serovars icterohaemorrhagiae, copenhageni, bataviae, autumnalis, australis and javanica are associated with rats and small rodents.

Due to the non-specific presentation of leptospirosis and its resemblance to many other diseases, there is a worldwide underdiagnosis of the disease, with mild cases probably being dismissed as flu and severe cases often confused with other diseases. Additionally, serological surveys suggest that subclinical and inapparent infections are common (Faine et al., 1999). As conclusive diagnosis cannot be made without laboratory confirmation of clinical samples, case determination may be dependent upon local facilities and expertise (Faine et al., 1999).

Leptospirosis is often considered to be an occupational disease related to proximity to animals or contaminated water. In developed countries, however, cases related to occupation seem to be on the decrease, while those related to recreation are increasing (Sandford, 1986; Waitkins, 1986; CDC, 1998; Kirsche, 2001) possibly reflecting increases in leisure time and the increasing trend of adventure or wilderness activities in the tropics and subtropics.

Compared with many other pathogens, leptospires have a comparatively low resistance to adverse chemical and physical conditions. They are seldom found in water of below pH 6.8, and they cannot tolerate drying or exposure to direct sunlight. Their survival in polluted water and seawater is poor (Noguchi, 1918; Alston & Broom, 1958). However, in the right circumstances, around neutral pH and when moderate temperatures and oxygen supersaturated conditions exist, leptospires are still detectable for up to about six months (Alston & Broom, 1958). It has been suggested that pathogenic leptospires may grow and multiply under certain environmental conditions, and large numbers (far in excess of what would be expected from contamination) have been found in some fast-flowing rivers (Alexander et al., 1975; Baker, 1965; Baker & Baker, 1964).

5.5 Guideline values

Evidence suggests that although infection with free-living microorganisms or pathogenic leptospires via recreational water use may be life-threatening, the incidence of such infection is very low and, in many cases, is limited to specific areas. As such, no specific guideline values have been recommended. Authorities should be aware of the potential hazards posed by these organisms and act accordingly.

5.6 Risk assessment and control measures

Given the nature of the microorganisms outlined in this chapter, assessment of the likely local hazard (e.g., the likelihood of thermal warming of fresh waters) and education of water users and health professionals will be important control measures.

5.6.1 Vibrios

Although human pathogenic *Vibrio* species are ubiquitous in marine waters, their presence represents only a minor risk of gastrointestinal disease to people bathing or involved in other recreational activities in the water. However, potentially life-threatening extraintestinal infections with *Vibrio* species may occur, and physicians should consider this diagnosis when people who have had recent contact with seawater present a wound infection or an acute ear infection.

5.6.2 Aeromonads

Aeromonas are ubiquitous both in freshwater and seawater recreational areas and therefore there is a high risk of exposure. The infective dose that produced colonisation in a single study in volunteers and in a 28-year-old laboratory worker after accidental ingestion was, in both cases, 10^9 cells (Morgan et al., 1985; Carnahan et al., 1991). The health significance of *Aeromonas* in consumed water is discussed in WHO (2002). However, the rapid onset of cellulitis in the setting of soft-tissue trauma with a history of water exposure should alert clinicians of the possible infection by *Aeromonas* (Gold & Salit, 1993). The presence of Gram-negative bacilli (after Gram-staining of purulent exudates) in a post-traumatic wound exposed to water is a sufficient basis to recommend empirical therapy (Gold & Salit, 1993).

Questioning patients about bathing water contact in *Aeromonas*-diarrhoeal processes may help to establish the epidemiological risk of acquiring these microbes during recreational activities. The use of typing techniques such as the ones employed in several studies (Kühn et al., 1997; Davin-Regli et al., 1998; Demarta et al., 2000; Martinez-Murcia et al., 2000; Bonadonna et al., 2002; Soler et al., 2003) may help to determine the epidemiological links between environmental and clinical strains.

5.6.3 Free-living amoebae

Acanthamoeba are common in soil and water habitats and occur in coastal and fresh waters. However, the incidence of human infections from this opportunistic pathogen is extremely low. Detailed risk assessments related to *Acanthamoeba* in coastal and freshwater bathing sites have not been undertaken and the possibility of acquiring an infection from such sites cannot be discounted. As such, immunocompromised individuals should be advised of the possible risk of acquiring GAE so that they can make an informed choice about swimming or immersion in natural waters.

Cases of PAM have been associated with freshwater lakes in the USA that receive solar warming in the summer months (Martinez, 1985), although Wellings et al. (1977) have estimated that only one case of PAM occurs for every 2.6 million exposures to water containing *N. fowleri* in Florida, USA. In some European countries, it is possible that solar heating could provide sufficient warming in the summer months to favour the proliferation of *N. fowleri*. However, no studies on the presence of *N. fowleri* at such sites and the potential risk to human health from recreational use of such water bodies have been conducted.

Studies have demonstrated that thermal discharges from electricity power stations in England and France can result in *N. fowleri* being present in rivers (Kilvington & Beeching, 1997). Cases of PAM have been reported from Belgium and Czechoslovakia in people swimming in warm effluent water from industrial processes (De Jonckheere, 1987). Accordingly, the direct use of such water for recreational purposes should be carefully evaluated. Surveys should also be undertaken to determine the presence and number of *N. fowleri* in rivers and lakes receiving thermally polluted water from industrial processes to enable risk assessments to be made from such sites.

B. mandrillaris encephalitis is a newly recognized disease, the incidence of which is still unknown. Infections would appear to be rare and, therefore, the risk to human health might be considered as minimal. Because the organism cannot be grown on standard media used for isolating other pathogenic free-living amoebae, the environmental habitat and possible sources of infection are undefined; as such, it is not possible to assess the risk from recreational water use at this point.

5.6.4 Leptospires

It is impractical to completely eradicate potential sources of leptospiral infection. Since the incidence of leptospirosis (certainly of the severe form) is relatively low, sensible precautionary measures for high-risk groups using freshwater environments are the best means of achieving the greatest protection. Public information highlighting sensible precautions, such as covering cuts and scratches with waterproof plasters or bandages prior to immersion, showering after water immersion and the provision of litter control and other measures to minimize the rodent population can be effective.

5.7 References

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CHAPTER 6
Microbial aspects of beach sand quality

Beaches represent the unconsolidated sediment that lies at the junction between water (oceans, lakes and rivers) and land and are usually composed of sand, mud or pebbles. From a recreational viewpoint, sand beaches are sought after. Especially in higher latitudes, a significant percentage of time is spent on the beach itself rather than in the water.

Microorganisms are a significant component of beach sand. Bacteria, fungi, parasites and viruses have all been isolated from beach sand. A number of genera and species that may be encountered through contact with sand are potential pathogens. Accordingly, concern has been expressed that beach sand or similar materials may act as reservoirs or vectors of infection (Nestor et al., 1984; Roses Codinachs et al., 1988; Mendes et al., 1997), although transmission by this route has not been demonstrated in epidemiological studies.

In this chapter, the incidence, dispersion and fate of microorganisms in beach sand are reviewed, as are potential management actions.

6.1 Microorganisms in beach sand

6.1.1 Faecal index microorganisms

Faecal index organisms are non-pathogenic microorganisms used to indicate the degree of faecal contamination. They are generally present in far greater numbers than pathogenic microorganisms and are easy to isolate, identify and enumerate. Faecal index organisms include coliforms (total coliforms, thermotolerant coliforms and *Escherichia coli*), intestinal enterococci (see Box 4.1), bacteriophages and clostridia.

The presence of total coliforms, thermotolerant coliforms, *E. coli* and intestinal enterococci in beach sand and the relationship between their counts in beach sand and their counts in adjacent waters have comprised a significant area of research, with apparently contradictory results. Total coliforms, thermotolerant coliforms and intestinal enterococci were isolated from surface sand samples in Marseilles and Agde, France. Counts of intestinal enterococci, probably originating from animals, were higher than counts of other indices (Conseil Supérieur d'Hygiène Publique de France, 1990). High numbers of thermotolerant coliforms and intestinal enterococci were isolated in beach sand along Taranto coastal waters in Italy (Signorile et al., 1992). Lower numbers of faecal index organisms were recorded in swimming areas in Tel Aviv, Israel, and in Barcelona, Spain (Figueras et al., 1992; Ghinsberg et al., 1994).

Low numbers of bacterial indices of faecal pollution were recovered in dry sand from a beach along the Thyrrenian coast (Italy). *E. coli* was recovered in 61% of the samples and enterococci outnumbered coliforms (Bonadonna et al., 2002).

In an Italian study, a significant correlation was found between contamination of beaches and contamination of adjacent seawaters, although the sand generally had higher bacterial counts than the water (Aulicino et al., 1985). A similar tendency was found at Barcelona beaches; in contrast to the Italian study, however, the level of contamination was not significantly different between sand and seawater (Roses Codinachs et al., 1988).

Papadakis et al. (1997) found no correlation between the indices of faecal pollution counted on the wet part of the beach and *Staphylococcus aureus* counts or the presence of fungi. A statistically significant correlation was detected between yeasts and molds, *E. coli* and enterococci, enterococci and spores of sulfite-reducing *Clostridium* and between clostridial spores and staphylococci in an investigation on wet and dry sands in Italy (Bonadonna et al., 2002). In an epidemiological study carried out on two beaches in Malaga, Spain, faecal index microorganisms, especially coliphages, were highly significantly correlated with dermatophyte fungi (microscopic fungi that grow on skin and mucous membranes) on one of the beaches. Only *E. coli* showed a significant correlation with *Candida albicans* (a pathogenic fungus). At the other beach, intestinal enterococci showed the best correlation with dermatophyte fungi. Again, coliphages were the indices that best correlated with *C. albicans* (Borrego et al., 1991).

6.1.2 Staphylococcus

According to some studies, *Staphylococcus* spp. predominate over other flora in the sand (Dowidart & Abdel-Monem, 1990). Of a total of 85 strains of Gram-positive cocci isolated from beach water and sand located at two popular beaches in Chile, 31% were classified as *S. epidermidis*, 9% as *S. haemolyticus*, 24% as *S. aureus* and 36% as *Staphylococcus* spp. (Prado et al., 1994).

The origin of *Staphylococcus* in beach sand is attributed to human activity. Its occurrence has been found to correlate with the number of swimmers on the beach, and the counts of *S. aureus* were found to correlate with the presence of yeasts of human origin in sand samples (Papadakis et al., 1997). Higher counts of *S. aureus* were recovered from the sand and water in summer, when there was a higher density of swimmers on the beach, than in winter. Also, higher counts of *S. aureus* were recovered from sand than from water samples (Ghinsberg et al., 1994; Papadakis et al., 1997).

Investigations carried out along the Tyrrhenian coast (Italy) showed higher densities of *Staphylococcus* spp. in sand of areas characterized by breakwaters than in sands found in open areas. *S. epidermidis* was the predominant species (Bonadonna et al., 1993a).

6.1.3 Pseudomonas aeruginosa

In a study in Israel, both seawater and sand on a number of beaches were found to contain various levels of *Pseudomonas aeruginosa*. The isolation of *P. aeruginosa* and of other *Pseudomonas* spp. was proportionally higher in sand than in seawater samples (Ghinsberg et al., 1994). *P. aeruginosa* was isolated from sandy beaches in Portugal under various tidal conditions, all beaches containing similar counts (Mendes et al., 1993).

6.1.4 Vibrio *spp.*

Vibrio parahaemolyticus isolates have been found in marine or brackish water and sand specimens collected from sand banks in Africa (Aldova, 1989). *Vibrio harvey* has been isolated from seashore water and sand samples collected on coarse sand or pebble beaches (Aldova, 1989; see also chapter 5).

6.1.5 *Enteric bacteria*

Species of bacteria that can cause gastroenteritis have been isolated from sand samples. However, their presence constitutes no apparent health threat to sunbathers. Sand beaches in Portugal contained similar counts of *Clostridium perfringens* under various tidal conditions (Mendes et al., 1993). Bonadonna et al. (1993b) suggested that *C. perfringens* could be a good index of faecal contamination in sand sediment. Low levels of *Campylobacter jejuni* were recorded in both coastal waters and sand on a number of Israeli beaches, with the beach sand containing higher counts than adjacent shore waters (Ghinsberg et al., 1994). In the United Kingdom, intertidal zone sediments appeared to serve as a substantial reservoir for thermophilic campylobacters, which could contribute significantly to bacterial numbers in surface waters, especially in rough weather (Obiri-Danso & Jones, 1997). Dabrowski (1982) isolated *Shigella* spp. from beach sand and water in the bay of Gdansk (Poland).

6.1.6 *Fungi*

Fungi that are often found in the environment as saprophytes may act as opportunistic pathogens, especially in immunocompromised patients (Hoog et al., 2000). Studies by Soussa (1990) in the Portuguese central coastal area showed dermatophytes in 42% of the sand beaches analysed. The most common were *Trichophyton mentagrophytes*, *T. rubrum* and *Microsporum nanum*, all isolated from sandy, non-flooded areas with organic residues. These species are all associated with skin infections, with *T. mentagrophytes* being the most common agent of dermatomycosis in Europe and *T. rubrum* the most common agent worldwide (Hoog et al., 2000). Saprophytic fungi (*Aspergillus candidus*, *A. ochraceus* and *A. fumigatus*) were isolated in the flooded and intermediate areas in high tidal conditions (Izquierdo et al., 1986).

Candida albicans and other *Candida* spp. have been isolated from sand beaches in the south of France (Bernard et al., 1988). In the same study, 8 keratinophilic fungi (i.e., those able to grow on keratin, a characteristic common to dermatophytes) and 11 non-keratinophilic species, all potential pathogens, were isolated. Izquierdo et al.

(1986) isolated 16 species of fungi from beach sand along the northeastern Mediterranean coast of Spain, among them some potentially pathogenic strains. Most of the species belonged to the genera *Penicillium*, *Aspergillus* and *Cladosporium*.

In Israel, Ghinsberg et al. (1994) isolated fungi in all beach sand samples, but not in seawater samples. In a study in Guadeloupe, Boiron et al. (1983) investigated fungal species in seawater and seashore sand, concluding that the similarity of bacterial species in sand and seawater, in conjunction with the fact that no *Candida albicans* was isolated, corroborated their hypothesis that the isolated yeasts were of marine origin. The isolated fungi belonged to the species *C. tropicalis*, *C. parapsilosis*, *C. langeronii*, *C. guilliermondii*, *Trichosporon cutaneum* and *Torulopsis* sp. The most frequently isolated genera from beach sand samples in a Spanish study were *Penicillium*, *Aspergillus*, *Cladosporium*, *Altenaria*, *Mucor*, *Monilia*, *Cephalosporium*, *Verticillium* and *Chrysosporium* (Roses Codinachs et al., 1988). Absence or low incidence of *C. albicans* has also been recorded by other researchers (Roses Codinachs et al., 1988; Figueras et al., 1992).

The fungal density of 180 samples of sand collected from 42 Spanish Mediterranean beaches was found to reach several hundred thousand colony-forming units per gram of sample. The most commonly isolated genera were *Penicillium*, *Cladosporium*, *Aspergillus, Acremonium, Altenaria* and *Fusarium* (Larrondo & Calvo, 1989). In a study carried out in the Attica area of Greece, fungal isolates included *Candida albicans*, *C. krusei*, *C. tropicalis*, *C. puilliermondi*, *C. rugosa*, *Pitirosporum orbiculare*, *Fusarium*, *Penicillium*, *Mucor*, *Helminthosporium* and *Aspergillus niger* (Papadakis et al., 1997), a number of which are pathogenic (Hoog et al., 2000).

6.1.7 Viruses and parasites

Very little information exists concerning the presence of viruses and parasites in beach sand. In a three-year study in Romania by Nestor et al. (1984), the incidence of enteroviruses was found to depend on season, with no viruses being present in water and beach sand during non-vacation seasons. In a study of two sand beaches in Marseilles, France, *Toxocara canis* was found to be the most common parasite, being present on average in 150 g of sand (Conseil Supérieur d'Hygiène Publique de France, 1990). However, in a study carried out on "dog beaches" in Perth, Australia, a total of 266 samples showed no traces of *Toxocara canis* eggs or other eggs/larvae of parasitic nematodes (Dunsmore et al., 1984). It was emphasized in this study that the major risk to humans was from an environment in which puppies, not older dogs, were found. The presence of other parasites transmitted by water (Marshall et al., 1997) that have not been investigated in recreational sand areas may be potentially significant.

6.2 Dispersion and fate of microorganisms in beach sand

The growth of microorganisms in beach sand is limited by nutrient input. Laboratory studies have shown that nutrients pass through the bacterial community into the protozoan and metazoan community (Khiyama & Makemson, 1973). Further studies have shown that microbial contamination is higher in sand than in adjacent waters, as the sand behaves as a passive harbour for cumulative pollution (Oliveira & Mendes, 1991, 1992; Oshiro & Fujioka, 1995). Higher levels of coliforms, *E. coli* and enterococci in sand from Hanauma Bay (Hawaii) were thought to originate from run off from the cliffs surrounding the bay (Oshiro & Fujioka, 1995). Faeces from pigeons and mongoose were also thought to be a source of beach sand contamination. This study concluded that the contaminated sand could be the major source of the periodically high levels of bacteria in the water. Sand contamination is highly variable over short distances, making interpretation of results difficult (Aubert et al., 1987; Figueras et al., 1992; Oshiro & Fujioka, 1995).

The survival of enteric bacteria on the surface of dry sand may essentially be of short duration, the bacteria being destroyed mostly by environmental pressure. Wet sand, the area where young children typically spend most of their time on the beach, is the most relevant. Wet sand, enriched with organic substances, provides a favourable environment for enteric bacteria, which enables them to survive longer than in seawater (Papadakis et al., 1997).

Various factors have been proposed as encouraging the survival and dispersion of faecal index microorganisms and pathogens on beach sand. These include the nature of the beach, tidal phenomena, sewage outlets, the season, the presence of animals and the number of bathers. Water movement, for example, causes erosion, transportation and deposition of beach sediment and redistribution of associated microorganisms. Obiri-Danso & Jones (1997) analysed sediment samples in the United Kingdom for thermophilic campylobacters and faecal index microorganisms before and after tidal cover over a 12-month period. Fifty-three per cent of the samples were positive for campylobacters before tidal cover; this figure was significantly lower than the 64% recovered after tidal disposition. However, there was no significant difference in index organism numbers with respect to samples taken before or after tidal cover. In the same study, a seasonal variation was observed in campylobacters, with the highest isolation rate in winter (100%), followed by secondary peaks in spring (33–67%) and autumn (67–78%). The lowest counts were found in summer, which correlated with the incidence of campylobacters in surface waters. In contrast, Mendes et al. (1993) studied the influence of tides on counts of faecal index microorganisms and pathogens in sand without finding any clear differences. Nestor et al. (1984) found that the incidence of some pathogens depended on the season, with no viruses present in seawater and sand of beaches outside the holiday season. Borrego et al. (1991) reported higher bacterial counts and longer survival time in beaches close to sewage outlets.

As outlined in the previous section, fungi are often encountered in sand, and their survival is longer than that of enteric bacteria due to their capacity to form resistant spores. It has been suggested that the presence and the level of fungi is related to direct or indirect contamination originating from the residues/detritus from beach users and/or tidal influence (Mendes et al., 1998). In an *in vitro* study, Anderson (1979) found that four pathogenic fungi (*Trichosporon cutaneum*, *Candida albicans*, *Microsporum gypseum* and *Trichophyton mentagrophytes*) survived for at least 1 month in non-sterile sand inoculated with propagules of such fungi. In a similar study, five species of dermatophytes (*Epidermophyton floccosum*, *Microsporum canis*, *M. gypseum*, *Trichophyton mentagrophytes* and *T. rubrum*) and *Scopulariopsis brevicaulis* survived for between 25 and 360 days (Carillo-Muñoz et al., 1990).

Intensively used water recreation areas provide opportunities for person-to-person transmission of pathogens (e.g., dermatophytes). Transmission may occur because individuals shed pathogens onto sand, by direct contact or through other means, although, with the exception of transmission via contaminated water (as discussed in chapter 4), none of these has been positively demonstrated. Papadakis et al. (1997) collected water and sand samples from two beaches—one more popular than the other—in summer and winter, and the numbers of swimmers present on the beaches were counted. Coliforms, thermotolerant coliforms, enterococci, *S. aureus*, yeasts and moulds were also investigated. Water and sand samples were very low in index organisms of faecal pollution. Human species of yeasts were present in water and sand samples from both sites. *S. aureus* was isolated from water and sand samples only twice in winter, when swimmer presence was exceptional. A significant correlation appeared between swimmer numbers present on the beach and *S. aureus* counts in water samples, the correlation being more pronounced on the more popular beach. In sand samples, *S. aureus* counts correlated with the number of swimmers present on the beach only at the more popular beach. Yeasts of human origin correlated with the number of swimmers on the more popular beach, both in water and in sand samples.

6.3 Guideline values

Bacterial indices of faecal pollution and several pathogens have been isolated from beach sand. However, the capacity of pathogens in beach sand to infect beach users remains undemonstrated, and the real extent of their threat to public health is unknown. There is, therefore, no evidence to support the establishment of a guideline value for index organisms or pathogenic microorganisms in beach sand. However, preventative measures, such as education campaigns, and the management actions described in section 6.5 are important precautionary measures.

6.4 Research and monitoring

Epidemiological evidence for health risks from exposure to sandy beaches has not been found. Epidemiological studies aimed at investigating cause–effect or at examining a possible dose–response relationship linking the microbial quality of beach sand with skin, eye, ear and gastrointestinal symptoms would improve understanding in this area.

Experience with systematic beach surveillance as part of pollution control is relatively limited, and routine monitoring of beach sand for index organisms is generally not justified. However, it has often been recommended for research. WHO/UNEP (1992, 1994) indicated that wet beach sand and sediments should be part of epidemiological and microbiological studies correlating recreational water quality with health effects, but evidence to date indicates that beach sand does not appear to constitute an infectious hazard (Chabasse et al., 1986; Conseil Supérieur d'Hygiène Publique de France, 1990).

6.5 Management actions

The principal microbial risk to human health encountered on beaches and in similar areas is that arising from contact with animal excreta—notably that of dogs, where, for example, such areas are used for exercising pets. Regulations, often local in character, may restrict access on a seasonal basis to frequently used beaches or place an obligation upon the owner to remove animal excreta. Increased public awareness may help to reduce exposure, especially among young children. While beach cleaning may contribute to the removal of animal excreta, it is more often undertaken for aesthetic reasons or to attempt to remove litter or sharp materials, such as broken glass. The majority of beach management award schemes would not give an award to a resort beach that allowed dogs during the swimming season.

In some countries, particularly at resort areas, mechanical sand cleaning is a common practice that can eliminate visible rubbish mixed with sand, reducing the amount of organic matter and therefore reducing the further development of microorganisms (Bartram & Rees, 2000 chapter 12). However, mechanical cleaning may disturb sand ecology (Llewellyn & Shackley, 1996). Studies that have investigated the microbiological quality of sand have shown that a clear improvement was achieved as a result of raising the general levels of hygiene and cleanliness (Fernandez & Ferrer, 1982).

Chemical products such as disinfectants are sometimes applied to sand without regard to their effectiveness or possible ecotoxicological effects. The Conseil Supérieur d'Hygiène Publique de France (1990) has argued that there is not enough evidence to demonstrate the need for and efficiency of sand disinfection. When sand treatment is necessary, simple methods, such as sweeping and aeration, could be applied (Figueras et al., 1992), together with constant beach supervision in order to prevent access by animals. The use of clean towels for use on the beach, good personal hygiene, the prohibition of animals and regular mechanical cleaning are considered, by some authorities, to be important (e.g., Conseil Supérieur d'Hygiène Publique de France, 1990).

6.6 References

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CHAPTER 7
Algae and cyanobacteria in coastal and estuarine waters

In coastal and estuarine waters, algae range from single-celled forms to the seaweeds. Cyanobacteria are organisms with some characteristics of bacteria and some of algae. They are similar in size to the unicellular algae and, unlike other bacteria, contain blue-green or green pigments and are able to perform photosynthesis; thus, they are also termed blue-green algae.

Algal blooms in the sea have occurred throughout recorded history but have been increasing during recent decades (Anderson, 1989; Smayda, 1989a; Hallegraeff, 1993). In several areas (e.g., the Baltic and North seas, the Adriatic Sea, Japanese coastal waters and the Gulf of Mexico), algal blooms are a recurring phenomenon. The increased frequency of occurrence has accompanied nutrient enrichment of coastal waters on a global scale (Smayda, 1989b).

Blooms of non-toxic phytoplankton species and mass occurrences of macro-algae can affect the amenity value of recreational waters due to reduced transparency, discoloured water and scum formation. Furthermore, bloom degradation can be accompanied by unpleasant odours, resulting in aesthetic problems (see chapter 9).

Several human diseases have been reported to be associated with many toxic species of dinoflagellates, diatoms, nanoflagellates and cyanobacteria that occur in the marine environment (CDC, 1997). The effects of these algae on humans are due to some of their constituents, principally algal toxins. Marine algal toxins become a problem primarily because they may concentrate in shellfish and fish that are subsequently eaten by humans (CDR, 1991; Lehane, 2000), causing syndromes known as paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP), amnesic shellfish poisoning (ASP), neurotoxic shellfish poisoning (NSP) and ciguatera fish poisoning (CFP).

Notwithstanding the importance of dietary exposure for humans, this chapter deals only with the possible risks associated with recreational activities in (or near) coastal and estuarine waters. Exposures through dermal contact, inhalation of sea spray aerosols and ingestion of water or algal scums are briefly considered, as are precautionary measures that can be taken. Chapter 8 deals with algae and cyanobacteria in freshwater. More detailed coverage of cyanobacteria and human health is available in *Toxic Cyanobacteria in Water* (Chorus & Bartram, 1999).

7.1 Exposure through dermal contact

Marine cyanobacterial dermatitis ("swimmers' itch" or "seaweed dermatitis") is a severe contact dermatitis (inflammation of the skin) that may occur after swimming in water containing blooms of certain species of marine cyanobacteria. The symptoms are itching and burning within a few minutes to a few hours after swimming in an area where fragments of the cyanobacteria are suspended. Visible dermatitis and redness develop after 3–8 h, followed by blisters and deep desquamation. Some marine beaches, for example, report widespread problems due to a benthic marine cyanobacterium, *Lyngbya majuscula*, which grows on rocks in tropical seas and may cause severe blistering if trapped under the bathing suits of swimmers; this generally happens following storm conditions, which cause the dispersal of the cyanobacterium (Grauer & Arnold, 1961). To date, incidents have been reported only from Japan, Hawaii and Australia (Grauer & Arnold, 1961; WHO, 1984; Yasumoto & Murata, 1993).

Some toxic components, such as aplysiatoxin, debromoaplysiatoxin and lyngbyatoxin A, have been isolated from marine cyanobacteria (Mynderse et al., 1977; Fujiki et al., 1985; Shimizu, 1996). The cyanobacterium *Lyngbya majuscula* is known to produce debromoaplysiatoxin and lyngbyatoxin A, and the cyanobacteria *Oscillatoria nigroviridis* and *Schizothrix calcicola* are known to produce debromoaplysiatoxin (Mynderse et al., 1977). These toxins are highly inflammatory and are potent skin tumour promoting compounds, utilizing mechanisms similar to those of phorbol esters (i.e., through the activation of protein kinase C) (Gorham & Carmichael, 1988; Fujiki et al., 1990). More research is needed to establish the possible tumour promotion risks for human populations.

Occasionally, skin irritation problems have also been reported by swimmers exposed to certain strains of the marine cyanobacterium *Trichodesmium*, as well as dense raphidophyte blooms of *Heterosigma akashiwo* (Falconer, pers. com.).

There is little information on the adverse effects of dermal contact with marine waters containing algal species producing DSP, PSP, ASP and NSP toxins or those species of marine dinoflagellates and flagellates that have been associated with the death of fish and invertebrates. However, people with occupational exposure to waterways (Pocomoke estuary in Maryland, USA) in which toxin-producing *Pfiesteria* or *Pfiesteria*-like dinoflagellates were present were found to be at risk of developing a reversible clinical syndrome characterized by difficulties with learning and higher cognitive function. The risk of illness appeared to be directly related to the degree of exposure (both dermal and exposure to aerosolized spray from the water) (Grattan et al., 1998). CDC (1997) noted that clinical features from exposure to *Pfiesteria piscicida* and related organisms include memory loss, confusion and acute skin burning.

7.2 Exposure through ingestion (of water or scum)

Nodularia spumigena was the first cyanobacterium recognized to cause animal death (Francis, 1878). The toxin produced by *N. spumigena*, called nodularin, is a cyclic pentapeptide. Nodularin is a hepatotoxin, in that it induces massive haemorrhages in the liver of mammals and causes disruption of the liver structure; it also has some effects on the kidneys (Eriksson et al., 1988; Sandström et al., 1990). Nodularin acts by inhibiting serine–threonine protein phosphatases (Fujiki et al., 1996). In the 19th century, several toxic blooms and accumulations of *Nodularia spumigena* were registered. Published literature relates to blooms of *N. spumigena* associated with poisoning of ducks (Kalbe & Tiess, 1964), dogs (Edler et al., 1985; Nehring, 1993), young cattle (Gussmann et al., 1985) and sheep (Main et al., 1977). To date, there have been no reports of human poisoning by *N. spumigena*, but humans may be as susceptible to the toxins as other mammals. Therefore, it is possible that small children, in particular, may accidentally ingest toxic material in quantities with potentially serious consequences.

Other than the study referred to in section 7.1, there is no evidence for adverse effects of ingestion of marine waters containing algal species producing DSP, PSP, ASP and NSP toxins, etc.

Some species of cyanobacteria are capable of causing dense scums, which contain high concentrations of cells. Since most toxin is intracellular, scums caused by toxigenic strains may contain elevated concentrations of toxin. The existence of a cyanobacterial scum caused by a toxigenic species represents an increased human health hazard. Scums are less of a problem in marine water than in fresh water, as the frequency of occurrence of scums is higher in lakes than in coastal areas.

7.3 Exposure through inhalation

Inhalation of a sea spray aerosol containing fragments of marine dinoflagellate cells and/or toxins (e.g., brevetoxins) released into the surf by lysed algae can be harmful to humans (Baden et al., 1984; Scoging, 1991). Brevetoxins are produced by the unarmoured marine dinoflagellate *Gymnodinium breve* (now referred to as *Karenia brevis*). For many years, these blooms were reported only from the south-east USA and eastern Mexico (Steidinger, 1993), but similar problems have now been reported in New Zealand (Fernandez & Cembella, 1995), which were thought to have been caused by *Karenia mikimotoi*. From 1998 to 2001 summer blooms of *Otreopsis ovata* occurred in the Apuan (Tuscany, Italy) benthic seawaters (Sansoni et al., 2002), with major consequences to the benthic flora. In 1998, on the tract of land inland from the bloom-affected area, some 100 people reported symptoms including coughing, sneezing and, in some cases, fever, which were associated with the inhalation of sea spray aerosol.

The signs and symptoms of exposure to brevetoxins by inhalation are severe irritation of conjunctivae and mucus membranes (particularly of the nose) followed by persistent coughing and sneezing and tingling of the lips. The asthma-like effects are not usually observed more than a few kilometres inland (Pierce, 1986).

7.4 Identification of marine toxic algae and cyanobacteria

Detailed information on sampling, identification and cell counts are described in Hallegraeff et al. (2003) for marine toxic phytoplankton and in Chorus & Bartram (1999) for cyanobacteria. Immunoassays are currently the most sensitive and specific methods for rapid screening of samples for microcystins, which are toxins produced by certain cyanobacteria (Ueno et al., 1996), they can also be used for algal toxins. These methods have also been developed for PSP toxins (Cembella et al., 1995), DSP toxins (Levine et al., 1988; Usagawa et al., 1989) as well as ASP and NSP toxins, although in recreational water health effects are not thought to be due to the toxins, but are more likely to be caused by different (largely uncharacterised) compounds, such as lipopolysaccharides.

In most cases, the identification of an algal or cyanobacterial species is not sufficient to establish whether or not it is toxic, because a number of strains with different toxicity may belong to the same species. As a consequence, in order to ascertain whether the identified species includes toxic strains, there is a need to characterize the toxicity. The most commonly employed method is the mouse bioassay, which has been successfully applied in the cases of cyanotoxins (Falconer, 1993), PSP toxins (WHO, 1984), NSP toxins (McFarren et al., 1960) and DSP toxins (Yasumoto et al., 1984). Toxicity is tested by intraperitoneal injection followed by 24-hour observation. This method is not specific but within a few hours provides a measure of the total toxicity. The mouse assay is not sensitive enough for testing ASP toxins. Many analytical methods based on high-performance liquid chromatography are now available to determine the occurrence of cyanotoxins (Lawton et al., 1994; Chorus & Bartram, 1999) as well as specific ASP (Lawrence et al., 1989), DSP (Lee et al., 1987), NSP (Pierce et al., 1985) and PSP (Sullivan & Wekell, 1987) toxins.

7.5 Guideline values

Available data indicate that the risk for human health associated with the occurrence of marine toxic algae or cyanobacteria during recreational activities is limited to a few species and geographical areas. As a result, it is inappropriate to recommend specific guideline values, although authorities should be aware of the potential hazard and act accordingly.

7.6 Precautionary measures

7.6.1 Monitoring

Within areas subject to the occurrence of marine toxic algae or cyanobacteria, it is important to carry out adequate monitoring activities and give information to the human population potentially affected. Monitoring programmes should be planned with the aim of preventing human exposure in areas affected by blooms of toxic algae or cyanobacteria. In some cases, satellite imagery can be used as a part of a proactive monitoring programme. For example, movements of the Gulf Stream and subsequent elevated water temperatures play a key role in *Gymnodinium breve* blooms; Gulf Stream temperatures monitored by remote sensing of infrared radiation can provide information on the likelihood of a bloom and its subsequent movement (Hungerford & Wekell, 1993).

Long data records on phytoplankton populations, toxic and otherwise, may contribute to a more comprehensive understanding of phytoplankton dynamics and ecosystem function, which could lead to more efficient monitoring. If, for instance, long time series of data concerning phytoplankton populations exist, it would be possible to decide if a species that has suddenly appeared is new to the area or if endemic species have become toxic. Important supporting parameters include temperature, salinity, chlorophyll (phytoplankton biomass) and surface current circulation (transport of harmful algae). Knowledge of the temporal and geographic distribution of inorganic nutrients and their sources, as well as other phytoplankton growth factors, are also important when planning and operating a monitoring programme (Andersen, 1996).

When conditions favourable to algal or cyanobacterial blooms are recognized, monitoring activities should be intensified and should include taxonomic ranking of potentially toxic species and eventually analysis of the algal toxins (Hallegraeff et al., 2003).

7.6.2 Information

In affected areas, it is appropriate to provide general practitioners and medical clinics with information regarding the health problems potentially associated with algal blooms and toxic algae, the diagnosis and treatment of poisonings, the surveillance of groups of people who could be at risk and procedures for reporting to public health authorities. Health information should also be made available to the general public and to recreational water users in particular. Information may be disseminated through various means, including schools, on-site notices, mass media and specific brochures. These should contain information about algal blooms and toxic algae, the possible health effects, reporting procedures for any health problems thought to be possibly linked with water-based recreation and recommended protective measures.

As a precaution, the following guidance is recommended for potentially affected areas and should be included in public information:

- Avoid areas with visible algal concentrations and/or algal scums in the sea as well as on the shore. Direct contact and swallowing appreciable amounts are associated with the highest health risk.
- On the beach, avoid sitting downwind of any algal material drying on the shore, which could form an aerosol and be inhaled (particularly in areas with *Gymnodinium breve* blooms).
- If sailing, windsurfing or undertaking any other activity likely to involve water immersion in the presence of algal blooms, wear clothing that is close fitting in the openings. The use of wet suits for water sports may result in a greater risk of rashes, because algal material in the water trapped inside the wet suit will be in contact with the skin for long periods of time.
- After coming ashore, shower or wash yourself down to remove any algal material.
- Wash and dry all clothing and equipment after any contact with algal blooms and scum.
- If any health effects are subsequently experienced and whatever the nature of the exposure, seek medical advice.

In some areas, information on harmful algal blooms is distributed rapidly to users of the monitoring system by telephone, telephone answering machine, fax, E-mail and/or Internet (e.g., the Baltic Sea Alg@line, found at http://www2.fimr.fi/project/algaline/algaetu.htm) (Andersen, 1996).

7.6.3 Prevention of marine algal blooms

There have been several attempts to develop practical methods for controlling algal blooms. The use of clays, herbicides, metals, chelators, artificial turbulence, dinoflagellate parasites and zooplankton all have been the subject of research. Unfortunately, many of these methods are not practical and may have adverse ecological side-effects.

Algal blooms result from a complex interaction between hydrographic, meteorological, biological and chemical conditions, of which only a few can be controlled. Without essential nutrients, principally nitrates and phosphates, algae will usually not reach bloom proportions. Excessive nutrient input from land-based sources is one of the most influential promoting factors, and minimization of nutrient availability will often contribute to controlling algal growth.

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CHAPTER 8

Algae and cyanobacteria in fresh water

The term algae refers to microscopically small, unicellular organisms, some of which form colonies and thus reach sizes visible to the naked eye as minute green particles. These organisms are usually finely dispersed throughout the water and may cause considerable turbidity if they attain high densities. Cyanobacteria are organisms with some characteristics of bacteria and some of algae. They are similar to algae in size and, unlike other bacteria, they contain blue-green and green pigments and can perform photosynthesis. Therefore, they are also termed blue-green algae (although they usually appear more green than blue).

Human activities (e.g., agricultural runoff, inadequate sewage treatment, runoff from roads) have led to excessive fertilization (eutrophication) of many water bodies. This has led to the excessive proliferation of algae and cyanobacteria in fresh water and thus has had a considerable impact upon recreational water quality. In temperate climates, cyanobacterial dominance is most pronounced during the summer months, which coincides with the period when the demand for recreational water is highest.

Livestock poisonings led to the study of cyanobacterial toxicity, and the chemical structures of a number of cyanobacterial toxins (cyanotoxins) have been identified and their mechanisms of toxicity established. In contrast, toxic metabolites from freshwater algae have scarcely been investigated, but toxicity has been shown for freshwater species of Dinophyceae and also the brackish water Prymnesiophyceae and an ichthyotoxic species (*Peridinium polonicum*) has been detected in European lakes (Pazos et al., in press; Oshima et al., 1989). As marine species of these genera often contain toxins, it is reasonable to expect toxic species among these groups in fresh waters as well.

Although many species of freshwater algae proliferate quite intensively in eutrophic waters, they do not accumulate to form dense surface scums (often termed blooms) of extremely high cell density, as do some cyanobacteria. The toxins that freshwater algae may contain are therefore not accumulated to concentrations likely to become hazardous to human health or livestock. For these reasons, this chapter will focus primarily on the health impacts of cyanobacteria. More detailed coverage of cyanobacteria and human health is available in *Toxic Cyanobacteria in Water* (Chorus & Bartram, 1999).

8.1 Occurrence of toxic cyanobacteria

Toxic cyanobacteria are found worldwide in inland and coastal water environments. At least 46 species have been shown to cause toxic effects in vertebrates (Sivonen & Jones, 1999). The most common toxic cyanobacteria in fresh water are *Microcystis* spp., *Cylindrospermopsis raciborskii*, *Planktothrix* (syn. *Oscillatoria*) *rubescens*, *Synechococcus* spp., *Planktothrix* (syn. *Oscillatoria*) *agardhii*, *Gloeotrichia* spp., *Anabaena* spp., *Lyngbya* spp., *Aphanizomenon* spp., *Nostoc* spp., some *Oscillatoria* spp., *Schizothrix* spp. and *Synechocystis* spp. Toxicity cannot be excluded for further species and genera. As research broadens and covers more regions over the globe, additional toxic species are likely to be found. Therefore, it is prudent to presume a toxic potential in any cyanobacterial population.

The most widespread cyanobacterial toxins are microcystins and neurotoxins (see section 8.3). Some species contain neurotoxin and microcystin simultaneously. Field populations of the most common bloom-forming genus, *Microcystis*, are almost always toxic (Carmichael, 1995), but non-toxic strains do occur. Generally, toxicity is not a trait specific for certain species; rather, most species comprise toxic and non-toxic strains. For microcystins, it has been shown that toxicity of a strain depends on whether or not it contains the gene for microcystin production (Rouhiainen et al., 1995; Dittmann et al., 1996) and that field populations are a mixture of both genotypes with and without this gene (Kurmayer et al., 2002). Experience with cyanobacterial cultures also shows that microcystin production is a fairly constant trait of a given strain or genotype, only somewhat modified by environmental conditions (see various contributions in Chorus, 2001). While conditions leading to cyanobacterial proliferation are well understood (the physiological or biochemical function of toxins for the cyanobacteria is the subject of many hypotheses—Chorus & Bartram, 1999), the factors leading to the dominance of toxic strains over non-toxic ones are not.

Worldwide, about 60% of cyanobacterial samples investigated contain toxins (see section 8.4). The toxicity of a single bloom may, however, change in both time and space. Demonstrations of toxicity of the cyanobacterial population in a given lake do not necessarily imply an environmental or human hazard as long as the cells remain thinly dispersed. Mass developments and especially surface scums pose the risks.

8.2 Formation of cyanobacterial blooms

In contrast to true algae, many species of planktonic cyanobacteria possess specialized intracellular gas vesicles. Stacks of these minute (<300 nm) proteinaceous hollow cylinders maintain a gas-filled space in the cell, which enables the organism to regulate its buoyancy and thus to actively seek water depths with optimal growth conditions. However, regulation of buoyancy by changing the amount of gas in the vesicles is slow. Cells adapted to turbulent mixing by enlarged gas vesicles will take a few days to reduce their buoyancy in order to adapt to more quiescent conditions. Thus, especially when the weather changes from stormy to fine (i.e., mixing conditions in the water change from turbulent to strongly stratified), many excessively buoyant cells or colonies may accumulate at the surface. Light winds drive them to leeward shores and bays, where they form scums (Figure 8.1). In extreme cases, such agglomerations may become very dense and even acquire a gelatinous consistency. More frequently, they are seen as streaks or slimy scums that may even look like blue-green paint or jelly. Such situations may change rapidly, within hours, or may remain unchanged for weeks (Chorus & Bartram, 1999).

Scums can be quickly broken by wave action and redispersed by renewed wind mixing. However, especially in shallow bays, scum material may take a long time to disperse, as a result of either wave wash or, ultimately, disintegration of the cells. Dying and lysing cells release their contents into the water, where pigments may adopt a copper-blue colour. Bacterial decomposition leads to rapid putrefaction of the material. The in-shore deposits are often repulsive and potentially very toxic.

Whereas agglomerations of cyanobacteria are usually caused by planktonic species in eutrophic waters, benthic mats in oligotrophic waters (which are relatively poor in plant nutrients) occasionally also cause problems; these surface-covering mats can grow only in clear water, in which sunlight penetrates to the bottom. During sunny days, their photosynthesis may lead to high rates of oxygen production, forming bubbles that loosen parts of the mats and drive them to the surface. Mats of benthic cyanobacteria washed to the shore and scavenged by dogs have been lethal (Edwards et al., 1992), and cattle deaths on Swiss alpine meadows may also be caused by benthic cyanobacteria (Mez et al., 1997, 1998). Although relevant for pets and livestock, the human health impact of these cyanobacteria on beaches will be considerably lower than that of scums in the water. Awareness of the potential toxicity of such beached mats is, however, important, because they accumulate along shores of clear waters usually not recognized as potentially producing harmful cyanobacteria or algae.

8.3 Cyanotoxins

Progress in analytical chemistry has enabled the isolation and structural identification of three neurotoxins with somewhat different modes of blocking neuronal signal transmission (anatoxin-a, anatoxin-a(s) and saxitoxins), one general cytotoxin, which inhibits protein synthesis (cylindrospermopsin), and a group of toxins termed microcystins (or nodularins, found in brackish waters), which inhibit protein phosphatases. Phosphatase inhibition is generally cytotoxic, but microcystins are primarily hepatotoxic, because they use the bile acid carrier to pass through cell membranes. These toxins were named after the organism from which they were first isolated, but most of them have been found in a wider array of genera, and some species contain more than one toxin or both microcystins and neurotoxins.

Although the toxins listed in Table 8.1 are assumed to be the substances most significant for human health, it is unlikely that all of the important cyanotoxins have been discovered. Yoo et al. (1995) pointed out that an increasing variety of individual toxins is continually being discovered. Numerous pharmacological working groups are conducting research for pharmacologically active substances from cyanobacteria (e.g., Mundt & Teuscher, 1988; Falch et al., 1995). Fastner et al.

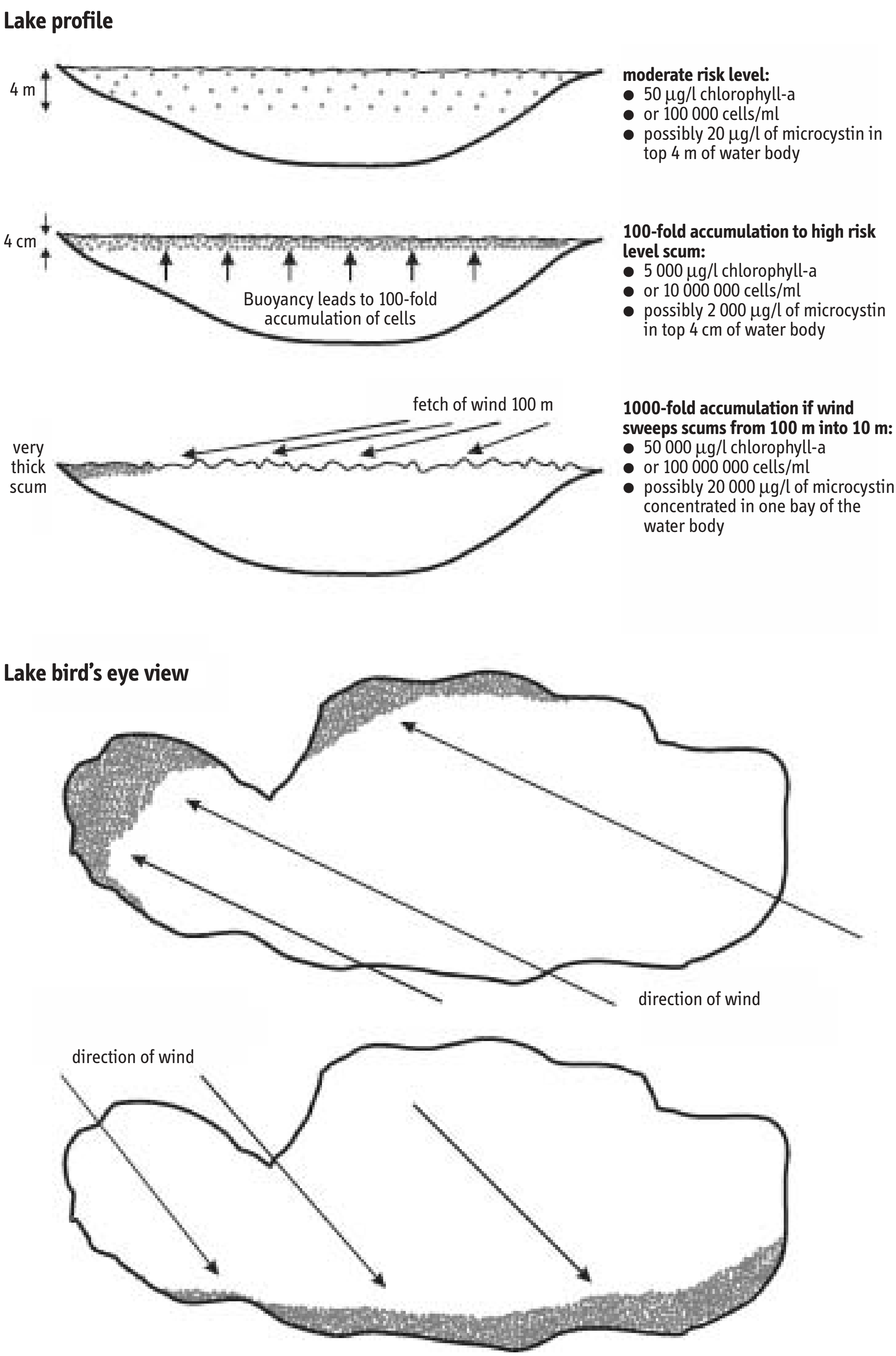

FIGURE 8.1. SCHEMATIC ILLUSTRATION OF SCUM FORMATION CHANGING THE CYANOTOXIN RISK FROM MODERATE TO HIGH (CHORUS & BARTRAM, 1999)

(2001) showed that primary rat hepatocytes reacted to microcystins in crude extracts of some strains of cyanobacteria in close correlation to their content of microcystins, but that this reaction was further enhanced by an unknown factor. Oberemm et al. (1997) demonstrated substantial toxicity of cyanobacterial crude extracts to fish eggs, the effects not being due to the content of any of the known cyanotoxins.

TABLE 8.1. CYANOBACTERIAL TOXINS AND THEIR ACUTE TOXICITY[a]

Cyanotoxins	LD_{50} (i.p. mouse)[b] of pure toxin (μg/kg)	Taxa known to produce the toxin(s)	Mechanism of toxicity
Protein phosphatase blockers (cyclic peptides with the amino acid ADDA)			
Microcystins in general (~60 known congeners)	45–>1000	*Microcystis*, *Planktothrix*, *Oscillatoria*, *Nostoc*	all block protein phosphatases by covalent
Microcystin-LR	60 (25–125)	*Anabaena*, *Anabaenopsis*	binding and cause
Microcystin-YR	70	*Hapalosiphon*	haemorrhaging of the
Microcystin-RR	300–600		liver; cumulative damage
Nodularin	30–50	*Nodularia spumigena*	may occur
Neurotoxins			
Anatoxin-a (alkaloid)	250	*Anabaena*, *Oscillatoria*, *Aphanizomenon*, *Cylindrospermum*	blocks post-synaptic depolarization
Anatoxin-a(s) (unique organophosphate)	40	known only from two species of *Anabaena*	blocks acetylcholinesterase
Saxitoxins (carbamate alkaloids)	10–30	*Aphanizomenon*, *Anabaena*, *Lyngbya*, *Cylindrospermopsis raciborskii*	block sodium channels
Cytotoxin			
Cylindrospermopsin (alkaloid)	2100 in 1 day 200 in 5–6 days	*Cylindrospermopsis raciborskii*	blocks protein synthesis; substantial cumulative toxicity

[a] derived from Turner et al., 1990; Kuiper-Goodman et al., 1999; Sivonen & Jones, 1999.

[b] LD_{50} = lethal $dose_{50}$ (the dose of a chemical that will, on average, kill 50% of a group of experimental animals); i.p. = intraperitoneal.

8.3.1 Microcystins

Microcystins are the most frequently occurring and widespread of the cyanotoxins. They are cyclic heptapeptides containing a specific amino acid (ADDA) side chain which, to date, has been found only in microcystins and nodularin (a cyclic pentapeptide toxin of cyanobacteria from brackish waters). About 70 structural analogues of microcystin have been identified (Rinehart et al., 1994; Sivonen & Jones, 1999). They vary with respect to methyl groups and two amino acids within the ring. This has consequences for the tertiary structure of the molecule and results in pronounced differences in toxicity as well as in hydrophobic/hydrophilic properties. Microcystins block protein phosphatases 1 and 2a (which are important molecular switches in all eukaryotic cells) with an irreversible covalent bond (MacKintosh et al., 1990).

The chief pathway for microcystins entry into cells is the bile acid carrier, which is found in liver cells and, to a lesser extent, in intestinal epithelia (Falconer, 1993). For vertebrates, a lethal dose of microcystin causes death by liver necrosis within hours up to a few days. Evidence for the permeability of other cell membranes to microcystins is controversial. It is possible that hydrophobic structural analogues can penetrate into some cell types even without the bile acid carrier (Codd, 1995). In addition, Fitzgeorge et al. (1994) published evidence for disruption of nasal tissues by the common hydrophilic analogue microcystin-LR. While toxicity by oral uptake is generally at least an order of magnitude lower than toxicity by intraperitoneal (i.p.) injection, intranasal application in these experiments was as toxic as i.p. injection, and membrane damage by microcystin enhanced the toxicity of anatoxin-a. This uptake route may be relevant for water sports activities that lead to inhalation of spray and droplets, such as waterskiing.

Microcystins are found in most populations of *Microcystis* spp. (which frequently form surface scums) and in strains of some species of *Anabaena* (which may also form scums). High microcystin content has also been observed in *Planktothrix* (syn. *Oscillatoria*) *agardhii* and *P. rubescens* (Fastner et al., 1999). *P. agardhii*, however, never forms scums, and where it occurs *P. rubescens* does not usually form scums during the recreational water use season, thus reducing the hazard to swimmers.

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

- liver injury results in externally noticeable symptoms only when it is severe;
- acute dose–response curves for microcystins are steep. Therefore, little acute damage may occur until levels close to severe acute toxicity are reached. As a result of the lack of apparent symptoms at moderate exposure, exposure is likely to be continued by people uninformed of the risk (e.g., for consecutive days of a holiday or a hot spell), which will increase the risk of cumulative liver damage.

There are two aspects of chronic microcystin damage to the liver—progressive active liver injury (Falconer et al., 1988) and the potential for promotion of tumour growth. Tumour-promoting activity of microcystins is well documented, although microcystins alone have not been demonstrated to be carcinogenic. Promotion of mouse skin tumours has been shown after initiation by topical exposure to a carcinogen (dimethylbenzanthracene) followed by ingestion of a *Microcystis aeruginosa* extract (Falconer & Buckley, 1989; Falconer & Humpage, 1996). In rat liver studies, the appearance of pre-neoplastic liver foci and nodules was promoted by pure microcystin-LR in a protocol involving one i.p. dose of diethylnitrosamine and i.p. doses of microcystin-LR over several weeks (Nishiwaki-Matsushima et al., 1992).

Studies on the mechanism of cell toxicity showed that microcystin interferes with cell structure and mitosis, and this may help to explain the tumour-promoting activity (Falconer & Yeung, 1992; Kaja, 1995). It has been suggested that, in China, cases of liver tumours in humans may be associated with the presence of cyanotoxins in drinking water (Ueno et al., 1996).

8.3.2 Neurotoxins

Irrespective of somewhat different modes of action, all three neurotoxins (Table 8.1) have the potential to be lethal by causing suffocation—anatoxin-a and a(s) through cramps, saxitoxins through paralysis. However, no human deaths from exposure to neurotoxins associated with recreational use of water are known.

Anatoxin-a(s) is the only known naturally occurring organophosphate cholinesterase inhibitor and causes strong salivation (the 's' in its name stands for salivation), cramps, tremor, diarrhoea, vomiting and an extremely rapid death (within minutes). Saxitoxins and anatoxin-a(s) are among the most neurotoxic substances known. However, evidence is accumulating that in lakes and rivers they do not occur as frequently as microcystins. This applies especially to anatoxin-a(s): to date, it has been found only in a small number of *Anabaena* blooms in North America. Furthermore, concentrations even of these highly toxic substances in scums will scarcely reach levels acutely neurotoxic to a human ingesting a mouthful. In contrast, neurotoxicity may be experienced by livestock that drink many litres of contaminated water and pets—especially dogs—that gather scum material in their fur and ingest it through grooming with the tongue.

After ingestion of a sublethal dose of these neurotoxins, recovery appears to be complete, and no chronic effects have been observed to date. For these reasons, the neurotoxins are a hazard to be aware of when using waters populated with cyanobacteria for recreation. On the basis of current knowledge, however, it is reasonable to consider them less dangerous than microcystins or cylindrospermopsin, which may cause ongoing injury.

8.3.3 Cylindrospermopsin

Cylindrospermopsin is an alkaloid isolated from *Cylindrospermopsis raciborskii* (Ohtani et al., 1992). It is a general cytotoxin that blocks protein synthesis, the first clinical symptoms being kidney and liver failure. In contrast to the pure toxin, crude extracts of the organism also cause injury to the lungs, adrenals and intestine, indicating further, unknown toxins in the organism. Clinical symptoms may become manifest only several days after exposure, so it will often be difficult to determine a cause-effect relationship. Patients intoxicated with cylindrospermopsin via drinking-water in an incident in Australia escaped death only through skilled and intensive hospital care (Falconer, 1996). *Cylindrospermopsis raciborskii* is considered to be a tropical and subtropical species, but has been reported to form blooms as far north as Vienna (Roschitz, 1996). Substantial populations have been reported from north-eastern Germany (C. Wiedner, personal communication), and generally *C. raciborskii* appears to be invading temperate regions (Padisák, 1997). Thus, cylindrospermopsin may become relevant in temperate zones in future.

8.3.4 *Analysis*

From the 1960s to the end of the 1980s, detection of cyanotoxin was primarily performed with the mouse bioassay (outlined in section 7.4), conducted to assess the safety of drinking-water supplies. Due to the high cost and lack of approved laboratories as well as ethical limitations of applicability, this method is not suitable for large screening or monitoring programmes. However, effective methods of chemical analysis are now available for the known cyanotoxins, and sensitive immunoassays as well as enzyme assays have become commercially available for the most important ones (e.g., microcystins and saxitoxins). This opens new possibilities for screening programmes targeted at assessment of the potential risk, as well as for regular surveillance (Chorus & Bartram, 1999).

8.4 Evidence for toxicity of cyanobacteria

Observations of lethal poisoning of animals drinking from water with mass developments of cyanobacteria are numerous. The first documented case of a lethal intoxication of livestock after drinking water from a lake heavily populated with cyanobacteria was published in the 1800s (Francis, 1878), and cases recorded since have included sheep, cattle, horses, pigs, dogs, fish, rodents, amphibians, waterfowl, bats, zebras and rhinoceroses (Codd et al., 1989). Dogs have died after grooming accumulations of cyanobacteria out of their fur or after ingesting beached mats of benthic cyanobacteria.

A number of human deaths have been reported through exposure to cyanobacterial toxins through renal dialysis (Carmichael, 1996; Jochimsen et al., 1998), and also implicated in drinking-water (Teixera et al., 1993). Health impairments are also seen from numerous anecdotal reports of irritations of the skin and/or mucous membranes and from documented cases of illness after exposure through drinking-water as well as accidental swallowing or aspiration of scum material. Other sources of information include toxicological data from animal experiments and data on concentrations of cyanobacterial toxins in waters used for drinking-water purposes and recreation.

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

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

Different cyanobacterial metabolites are likely to be involved in evoking symptoms associated with these exposure routes.

8.4.1 Exposure through dermal contact

Allergic or irritative dermal reactions of varying severity have been reported from a number of freshwater cyanobacterial genera (*Anabaena*, *Aphanizomenon*, *Nodularia*, *Oscillatoria*, *Gloeotrichia*) after recreational exposure. Bathing suits and particularly wet suits tend to aggravate such effects by accumulating cyanobacterial material and enhancing disruption of cells and liberation of cell content. Reports from the USA have recorded allergic reactions from recreational exposure, and the cyanobacterial pigment phycocyanin has been shown to be responsible in one case (Cohen & Reif, 1953). In addition, cutaneous sensitization to cyanobacteria has been documented. Skin irritations were a frequent symptom found in an epidemiological study by Pilotto et al. (1997) on health effects after recreational exposure to cyanobacteria. This study showed correlation to cyanobacterial cell density and duration of exposure, but not to microcystin concentrations. It is probable that these symptoms are not due to the recognized cyanotoxins listed in Table 8.1, but rather to currently largely unidentified substances.

Allergic reactions to cyanobacteria are frequently reported at the level of "anecdotal evidence" from eutrophic recreational waters, and it has been claimed that "allergic reactions to cyanobacteria are relatively common" (Yoo et al., 1995, p. 77). However, these have been rarely investigated in scientific studies or published. Among the small number of publications available, Heise (1949) described ocular and nasal irritations in swimmers exposed to Oscillatoriaceae. McElhenny et al. (1962) applied extracts from four different algal species, including cyanobacteria and Chlorophyceae (as intracutaneous skin tests), to 20 non-allergic children, none of who responded, and to 120 children with respiratory allergies, 98 of who showed clear positive reactions to at least one of the test strains. Mittal et al. (1979) tested 4000 patients in India with respiratory allergies, 25% of who showed positive reactions to either cyanobacteria or Chlorophyceae, or to both.

Allergic reactions are not confined to cyanobacteria, but may also be evoked by planktonic algae. However, allergic reactions require elevated cell densities in water used for swimming, and mass developments in fresh waters are most frequently due to cyanobacteria. Furthermore, other groups of algae do not accumulate as surface scums, and therefore their metabolites will not occur in comparably high concentrations. Thus, cyanobacteria are likely to be the most frequently occurring cause of such reactions.

8.4.2 Exposure through ingestion or aspiration

Swallowing or aspiration was the exposure route in most of the documented cases of human illness that have been associated with cyanobacteria (Box 8.1). In contrast to dermal contact, uptake of cyanobacteria involves a risk of intoxication by the cyanotoxins listed in Table 8.1. This risk may be estimated from cell density, cellular toxin content and known mechanisms of toxicity. Acute mechanisms of toxicity are well known for the neurotoxins and microcystins, and some information is available to estimate risks due to repeated or chronic exposure.

BOX 8.1 HUMAN ILLNESS ASSOCIATED WITH EXPOSURE TO CYANOBACTERIA

ILLNESS ATTRIBUTED TO CYANOTOXINS IN RECREATIONAL WATER

1959: **Canada:** In spite of a kill of livestock and warnings against recreational use, people still swam in a lake infested with cyanobacteria. Thirteen persons became ill (headaches, nausea, muscular pains, painful diarrhoea). In the excreta of one patient—a medical doctor who had accidentally ingested water—numerous cells of *Microcystis* spp. and some trichomes of *Anabaena circinalis* could be identified (Dillenberg & Dehnel, 1960).

1989: **England:** Ten out of 20 soldiers became ill after swimming and canoe training in water with a heavy bloom of *Microcystis* spp.; two developed severe pneumonia attributed to the inhalation of a *Microcystis* toxin and needed hospitalization and intensive care (Turner et al., 1990). Swimming skills and the amount of water ingested appear to have been related to the degree of illness.

1995: **Australia:** Epidemiological evidence of adverse health effects after recreational water contact from a prospective study involving 852 participants showed elevated incidence of diarrhoea, vomiting, flu symptoms, skin rashes, mouth ulcers, fevers, and eye or ear irritations within 2–7 days after exposure (Pilotto et al., 1997). Symptoms increased significantly with duration of water contact and density of cyanobacterial cells, but were not related to the content of known cyanotoxins.

ILLNESS ATTRIBUTED TO CYANOTOXINS IN DRINKING-WATER

1931: **USA:** A massive *Microcystis* bloom in the Ohio and Potomac rivers caused illness of 5000–8000 people whose drinking-water was taken from these rivers. Drinking-water treatment by precipitation, filtration and chlorination was not sufficient to remove the toxins (Tisdale, 1931).

1968: **USA:** Numerous cases of gastrointestinal illness after exposure to mass developments of cyanobacteria were compiled by Schwimmer & Schwimmer (1968).

1979: **Australia:** Combating a bloom of *Cylindrospermopsis raciborskii* in a drinking-water reservoir on Palm Island with copper sulfate led to liberation of toxins from the cells into the water and resulted in serious illness (with hospitalization) of 141 people supplied from this reservoir (Falconer, 1993, 1994).

1981: **Australia:** In the city of Armidale, liver enzyme activities (a sign of exposure to toxic agents) were found to be elevated in the blood of the population supplied from surface water polluted by *Microcystis* spp. (Falconer et al., 1983).

1985: **USA:** Carmichael (1994) compiled case studies on nausea, vomiting, diarrhoea, fever and eye, ear and throat infections after exposure to mass developments of cyanobacteria.

1988: **Brazil:** Following the flooding of the Itaparica Dam in Bahia State, some 2000 cases of gastroenteritis were reported over a 42-day period, of which 88 resulted in death. Investigation of potential causes of this epidemic eliminated pathogens and identified a very high population of toxic cyanobacteria in the drinking-water supply in the affected areas (Teixera et al., 1993).

1993: **China:** The incidence of liver cancer was related to water sources and was significantly higher for populations using cyanobacteria-infested surface waters than for those drinking groundwater (Yu, 1995).

Continued

1994: **Sweden:** Illegal use of untreated river water in a sugar factory led to an accidental cross-connection with the drinking-water supply for an uncertain number of hours. The river water was densely populated by *Planktothrix agardhii* and samples taken a few days before and a few days after the incident showed these cyanobacteria to contain microcystins. In total, 121 of 304 inhabitants of the village (as well as some dogs and cats) became ill with vomiting, diarrhoea, muscular cramps and nausea (Anadotter et al., 2001).

ILLNESS ATTRIBUTED TO CYANOTOXINS IN WATER USED FOR HAEMODIALYSIS

1975: **USA:** Endotoxic shock of 23 dialysis patients in Washington, DC, was attributed to a cyanobacterial bloom in a drinking-water reservoir (Hindman et al., 1975).

1996: **Brazil:** In total, 131 dialysis patients were exposed to microcystins from the water used for dialysis; 56 died. At least 44 of these victims showed the typical symptoms associated with microcystin, now referred to as "Caruaru Syndrome", and liver microcystin content corresponded to that of laboratory animals having received a lethal dose of microcystin (Jochimsen et al., 1998).

Most documented cases of human injury through cyanotoxins involved exposure through drinking-water, and they demonstrate that humans have become ill—in some cases seriously—through ingestion or aspiration of toxic cyanobacteria. The low number of reported cases may be due to lack of knowledge about the toxicity of cyanobacteria; neither patients nor doctors associate symptoms with this cause. Symptoms reported include "abdominal pain, nausea, vomiting, diarrhoea, sore throat, dry cough, headache, blistering of the mouth, atypical pneumonia, and elevated liver enzymes in the serum, especially gamma-glutamyl transferase" (Carmichael, 1995, p. 9), as well as hay fever symptoms, dizziness, fatigue, and skin and eye irritations; these symptoms are likely to have diverse causes, with several classes of toxin and genera of cyanobacteria involved.

8.5 Evidence for toxicity of algae

Systematic investigation of the toxicity of freshwater algae is required, particularly for species related to toxic marine taxa (dinoflagellates, diatoms, haptophytes). However, as discussed above, freshwater algae are considerably less likely to pose recreational health hazards comparable to those of scum-forming cyanobacteria, because algae lack similarly effective mechanisms of accumulation.

Oshima et al. (1989) isolated and identified three ichthyotoxins (polonicumtoxins A, B and C) from a dinoflagellate, *Peridinium polonicum*. Toxicity in the mouse bioassay was 1.5–2 mg/kg, i.e., several orders of magnitude lower than the toxicity of microcystin-LR. The Ames test showed no mutagenicity, but the authors emphasized the need for studies on chronic toxicity to evaluate the potential health risk of these toxins.

Allergic reactions have been investigated as outlined in section 8.4.1. Skin reactions in response to a bloom of *Uroglena* spp. were observed in a small number of swimmers. These reactions were especially pronounced under bathing suits, where cells accumulated and were partially disrupted during swimming (Chorus, 1993). Divers frequently complain of dermal reactions to algal material accumulating under their wet suits, which tend to act as a strainer that lets out water but collects algae between skin and suit. Pressure and friction between fabric and skin lead to cell disruption, liberation of content and intensified dermal exposure, not only to algal cell wall material, but also to substances otherwise largely confined within the cells.

One of the few reports involved the raphidophyte algal species *Gonyostomum semen* (related to *Heterosigma* mentioned in chapter 7), which may develop high population densities in slightly acidic waters and emits a slimy substance causing skin irritation and allergic reactions. In Sweden, occurrence of this species led to closure of a number of freshwater recreational sites (Cronberg et al., 1988).

8.6 Health risk evaluation

Documented evidence of significant human health impairment exists only for cyanobacteria, not for freshwater algae. Data from surveys in a number of countries show that toxicity is to be expected in about 60% of all samples containing cyanobacteria (Table 8.2). Generally, the liver-toxic microcystins appear to be more common than neurotoxins, although the latter have caused severe animal poisonings in North America, Europe and Australia. Blooms containing cylindrospermopsin have been reported from Australia, Hungary, Japan, Israel and Germany.

While a general picture of the frequency of occurrence of cyanotoxins associated with certain cyanobacterial taxa is emerging, it is less clear what cyanotoxin levels may be expected in recreational waters containing cyanobacteria. Very few studies have addressed the variability of toxin content in the course of the development of cyanobacterial populations (Benndorf & Henning, 1989; Jungmann, 1995; Kotak et al., 1995; Fastner et al., 1999), although this knowledge would be important for risk assessment. This is because the cumulative toxicity of microcystins means that hazards are greatest for persons exposed regularly over a number of days or weeks. For management of recreational waters, a few years of regular investigation of the toxin content of prevalent cyanobacterial blooms may provide information on the variability of toxin content in both time and space. If the toxin content proves to show little variation during several weeks or even months of blooming for certain key species, a basis for future predictions of cellular toxin content from frequent cell counts and only occasional toxin analysis may be established.

Most studies have focused on the quantity of toxins contained in the cells of the dominant cyanobacteria. If the cell density is known in addition to the toxin content per cell, toxin concentrations per litre of water can be calculated. A few studies have directly addressed concentrations per litre, and sensitive detection methods now allow direct determination of toxin concentrations per litre rather than requiring enrichment of cell material.

Generally, the cyanotoxin content of cells can reach levels of several milligrams per gram dry weight. This has been established for microcystins, nodularin, cylindrospermopsin, anatoxin-a and saxitoxins, the maximum being found for nodularin:

18 mg/g dry weight (Sivonen & Jones, 1999). If both toxin content and cell density or biomass of cyanobacteria per litre is known for a given water body, maximum toxin concentrations to be expected can be estimated from such data. As the toxic concentrations depend upon cell density, scum formation is critical in determining cell density. In one study, microcystin concentrations ranged from 0.01 to 0.35 mg/litre while the cyanobacteria were evenly dispersed (Fastner et al., 1999). However, sampling of shoreline scums of the same water bodies showed microcystin concentrations of more than 1 mg/litre in 7 of 34 samples, and maxima reached 24 mg/litre (Chorus & Fastner, 2001). Some commonly occurring species, such as *Planktothrix agardhii*, never form scums. The maximum reported microcystin concentration per litre of water for *P. agardhii* is 0.35 mg/litre (Fastner et al., 1999).

TABLE 8.2. FREQUENCIES OF MASS OCCURRENCES OF TOXIC CYANOBACTERIA IN FRESH WATERS[a]

Country	No. of samples tested	% of toxic samples
Australia	231	42
Australia	31	84[b]
Brazil	16	75
Canada, Alberta	24	66
Canada, Alberta	39	95
Canada, Alberta (three lakes)	226	74[b]
Canada, Saskatchewan	50	10
China	26	73
Czech Republic and Slovakia	63	82
Finland	215	44
France, Brittany	22	73[b]
Germany	533	72[b]
Germany	393	22
Former German Democratic Republic	10	70
Greece	18	?
Hungary	50	66
Japan	23	39
Netherlands	10	90
Portugal	30	60
Scandinavia	81	60
Denmark	296	82
Norway	64	92
Sweden	331	47
United Kingdom	50	48
United Kingdom	50	28[b]
USA, Minnesota	92	53
USA, Wisconsin	102	25
Mean		**59**

[a] From Sivonen & Jones (1999).

[b] High-performance liquid chromatography was used to determine the toxin content of the samples.

For practical purposes, the present state of knowledge implies that health authorities should regard any mass development of cyanobacteria as a potential health hazard.

8.7 Guideline values

As discussed above, approaches to recreational water safety should address the occurrence of cyanobacteria as such, because it is as yet unclear whether all important cyanotoxins have been identified, and the health outcomes observed after recreational exposure—particularly irritation of the skin and mucous membranes—are probably related to cyanobacterial substances other than the well known toxins listed in Table 8.1. Additionally, the particular hazard of liver damage by microcystins should be considered. In face of the difficulty of representative quantitative sampling due to the heterogeneous distribution of cyanobacteria in time and space, particularly with respect to scum formation and scum location, approaches should further include addressing the capacity of a water body to sustain large cyanobacterial populations.

Health impairments from cyanobacteria in recreational waters must be differentiated between the chiefly irritative symptoms caused by unknown cyanobacterial substances and the potentially more severe hazard of exposure to high concentrations of known cyanotoxins, particularly microcystins. A single guideline value therefore is not appropriate. Rather, a series of guideline values associated with incremental severity and probability of health effects is defined at three levels (Table 8.3).

8.7.1 Relatively low probability of adverse health effects

For protection from health outcomes not due to cyanotoxin toxicity, but rather to the irritative or allergenic effects of other cyanobacterial compounds, a guideline level of 20 000 cyanobacterial cells/ml (corresponding to 10 μg chlorophyll-a/litre under conditions of cyanobacterial dominance) can be derived from the prospective epidemiological study by Pilotto et al. (1997). Whereas the health outcomes reported in this study were related to cyanobacterial density and duration of exposure, they affected less than 30% of the individuals exposed. At this cyanobacterial density, 2–4 μg microcystin/litre may be expected if microcystin-producing cyanobacteria are dominant, with 10 μg/litre being possible with highly toxic blooms. This level is close to the WHO provisional drinking-water guideline value of 1 μg/litre for microcystin-LR (WHO, 1998), which is intended to be safe for lifelong consumption. Thus, health outcomes due to microcystin are unlikely, and providing information for visitors to swimming areas with this low-level risk is considered to be sufficient. Additionally, it is recommended that the authorities be informed in order to initiate further surveillance of the site. The results of the epidemiological study (Pilotto et al., 1997) reported some mild irritative effects at 5000 cells but the level of health effect and the small number of people affected were not considered to be a basis to justify action.

8.7.2 Moderate probability of adverse health effects

At higher concentrations of cyanobacterial cells, the probability of irritative symptoms is elevated. Additionally, cyanotoxins (usually cell-bound) may reach concentrations with potential health impact. To assess risk under these circumstances, the data used for the drinking-water provisional guideline value for microcystin-LR

TABLE 8.3. GUIDELINES FOR SAFE PRACTICE IN MANAGING RECREATIONAL WATERS[a]

Guidance level or situation	How guidance level derived	Health risks	Typical actions[b]
Relatively low probability of adverse health effects			
20 000 cyanobacterial cells/ml *or* 10 µg chlorophyll-a/litre with dominance of cyanobacteria	• From human bathing epidemiological study	• Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Post on-site risk advisory signs • Inform relevant authorities
Moderate probability of adverse health effects			
100 000 cyanobacterial cells/ml *or* 50 µg chlorophyll-a/litre with dominance of cyanobacteria	• From provisional drinking-water guideline value for microcystin-LR[c] and data concerning other cyanotoxins	• Potential for long-term illness with some cyanobacterial species • Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Watch for scums or conditions conducive to scums • Discourage swimming and further investigate hazard • Post on-site risk advisory signs • Inform relevant authorities
High probability of adverse health effects			
Cyanobacterial scum formation in areas where whole-body contact and/or risk of ingestion/aspiration occur	• Inference from oral animal lethal poisonings • Actual human illness case histories	• Potential for acute poisoning • Potential for long-term illness with some cyanobacterial species • Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Immediate action to control contact with scums; possible prohibition of swimming and other water contact activities • Public health follow-up investigation • Inform public and relevant authorities

[a] Derived from Chorus & Bartram, 1999.

[b] Actual action taken should be determined in light of extent of use and public health assessment of hazard.

[c] The provisional drinking-water guideline value for microcystin-LR is 1 µg/litre (WHO, 1998).

(WHO, 1998) may be applied. Swimmers involuntarily swallow some water while swimming, and the harm from ingestion of recreational water will be comparable to the harm from ingestion of water from a drinking-water supply with the same toxin content. For recreational water users with whole-body contact (see chapter 1), a swimmer can expect to ingest 100–200 ml of water in one session, sailboard riders and waterskiers probably more.

A level of 100 000 cyanobacterial cells/ml (which is equivalent to approximately 50 µg chlorophyll-a/litre if cyanobacteria dominate) represents a guideline value for a moderate health alert in recreational waters. At this level, a concentration of 20 µg microcystin/litre is likely if the bloom consists of *Microcystis* and has an average toxin content of 0.2 pg/cell, or 0.4 µg microcystin/µg chlorophyll-a. Levels may be approximately double if *Planktothrix agardhii* dominates. With very high cellular microcystin content, 50–100 µg microcystin/litre would be possible.

The level of 20 µg microcystin/litre is equivalent to 20 times the WHO provisional guideline value concentration for microcystin-LR in drinking-water (WHO, 1998) and would result in consumption of an amount close to the tolerable daily intake (TDI) for a 60-kg adult consuming 100 ml of water while swimming (rather than 2 litres of drinking-water). However, a 15-kg child consuming 250 ml of water during extensive playing could be exposed to 10 times the TDI. The health risk will be increased if the person exposed is particularly susceptible because of, for example, chronic hepatitis B. Therefore, cyanobacterial levels likely to cause microcystin concentrations of 20 µg/litre should trigger further action.

Non-scum-forming species of cyanobacteria such as *Planktothrix agardhii* have been observed to reach cell densities corresponding to 250 µg chlorophyll-a/litre or even more in shallow water bodies. Transparency in such situations will be less than 0.5 m measured with a Secchi disc. *Planktothrix agardhii* has been shown to contain very high cell levels of microcystin (1–2 µg microcystin/µg chlorophyll-a), and therefore toxin concentrations of 200–400 µg/litre can occur without scum formation.

An additional reason for increased alert at 100 000 cells/ml is the potential for some frequently occurring cyanobacterial species (particularly *Microcystis* spp. and *Anabaena* spp.) to form scums. These scums may increase local cell density and thus toxin concentration by a factor of 1000 or more in a few hours (as illustrated in Figure 8.1), thus rapidly changing the risk from moderate to high for bathers and others involved in body-contact water sports. Cyanobacterial scum formation presents a unique problem for routine monitoring at the usual time intervals (e.g., 1 or 2 weeks) because such monitoring intervals are unlikely to pick up hazardous maximum levels. Because of the potential for rapid scum formation at a cyanobacterial density of 100 000 cells/ml or 50 µg chlorophyll-a/litre (from scum-forming cyanobacterial taxa), intensification of surveillance and protective measures are appropriate at these levels. Daily inspection for scum formation (if scum-forming taxa are present) and measures to prevent exposures in areas prone to scum formation are the two principal actions important in these situations.

Intervention is recommended to trigger effective public information campaigns to educate people on avoidance of scum contact. Furthermore, in some cases (e.g., areas with frequent scum formation), restriction of water contact activities may be judged to be appropriate. An intensified monitoring programme should be implemented, particularly looking for scum accumulations. Health authorities should be notified immediately.

8.7.3 High probability of adverse health effects

Abundant evidence exists for potentially severe health outcomes associated with scums caused by toxic cyanobacteria. No human fatalities have been unequivocally associated with cyanotoxin ingestion during recreational water activities, although numerous animals have been killed by consuming water with cyanobacterial scum material. This discrepancy can be explained by the fact that animals will drink greater volumes of scum-containing water in relation to their body weight, whereas accidental ingestion of scums by humans during swimming will typically result in a lower dose.

Cyanobacterial scums can represent thousand-fold to million-fold concentrations of cyanobacterial cell populations. Calculations suggest that a child playing in *Microcystis* scums for a protracted period and ingesting a significant volume could receive a lethal dose, although no reports indicate that this has occurred. Based on evidence that a lethal oral dose of microcystin-LR in mice is 5000–11 600 μg/kg body weight and sensitivity between individuals may vary approximately 10-fold, the ingestion of 5–50 mg of microcystin could be expected to cause acute liver injury in a 10-kg child. Concentrations of up to 24 mg microcystin/litre from scum material have been published (Chorus & Fastner, 2001). Substantially higher enrichment of scums—up to gelatinous consistency—is occasionally observed, of which accidental ingestion of smaller volumes could cause serious harm. Anecdotal evidence indicates that children, and even adults, may be attracted to play in scums. The presence of scums caused by cyanobacteria is thus a readily detected indicator of a risk of potentially severe adverse health effects for those who come into contact with the scums. Immediate action to control scum contact is recommended for such situations.

8.7.4 Conclusions

The approach outlined in this section does not cover all conceivable situations. Swimmers may be in contact with benthic cyanobacteria after a storm breaks off clumps of filaments or cyanobacterial mats naturally detach from the sediment and are accumulated on shorelines (Edwards et al., 1992). Measures of cyanobacterial cell density will not detect these hazards. Instead, this cyanotoxin hazard calls for critical and well informed observation of swimming areas, coupled with a flexible response.

It is difficult to define "safe" concentrations of cyanobacteria in recreational water for allergenic effects or skin reactions, as individual sensitivities vary greatly. Aggravation of dermal reactions due to accumulation of cyanobacterial material and enhanced disruption of cells under bathing suits and wet suits may be a problem even at densities below the guideline levels described above.

8.8 Management options

For purposes of management, it is important to understand that cyanotoxins are chiefly found within cyanobacterial cells. Liberation into the surrounding water is possible, particularly when cells die and lyse, and differences may occur between toxins and species regarding "leakage" from intact cells. However, toxin dissolved in water is rapidly diluted and probably also degraded, whereas hazardously high toxin concentrations usually result from the accumulation of cell material as scums.

Because adequate surveillance is difficult and few immediate management options are available (other than precluding or discouraging use or cancelling water sports activities such as competitions), provision of adequate public information is a key short-term measure. Medium- to long-term measures are identification of the sources of nutrient (in many ecosystems phosphorus, sometimes nitrogen) pollution and significant reduction of nutrient input in order to effectively reduce proliferation not only of cyanobacteria, but of potentially harmful algae as well.

8.8.1 Short-term measures

Providing adequate information to the public on the cyanobacterial risk associated with using a particular recreational water area is important not only for avoiding this hazard, but also for understanding symptoms potentially caused by exposure and identifying their cause. Communication of warnings to the public may occur through local news media, by posting warning notices and through other means. They may accompany information on other recreational water quality parameters regularly monitored by the authorities and/or some further information on cyanobacteria.

Differentiation between the degree of water contact in different types of water sports should be included in warning notices. Information on the frequently transient nature and very variable local distribution of scums is important to convey the message that recreational activities are restricted only temporarily and often only very locally, and that in such cases acceptable water quality may be found nearby, e.g., at another site of the same lake.

As a precaution, the following guidance is recommended for all freshwater-based recreation and should be included in public information:

- Avoid areas with visible cyanobacterial or algal concentrations and/or scums in the water as well as on the shore. Direct contact and swallowing appreciable amounts are associated with the greatest health risk.
- Where no scums are visible, but the water shows strong greenish discoloration and turbidity, test if you can still see your feet when standing knee-deep in the water (after wading in without stirring up sediment). If not, avoid bathing—or at least avoid ingestion of water, i.e., submersion of your head.
- In such situations, avoid water-skiing because of potentially substantial exposure to aerosol.
- If sailing, sailboarding or undertaking any other activity likely to involve accidental water immersion in the presence of cyanobacterial or algal blooms, wear clothing that is close fitting in the openings. The use of wet suits for water sports may result in a greater risk of rashes, because cyanobacterial or algal material in the water trapped inside the wet suit will be in contact with the skin for long periods of time.
- After coming ashore, shower or wash yourself down to remove cyanobacterial or algal material.

- Wash and dry all clothing and equipment after contact with cyanobacterial or algal blooms and scum.

8.8.2 *Long-term measures*

The aim of long-term measures to minimize health risks due to toxic algae and cyanobacteria is to prevent or reduce the formation of cyanobacterial blooms in water used for recreational water activities. This can be achieved by keeping total phosphorus concentrations below the "carrying capacity," which sustains substantial population densities. Experience from numerous water bodies shows that this can be achieved if total phosphorus concentrations are 0.01–0.03 µg/litre (depending somewhat on the size and mixing regime of the water body).

This threshold may be difficult to reach in water bodies with multiple sources of nutrient pollution. However, nutrient sources are locally very variable. Therefore, identifying the chief sources and developing strategies for preventing the formation of cyanobacterial blooms are recommended and may in many cases prove to be more feasible than initially assumed (Chorus & Mur, 1999). In particular, nutrient input from agricultural runoff may in many cases be reduced by decreasing the application of fertilizers to match the actual demand of the crop or by protecting the shoreline from erosion by planting shrubs along a buffer strip about 20 m wide along the shoreline, rather than ploughing and fertilizing to the very edge of the water.

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CHAPTER 9

Aesthetic issues

Aesthetic issues play an important role in the public's perception of a recreational water area, for example public opinion surveys about desirable seaside resort characteristics have found that some 10% of respondents cite the importance of a clean beach (Oldridge, 1992). The principal aesthetic concern is revulsion associated with obvious pollution of the water body, turbidity, scums or odour (which may relate to inadequate levels of dissolved oxygen, see chapter 10). Pollution may cause nuisance for local residents and tourists as well as environmental problems and may lessen the psychological benefits of tourism (WHO, 1980). In this chapter, the aesthetic parameters that affect the acceptability of a recreational water area are described.

9.1 Aesthetic parameters

The general aesthetic acceptability of recreational water can be expressed in terms of criteria for transparency, odour and colour. It has been suggested that values for light penetration, colour and turbidity should not be significantly increased over natural background. The aesthetic value of recreational water areas implies freedom from visible materials that will settle to form objectionable deposits, floating debris, oil, scum and other matter, substances producing objectionable colour, odour, taste or turbidity, and substances and conditions that produce undesirable aquatic life (Department of National Health and Welfare, Canada, 1992).

9.1.1 Transparency and colour

Safety hazards associated with turbid or unclear water depend on the intrinsic nature of the water itself. 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 who may be in difficulty (see chapter 2). Aside from the safety factor, clear water fosters enjoyment of the aquatic environment. The clearer the water, the more desirable the swimming area (National Academy of Sciences, 1973). The principal factors affecting the depth of light penetration in natural waters include suspended microscopic algae and animals, suspended mineral particles, stains that impart a colour (iron, for example, may impart a reddish colour to water), detergent foams and dense mats of floating and suspended debris, or a combination of these factors.

There are two measures of colour in water—true and apparent. The true colour of natural water is the colour of water from which turbidity has been removed (i.e., filtered water). Natural minerals give true colour to water; for example, calcium carbonate in limestone regions gives a greenish colour, ferric hydroxide, red. Organic substances, tannin, lignin and humic acids from decaying vegetation also give true colour to water (Reid & Wood, 1976). Apparent colour is an aesthetic quality and cannot be quantified. It is usually the result of the presence of coloured particulates, the interplay of light on suspended particles and such factors as reflection of the bottom or sky. An abundance of (living) blue-green algae (cyanobacteria) may impart a dark green hue; diatoms give a yellow or yellow-brown colour; some algae impart a red colour. Zooplankton, particularly microcrustaceans, may occasionally tint the water red (Reid & Wood, 1976). The causes of colour in marine waters are not thoroughly understood, but dissolved substances are one of the contributory factors. The blue of the sea is a result of the scattering of light by water molecules, as in inland waters. Suspended detritus and living organisms give colours ranging from brown through red and green. Estuarine waters have a different colour to the open sea; the darker colours result from the high turbidity usually found in such situations (Reid & Wood, 1976). This characteristic colour can also impact on coastal recreational waters receiving estuarine input, where public perception may be that the colour change represents some form of pollution as illustrated in Box 9.1.

BOX 9.1 AESTHETIC REVULSION RELATING TO WATER COLOUR PRODUCED BY A NON TOXIC ALGAL BLOOM

Within the monitoring programme for bathing waters of Catalunya (NE Spain), which is the responsibility of *l'Agència Catalana de l'Aigua—Departament de Medi Ambient-Generalitat de Catalunya*, a persistent problem was detected at La Fosca beach (Costa Brava) characterised by the discoloration 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 wastewater and sewage inputs. An intensive monitoring programme was conducted, this included:

- sanitary inspection of the beach and sewage system to search for unauthorised outlets;
- inspection of possible inland water influence;
- study of the temporal and spatial variations of the microbial water quality;
- analysis of physico-chemical parameters;
- study of sediments and flora, and finally;
- an investigation of phytoplankton.

The programme (which cost US$35,000 at 1994–1996 prices) unequivocally ruled out wastewater or sewage inputs. The discoloration was eventually attributed to a non-toxic dinoflagellate *Alexandrium taylori* (Delgado et al., 1997). Once the origin of the problem was identified a series of press conferences and a local publicity campaign was undertaken to inform the public. *A. taylori* had not previously been identified in the Mediterranean. Since its identification at La Fosca, however, it has been reported at other Mediterranean locations (Garcés et al., 2000).

This incident illustrates that not all water discoloration should be assumed to be due to sewage pollution. In this instance a preliminary investigation to identify dinoflagellate species would have saved both 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 local level because many waters may have naturally high levels of turbidity/colour. It is, therefore, more common that reference to changes from the normal situation be used to indicate potential water pollution.

9.1.2 Oil, grease and detergents

Even very small quantities of oily substances make water aesthetically unattractive (Environment Canada, 1981). Oils can form films on the surface, and some oil-derived substances, such as xylenes and ethylbenzene, which are volatile, may also give rise to odours or tastes, even though they are of low toxicity. In some countries (e.g., Canada), it has been reasoned that oil or petrochemicals should not be present in concentrations that can be detected as a visible film, sheen or discoloration on the surface, be detected by odour or form deposits on shorelines and bottom sediments that are detectable by sight or odour (International Joint Commission, 1977; Department of National Health and Welfare, Canada, 1992) (see also chapter 10). It is difficult to establish criteria for oil and grease, as the mixtures falling under this category are very complex. Tar may also present a problem on the shore; this can be removed by mechanical cleaning of the sand (see chapter 6).

Detergents can give rise to aesthetic problems if foaming occurs, particularly since this can be confused with foam caused by the by-products of algal growth (see chapters 7 and 8; Bartram & Rees, 2000 chapter 10).

9.1.3 Litter

Beach litter is derived from three main sources: marine, riverine (including torrents) and beach user discards. Visitor enjoyment of any beach is likely to be marred by litter, although litter perception varies with respect to many parameters, such as age, socioeconomic status and gender. Although not litter, as such, large accumulations of seaweed and algae are likely to be an aesthetic problem (both in terms of visual impact and odour) and also, if associated with flying and/or biting insects, a nuisance (see chapter 11).

The variety of litter found in recreational water or washed up on the beach is considerable. Some examples of unwanted recreational water flotsam and jetsam include wooden crates and palettes, cardboard cartons, newspaper, steel drums, plastic containers and foam products, rubber goods such as vehicle tyres, bottles and cans, dead animals or animal bones, human hair, discarded clothing, hypodermic syringes, needles and other medical wastes, bottle tops, cigarette butts and packets, matchsticks, fish netting and rope ends.

Litter counts have been considered as possible proxy indicators for the likelihood of gastrointestinal effects associated with swimming. For example, high incidence rates of self-reported gastrointestinal illness after bathing in sewage-polluted water have been associated with public perceptions of different items affecting the aesthetic appearance of recreational water and beaches (University of Surrey, 1987). The presence of the following items was positively correlated with the likelihood of self-reported gastrointestinal symptoms: discarded food/wrapping, bottles/cans, broken bottles, paper litter, dead fish, dead birds, chemicals, oil slicks, human/animal excrement (particularly from dogs, cats, cattle or birds), discarded condoms and discarded sanitary towels.

9.1.4 Odour

Objectionable smells associated with sewage effluent, decaying organic matter such as vegetation, dead animals or fish, and discharged diesel oil or petrol can deter recreational water and beach users. Odour thresholds and their association with the concentrations of different pollutants of the recreational water environment have not been determined. The presence of dissolved oxygen in the water body will be of great importance in preventing the formation of undesirable amounts of odorous hydrogen sulfide (see chapter 10).

9.1.5 Noise

Traffic on nearby roads, trade hawkers and indiscriminate use of beach buggies, motorbikes, portable radios and hi-fi equipment, motorboats and jet skis can all impact on tranquillity for the beach and water user; at the same time, some people thrill to noisy activities (Velimirovic, 1990). Mindful of the need for mutual respect (WHO, 1989), zoning of areas for different activities is often undertaken.

9.2 Economic consequences

The public often perceives the quality of recreational water to be very different from its actual microbial and/or chemical quality (Philipp, 1994). Some studies have shown that rivers of good microbial or chemical quality have been perceived as poor by the public because of aesthetic pollution (Dinius, 1981; House, 1993). Poor aesthetic recreational water and beach quality may, however, also imply poor microbial/chemical water quality.

The economic aspects associated with cleaning the coastline have previously been reviewed (Bartram & Rees, 2000). Local economies may depend on the aesthetic quality of recreational water areas, and many fear that environmental degradation of beaches could lead to loss of income from tourism (WHO, 1990; Godlee & Walker, 1991; Philipp, 1992). At resort beaches, litter may have an economic effect on the region. During 1987 and 1988, beach closures in New York and New Jersey, USA, due to litter accumulation, together with the public's perception of degraded beach and water quality, cost the local economy several billion dollars (Valle-Levinson & Swanson, 1991).

The upper Adriatic coast of the Mediterranean Sea was hit during the 1989 summer season by a very severe episode of eutrophication, which, together with mucilage caused by the production of viscous substances from benthic micro-algae, generated considerable concern among tourists about their health. The unpleasant sight of large tracts of this viscous amorphous substance along the shoreline resulted in a large number of beaches along the Italian coastline becoming temporarily unsuitable for bathing (WHO, 1990). There was a 40% reduction in local tourism as a consequence of this (Philipp, 1992), and aesthetic considerations alone were sufficient to prevent would-be bathers from entering the water (WHO, 1990). The economic effects attributed to the loss of use of the environment for tourists and other economic purposes were:

- loss of tourist days;
- damage to the local tourist infrastructure (loss of income for hotels, restaurants, bathing resorts, other amenities, etc.);
- damage to tourist-dependent activities (loss of income for clothing manufacture, food industry, general commerce, etc.);
- damage to fisheries activities (reduction in fish catch, depreciation of the price of seafood);
- damage to fisheries-dependent activities (fishing equipment production and sales, fisheries products, etc.); and
- damage to the image of the Adriatic coast as a recreational resort at both national and international levels (WHO, 1990; Philipp, 1992).

A further economic factor that should be taken into consideration is the health care cost associated with beach litter, in particular hospital waste washed up on beaches (Philipp, 1991; Walker, 1991; Anon., 1994). The direct health care costs arising from discarded hypodermic syringe needles have been studied and found to be considerable (Philipp, 1993).

9.3 Marine debris monitoring

Methods to undertake marine debris surveys have been presented and discussed elsewhere (Bartram & Rees, 2000 chapter 12). The purposes of marine debris monitoring may include one or more of the following:

- to provide information on the types, quantities and distribution of marine debris (Williams & Simmons, 1997);
- to provide insight into problems and threats associated with an area (Rees & Pond, 1995);
- to assess the effectiveness of legislation and coastal management policies (Earll et al., 1997);
- to identify sources of marine debris (Earll et al., 1997);
- to explore public health issues relating to marine debris (Philipp et al., 1993, 1997); and
- to increase public awareness of the condition of the coastline (Rees & Pond, 1995).

In the United Kingdom, for example, one series of studies identified a 4-fold deterioration in coastal environmental quality during three consecutive years (Philipp et al., 1994). The results helped to justify national legislation for tighter controls on discharges from seawater sewage outfall pipes and the removal of screenings for disposal elsewhere, better provision and emptying of litter bins and improved advice for the public (Philipp et al., 1994, 1997). In Catalunya (Spain), a programme of aesthetic monitoring was undertaken to supplement microbial water quality data (Box 9.2).

BOX 9.2 VISUAL INSPECTION AND MICROBIAL WATER QUALITY

The monitoring programme conducted in the Catalunya region of NE Spain has been implemented to provide the public with information on the aesthetic aspects of water and sand in combination with data on microbial water quality. Microbial water quality monitoring is conducted once a week, while aesthetic aspects are assessed more frequently (up to five times a week). Data is collected on the presence and amount of:

- plastics;
- sanitary residues;
- algae;
- tar;
- oil;
- litter;
- abnormal water colour; and
- anything else that may cause aesthetic revulsion.

In addition, information on how thoroughly a beach is machine cleaned and how frequently litter containers are emptied is recorded.

The aesthetic data are processed alongside the microbial water quality data and result in a combined grading for the beach. Aesthetic aspects are considered to be so important that an excellent microbial grading may be reduced to good or even poor if the beach looks bad.

Municipalities, tourist information offices, NGOs, 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 and the results of the visual inspection along with suggestions for improvements. This system gives confidence to the public that their concerns are being taken seriously and has also encouraged many municipalities to improve the aesthetic aspects of their bathing areas.

The reliability and validity of litter counts as measures of health protection need to be tested among different populations and in different exposure situations (Philipp et al., 1997). Beach surveys for the extent of littering are, however, useful as indicators of the need for behavioural change (WHO, 1994). To be worthwhile in the research context, litter counts, as measures of aesthetic quality and as potential indicators of the likelihood of illness associated with the use of the recreational water area, must be able to:

- classify different levels of beach and water quality and the density of different litter and waste items before and after any environmental improvements or cleansing operations;

- be useful when compared with conventional microbial and chemical indicators of recreational water and beach quality;
- differentiate the density of different pollutants deposited by the public on beaches from pollutants that originated elsewhere and were then washed ashore;
- show consistent findings when used in studies of similar population groups exposed to the same pollutant patterns; and
- show a correlation with variations in the human population density of recreational water and beaches (Philipp, 1992; IEHO, 1993; Philipp et al., 1997).

Large-scale monitoring programmes for marine debris often rely on volunteers to survey the beaches and collect data (Marine Conservation Society, 2002). It is, however, not usually possible, with staffing constraints, to verify the findings in a sample of locations before the next high tide. Tide changes can, too, be accompanied by changes in water currents and wind direction. Nevertheless, reliable data can be collected if comprehensive guidance is given to ensure comparable approaches by different groups of volunteers and if validated questionnaire methods are used in consistent and uniform ways. Internal cross-checks of such methods have been undertaken, and they have confirmed consistency of the data collected (Philipp et al., 1993).

9.4 Guideline values and management

As guidelines are aimed at protecting public health, no guideline values have been established for aesthetic aspects. Aesthetic aspects, however, are important in terms of maximizing the benefit of recreational water use.

In terms of aesthetic factors, questions frequently raised for local managerial consideration include the following (Philipp, 1993):

- Are wastes there?
- If present, where are the wastes coming from?
- Are they causing aesthetic problems?
- Could the aesthetic problems be responsible for economic losses in the local community?
- Can the effects (if any) be stopped?
- Who should control the problems?
- What will it cost, and can any loss of environmental opportunity be measured?

Mechanical beach cleaning (see also chapter 6 and Bartram & Rees, 2000 chapter 12) usually involves motorized equipment utilizing 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 areas for visitors. In areas with, for example, medical waste, sewage-related debris or other potentially harmful items, it reduces health risks for those cleaning the beach, because no manual picking up of material is involved. The utilization of mechanical cleaning at rural beaches has been questioned, as such cleaning affects local ecology (Llewellyn & Shackley, 1996).

Other strategies for keeping beaches free of litter include providing waste bins on beaches and emptying them frequently, suggesting that recreational water users take their litter home with them and using people to manually pick up litter.

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CHAPTER 10

Chemical and physical agents

Chemical contaminants can enter surface waters or be deposited on beaches from both natural and anthropogenic sources. These may be either point sources, such as an industrial outfall or a natural spring, or non-point (diffuse) sources, such as runoff from land. In most cases, there will be significant dilution or attenuation of contaminants, depending on circumstances. In all cases, chemical and physical contamination must be assessed on a local basis.

The potential risks from contamination of recreational water environments by chemical and physical agents are described in this chapter. Chemical and physical agents may also lead to degradation of the aesthetic quality of recreational water environments, which is addressed in chapter 9. Toxins from cyanobacteria and algae, while chemical in nature, are addressed in chapters 7 and 8.

10.1 Exposure assessment

Exposure is one of the key issues in determining the risk of toxic effects from chemicals in recreational waters. The form of recreational activity will therefore play a significant role. Routes of exposure will be direct surface contact, including skin, eyes and mucous membranes, inhalation and ingestion. In assessing the risk from a particular contaminant, the frequency, extent and likelihood of exposure are important parts of the evaluation.

Generally, exposure of skin and mucous membranes is most frequent. For activities involving whole-body contact, the probability that some water will be ingested increases. The skill of the participant in their water recreation activity will be important in determining the extent of involuntary exposure, particularly by ingestion.

Inhalation can be important in circumstances where there is a significant amount of spray, such as in waterskiing or white water canoeing. Generally, however, inhalation is of greater significance in swimming pools and related environments where disinfection is practised (see Volume 2 of *Guidelines for Safe Recreational Water Environments*).

The use of wet suits implies that long periods may be spent in the water. In addition, by trapping water against the skin, the wet suit will create a micro-environment that will enhance the absorption of chemicals through the skin and potentially the development of skin irritation or allergy (see also chapters 7 and 8).

Many substances of potential concern are of low water solubility and will tend to migrate to sediments, where they may accumulate. Where the sediments remain undisturbed, this is of low concern. However, where the sediment is disturbed and resuspended or where recreational water users are in intimate contact with sediment, then this may contribute to exposure. This can result in increased skin exposure, but little is known of the quantitative movement of chemicals adsorbed on sediment through skin. In general, it is probable that this will make only a minor contribution to overall exposure.

10.2 Hydrogen ion concentration (pH)

pH has a direct impact on the recreational users of water only at very low or very high values. Under these circumstances, pH may have effects on the skin and eyes.

Primary irritation of the skin appears to be linked to high pH, although the mechanism is unclear. It is unlikely that irritation or dermatitis would be caused directly by high or low pH, although these conditions may be exacerbated, particularly in sensitive subjects.

High or low pH may also to and exacerbate irritation of the eye by chemicals. However, no adverse effects on the eye were noted in a study by Basu et al. (1984), who examined the capacity of water from two inland lakes in Ontario, Canada (Clearwater Lake: pH ~4.5, acid neutralizing capacity 40 µeq/litre; Red Chalk Lake: pH ~6.5, acid neutralizing capacity 70 µeq/litre), to cause eye irritation in rabbits and human volunteers.

Water of high pH could have an adverse effect on hair condition by causing the hair fibres to swell and by cleaving the cystine bridges between adjacent polypeptide chains of hair protein. However, the impact will also be dictated by the buffering capacity of the water.

In very soft and poorly buffered waters with an alkalinity of less than about 40 mg of calcium carbonate per litre, pH will be more susceptible to wide fluctuations. In well buffered waters, pH is much less likely to reach extreme values, but the significance of high or low pH for skin reactions and eye irritation will be greater.

10.3 Dissolved oxygen

Dissolved oxygen will not have a direct effect on users, but it will influence microbial activity and the chemical oxidation state of various metals, such as iron. It will be of great importance in preventing the formation of undesirable amounts of hydrogen sulfide. These factors are not a human health concern, but may give rise to aesthetic issues (see chapter 9). These problems will not occur in waters with sufficient dissolved oxygen.

10.4 Chemical contaminants

In general, the potential risks from chemical contamination of recreational waters, apart from toxins produced by marine and freshwater cyanobacteria and algae (chapters 7 and 8), marine animals (chapter 11) or other exceptional circumstances, will be very much smaller than the potential risks from other hazards outlined in chapters 2–5). It is unlikely that water users will come into contact with sufficiently high concentrations of most contaminants to cause adverse effects following a single exposure. Even repeated (chronic) exposure is unlikely to result in adverse effects at the concentrations of contaminants typically found in water and with the exposure patterns of most recreational water users. However, it remains important to ensure that chemical hazards and any potential human health risks associated with them are recognized and controlled and that users can be reassured as to their personal safety.

For recreational water area users, the dangers of chemical contamination will depend on the particular circumstances of the area under consideration. For example, a fast-flowing upland river, remote lakes or drinking-water reservoir used for recreation will be unlikely to suffer from significant chemical contamination. However, slow-flowing lowland rivers, lowland lakes and coastal waters may be subject to continuous or intermittent discharges and may have suffered from past pollution, which could result in contaminated sediments. Where motorboats are used extensively, chemical contamination of the water by gasoline additives may cause concern. Where a water body used for recreational purposes receives significant wastewater discharges, its chemical constitution and how recreational areas will be influenced should be considered, taking into account both the dilution and dispersion of the discharge.

In general, significant contamination by naturally occurring contaminants is less likely than contamination by industrial, agricultural and municipal pollution, but there may be circumstances where small recreational water bodies containing water from mineral-rich strata could contain high concentrations of some substances. Such waters, however, are more likely to contain metals, such as iron, that may give rise to aesthetic degradation of the water (see chapter 9).

There is a great deal of anecdotal evidence regarding skin rashes and related effects in individuals coming into contact with chemically contaminated water. Except in circumstances of extreme contamination or the presence of algal blooms (covered in chapters 7 and 8), evidence amenable to critical scientific evaluation is not available.

10.5 Guideline values

The chemical quality of recreational waters does not seem to represent a serious health risk for recreational water users, and in most cases the concentration of chemical contaminants will be below drinking-water guideline values. There are no specific rules that can easily be applied to calculate guideline values for chemical contaminants in recreational waters. However, as long as care is taken in their application, the WHO *Guidelines for Drinking-water Quality* (WHO, 1993, 1998) can provide a starting point for deriving values that could be used to make a screening level risk assessment under specific circumstances.

WHO drinking-water guideline values relate to water ingestion and, in most cases, to lifetime exposure. However, drinking-water guidelines may be related to recreational exposure. Mance et al. (1984) suggested that environmental quality standards for chemicals in recreational waters should be based on the assumption that recreational water makes only a relatively minor contribution to intake. They assumed a contribution for swimming of an equivalent of 10% of drinking-water consumption. Since most authorities (including WHO) assume consumption of 2 litres of drinking-water per day, this would result in an intake of 200 ml per day from recreational contact with water.

A simple screening approach is therefore that a substance occuring in recreational water at a concentration ten times that stipulated in the drinking-water guidelines may merit further consideration.

10.5.1 Inorganic contaminants

Most recreational exposure to inorganic contaminants will be by ingestion, with dermal contact and inhalation contributing little to exposure. Based on the assumptions given above, screening values for the ingestion of inorganic contaminants in recreational waters can be calculated from the WHO *Guidelines for Drinking-water Quality* (WHO, 1993, 1998). However, if the corresponding value for a particular inorganic contaminant is exceeded, this does not necessarily imply that a problem exists. Rather, it suggests the need for a specific evaluation of the contaminant, taking into consideration local circumstances and conditions of the recreational water area (see section 10.6). These could include, for example, the characteristics of the typical recreational water user, the degree of water contact of the recreational water activities carried out, effects of winds/currents/tides on contaminant concentration and the chemical form of the inorganic contaminant. For example, the chemical form of metals may significantly affect their solubility and absorption, and this should be taken into account in assessing any potential risks from exposure.

10.5.2 Organic contaminants

There are many organic contaminants that can be present in surface waters as a consequence of industrial and agricultural activity. Many of these substances will primarily be associated with sediments and particulate matter. This is particularly true of substances that are highly lipophilic, such as chlorinated biphenyls.

Skin absorption from contact with sediment is a possibility that cannot be ruled out, however, for most recreational purposes the extent of contact is likely to be small. However, consideration should be given to the likelihood of sediment being disturbed and the possibility of ingestion by some groups, such as infants and small children.

Some small chlorinated molecules (e.g., chloroform or tri- and tetrachloroethene) and hydrocarbons (e.g., toluene) have been shown to be absorbed through skin from water. A study by the US EPA (1992) concluded that the contribution from skin absorption and inhalation could contribute as much again as water ingestion.

As with inorganic contaminants, the WHO *Guidelines for Drinking-water Quality* (WHO, 1993, 1998) can be used as a basis for screening the potential risk from specific organic chemicals. Again, if the screening value for a particular organic contaminant is exceeded, this does not necessarily imply that a problem exists (see section 10.6). Rather, it suggests the need for a specific evaluation of the contaminant, taking into consideration local circumstances and conditions.

10.6 Approach to assessing chemical hazards in recreational waters

1. An inspection of the recreational water area will show if there are any obvious sources of chemical contamination, such as outfalls. These are a problem if they

are easily accessible or if the effluent does not receive immediate and significant dilution. Intelligence on past industry in the recreational area and upstream will give an indication of whether contaminated sediments are likely to be present and also the identity of possible contaminants. Knowledge is required of upstream industry and whether direct or indirect discharges are made to the water.

2. The pattern and type of recreational use of the water need to be carefully considered to determine the degree of contact with the water and if there is a significant risk of ingestion.
3. If it is probable that contamination is occurring and there is significant exposure of users, then chemical analysis will be required to support a quantitative risk assessment. Care should be taken in designing the sampling programme to account for variation in time and water movement. If resources are limited and the situation complex, then samples should first be taken at the point considered to give rise to the worst case; only if this gives rise to concern is there a need for wider sampling.
4. The quantitative risk assessment should consider the anticipated exposure in terms of both dose (i.e., is there significant ingestion?) and frequency of exposure. The WHO *Guidelines for Drinking-water Quality*, which provide a point of reference for exposure through ingestion, with a few exceptions described in the guideline summaries, relate to lifetime exposure.
5. It is important that the basis of any guidelines or standards, which are considered to be necessary, be made transparent. Without this, there is a danger that even occasional or trivial exceedances could unnecessarily undermine users' confidence.

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CHAPTER 11

Dangerous aquatic organisms

Dangerous aquatic organisms may be encountered during recreational use of freshwater and coastal environments (Halstead, 1988; Williamson et al., 1996). Such organisms vary widely and are generally of local or regional importance. The likelihood and nature of human exposure often depend significantly on the type of recreational activity concerned.

Because of the wide variety of organisms that may be encountered, this chapter summarizes only those known to have caused significant ill-health, injury or death to recreational water users. These include both non-venomous organisms (disease vectors, "in-water" hazardous organisms and "water's-edge" hazardous organisms) and venomous vertebrates and invertebrates (see Table 11.1). Space prohibits full coverage of their geographic distribution, identification, management or first aid treatment. Readers are advised to turn to specialized texts for such information, such as the WHO publication *International Travel and Health*, which is updated annually and is available on the internet (http://www.who.int/ith). Rats, which may spread illnesses such as leptospirosis, are not included but are covered in chapter 5.

Two types of risks can be distinguished in relation to dangerous aquatic species. The first type of risk is infectious disease transmitted by species with life cycles that are linked to the aquatic environment. The second type is injury or intoxication (e.g., ciguatera, histamine poisoning, shellfish and so on) resulting from direct encounters with large animals or venomous species. Injuries from encounters with dangerous aquatic organisms are generally sustained in one of the following ways:

- accidentally brushing past a venomous sessile or floating organism when swimming;
- entering waters frequented by dangerous jellyfish (e.g., box jellyfish);
- inadvertently treading on a stingray, weeverfish or sea urchin;
- unnecessary handling of venomous organisms during seashore exploration;
- invading the territory of large animals when swimming or at the waterside;
- swimming in waters used as hunting grounds by large predators; or
- intentionally interfering with, or provoking, dangerous aquatic organisms.

Perceived risks involving dangerous aquatic organisms may have important economic repercussions in areas that depend to a large extent on recreational tourism as a source of income. An example is the decline in South African tourists visiting Lake Malawi because of news reports about schistosomiasis (bilharzia) cases. Similarly, news about malaria outbreaks in East Africa and dengue outbreaks in the Caribbean

TABLE 11.1. RELATIVE RISK TO HUMANS POSED BY SEVERAL GROUPS OF AQUATIC ORGANISMS

Organism	Discomfort	Requires further medical attention	May require emergency medical attention
Non-venomous organisms			
Sharks		✓	✓✓
Barracudas		✓	
Needlefish		✓	✓✓
Groupers		✓	
Piranhas		✓	
Conger eels		✓	
Moray eels		✓	
Electric fish		✓	✓✓
Seals and sea lions		✓	
Hippopotami		✓	✓✓
Crocodiles and alligators		✓	✓✓
Venomous invertebrates			
Sponges	✓	✓	
Hydroids	✓	✓	
Portuguese man-of-war	✓	✓	✓✓
Jellyfish	✓	✓	
Box jellyfish		✓	✓✓
Hard corals	✓	✓	
Sea anemones	✓	✓	
Blue-ringed octopus		✓	✓✓
Cone shells		✓	✓✓
Bristleworms	✓	✓	
Crown of thorns starfish	✓	✓	
Sea urchins (most)	✓		
Flower sea urchin		✓	✓(✓)
Venomous vertebrates			
Stingrays		✓	✓✓
Stonefish		✓	✓(✓)
Other spiny fish (e.g., catfish, weeverfish, etc.)	✓	✓	
Surgeonfish	✓	✓	
Sea snakes		✓	✓✓
Water moccasin		✓	✓

✓✓—associated with fatalities ✓(✓)—probably associated with fatalities.

have had a serious impact on local economies. Incidents that have less effect on general public health, such as repeated shark attacks, usually have a less intense, and shorter-lived, impact in this sense.

Many serious incidents can be avoided through an increase in public education and awareness. It is therefore important to identify and assess the hazards posed by various aquatic organisms in a given region and bring the results to public attention. Awareness raising should be targeted at groups at particular risk (such as those known to have suffered adverse health effects), which may include local and/or visiting populations. In addition, at locations where hazards involving dangerous aquatic organisms have been identified, procedures should be developed for treating any injuries sustained.

11.1 Disease vectors

Animals that carry diseases are typically small and in themselves relatively harmless, with only a few individuals of a population carrying the disease. If present in large numbers, however, they may represent a major nuisance and also be an aesthetic issue (see chapter 9).

11.1.1 Mosquitoes

Tropical freshwater or brackish water environments are havens for mosquitoes. Female mosquitoes require a blood meal (from humans or other animals) to develop their eggs. In the process of taking a blood meal, mosquitoes may ingest pathogens (e.g., the parasite causing malaria) from an infected person or animal. At the next blood meal (mosquitoes go through various cycles of egg production), they then inject the pathogen into the next person, and this will spread the disease. All mosquitoes go through an aquatic larval stage, but the exact ecological requirements vary for the different species in different regions.

Two groups of mosquito-borne diseases are of particular public health importance for those who visit areas where transmission takes place (so-called endemic areas): malaria and arboviral diseases. (The HIV virus, which causes AIDS, is not transmitted by mosquitoes.)

Malaria is caused by one of four species of parasite belonging to the genus *Plasmodium*. Malaria parasites are transmitted by *Anopheles* mosquitoes. These mosquitoes bite between dusk and dawn. Their breeding places are generally in clean fresh water, standing or slowly running, with some species breeding in brackish water coastal lagoons. They never breed in polluted water. Unlike *Culex* mosquitoes (see below), *Anopheles* mosquitoes do not produce the typical high-pitched buzz that is part of the nuisance experienced in mosquito-infested areas. The position of the mosquito body with respect to the wall (at a 45-degree angle) when the insect is resting is probably the easiest way to distinguish anopheline mosquitoes from culicine ones.

Arboviral diseases (arbo = arthropod-borne) are caused by infections that are exclusively transmitted by mosquitoes. They include yellow fever, dengue and various types of encephalitis, such as Japanese encephalitis, when it is associated with flooded rice fields in south, south-east and east Asia. Many of these infections, notably yellow fever and Japanese encephalitis, are preventable by vaccination. For dengue fever (also known as break-bone fever in some parts of the world) and its more severe variant, dengue haemorrhagic fever, there is, however, no vaccine available.

The *Aedes* mosquitoes, which transmit the dengue virus, breed in small water collections in a human-made environment—hence the urban/human settlement-associated distribution of the disease. While dengue haemorrhagic fever is an important cause of death among children during outbreaks of the disease, classic dengue is a much less severe but very debilitating disease lasting for 4–6 weeks. *Aedes* mosquito species have black and white banded legs, and they (sometimes ferociously) bite during daytime.

Culex mosquitoes, which breed in organically polluted water, are mainly known for the transmission of filariasis (which can eventually develop into elephantiasis). This disease is likely to develop only in people who have been exposed to infectious bites for many years.

11.1.2 Freshwater snails and Schistosoma

Certain species of small freshwater snails (*Bulinus* sp., *Biomphalaria* sp. and *Oncomelania* sp., the last one being amphibic) are the essential intermediate hosts for the larval development of trematode parasites of the genus *Schistosoma*. These snails live in tropical lakes (either natural or man-made), in slow-flowing rivers and in the irrigation and drainage channels of agricultural production systems. Contamination of these waters with human excreta from parasite carriers releases first stage larvae (miracidia) that invade the snails. Once the larvae have developed into their infectious stage inside the snail (cercariae), they are released into the water. They adhere to and penetrate the human skin. Following a complex trajectory through the human body (and an associated metamorphosis), they grow into adult trematode worms living in the veins of the liver or the bladder.

Humans infected by *Schistosoma* suffer from a slowly developing chronic, debilitating and potentially lethal tropical disease known as bilharzia or schistosomiasis. Typical symptoms include fever, anaemia and tissue damage. Upon diagnosis, complete cure is possible using the drug praziquantel.

Trichobilharzia ocellata is a schistosome parasite of ducks, which occurs in temperate areas and leads to a far less serious form of infection than outlined above. Cercarial dermatitis or "swimmers' itch" results when the infectious stage of the parasite, known in some cultures as "duck fleas" invade humans. Symptoms may include a prickling sensation shortly after leaving the water, which is followed by an itchy papular dermatitis. The rash is confined to immersed areas of the body. In severe cases the rash can be accompanied by fever, nausea and vomiting (Fewtrell et al., 1994).

11.1.3 Preventive measures

Preventive measures can be taken by the individual:

- Always try to obtain information from appropriate international agencies (e.g., WHO, 1997, 2002) or local health authorities about the local vector-borne disease situation and follow their guidance in risk prevention.
- In malaria endemic areas, take the recommended prophylactic medicine.
- Wear protective clothing (long-sleeved shirts, long trousers) at the indicated biting times.
- Protect exposed parts of your body with repellents (e.g., N,N-diethyl-meta-toluamide—DEET).
- Screened windows and air-conditioning help keep mosquitoes out of houses.
- On return from a malarial area, consult your physician about the possible risk of having contracted the disease, should you have symptoms such as fever, headaches, chills or nausea.

- Avoid swimming or wading in fresh water in countries in which schistosomiasis occurs. Wearing full–length boots, which prevent water contact if wading in the water, will decrease the chances of infection. Although vigorous towel drying after an accidental, very brief, water exposure may help to prevent the *Schistosoma* parasite from penetrating the skin, do not rely on vigorous towel drying to prevent schistosomiasis.

11.2 "In-water" hazardous organisms

Although attacks by "in-water" hazardous organisms, such as sharks, usually attract a lot of public and media attention, the organisms are endemic to certain regions only, and their real public health significance is variable.

11.2.1 Piranhas (freshwater)

Piranhas are restricted to the fresh waters of northern South America, in the Amazon Basin. The largest species is *Pygocentrus piraya*, which reaches a size of 60 cm. Piranhas have powerful jaws with very sharp teeth, which they use to communally attack and kill large prey animals. They can be dangerous to humans. Splashing of the surface water is sufficient to attract a school of piranhas.

11.2.2 Snakes (freshwater)

Some non-venomous but large freshwater snakes such as the semi-aquatic anaconda (*Eunectes murinus*) can present a danger. The anaconda, which reaches lengths of up to 7.6 m, lives in tropical South America. Anacondas generally constrict and suffocate large prey, often viciously (non-venomous) biting the victim before coiling. Attacks on humans have occurred, but the snake is not generally aggressive towards people and will usually endeavour to escape if approached (see section 11.5.6 for venomous snakes).

11.2.3 Electric fishes (freshwater and marine)

Approximately 250 species of fish have specialized organs for producing and discharging electricity and are capable of delivering powerful electric shocks. These specialized organs are used by the fish to locate and stun prey, as a means of defence and for navigation. The electric shock is delivered to a person when contact is made with the animal's skin surface. The majority of electric fishes continuously emit a low-voltage electric charge in a series of pulses, with only two groups of electric fishes posing a serious threat to humans. The most dangerous of these is the freshwater electric eel (*Electrophorus electricus*), capable of producing an electric field of more than 600 volts. It can grow up to 3.4 m and lives in shallow rivers in tropical and subtropical South America. The fish is probably the only electric fish capable of killing a full-grown human.

The most powerful marine electric fishes are the torpedo rays (*Narcine* sp. and *Torpedo* sp.), which are bottom dwellers in all shallow temperate and warm seas. Electric rays vary greatly in their electric potential, some generating an electric field of up to 220 volts. Although the shocks are strong enough to be dangerous, no fatalities are known. Fishermen in European waters have been known to receive a shock from their line before seeing what was caught (Dipper, 1987).

11.2.4 Sharks (mainly marine)

Sharks live in all the oceans (excluding the Southern Ocean around the Antarctic continent) but are most abundant in tropical and subtropical waters. The majority of shark species are marine, and representatives are found at all depths. Some shark species migrate regularly from salt to fresh water, and a few inhabit freshwater lakes and rivers. Not all shark species are dangerous to humans.

Sharks are attracted by brightly coloured and shiny metallic objects, by the scent of blood, e.g., radiating from speared fish, and also by low-frequency vibrations and explosions. Sharks are furthermore attracted to nearshore garbage dumping grounds. In tropical waters, most shark attacks on humans occur during their habitual feeding times during late afternoons and at night. Sharks rarely "attack" humans, and such incidents are usually cases of mistaken identity, with the shark confusing the swimmer for its prey. Many attacks are a "bite," simply as a taste of the possible prey (Last & Stevens, 1994).

Shark species include the following:

- The great white shark (*Carcharodon carcharias*) lives mainly in the open ocean, although some swim into shallow water. Most of the attacks on people have happened in estuaries. The great white shark is responsible for the largest number of reported attacks on humans. It is thought that humans might be mistaken for its normal seal prey.
- The tiger shark (*Galeocerdo cuvier*) is extremely widespread in the tropics and subtropics. Following the great white shark, the second most reported attacks on humans are attributed to tiger sharks.
- The mako shark (*Isurus oxyrinchus*) is mainly an open ocean shark and occurs in all temperate and tropical oceans. It is often aggressive and dangerous when close to shore.
- The smooth hammerhead shark (*Sphyrna zygaena*), with its very distinctive head shape, lives in all warm water oceans.
- The silvertip shark (*Carcharhinus albimarginatus*) is very abundant around reefs and islands in the Pacific and Indian oceans.
- The bull shark (*Carcharhinus leucas*) is mainly located in the warm oceans of the world, although it can at times be found up the Amazon and rivers in Australia, Central America and south-eastern Africa (Halstead et al., 1990).

11.2.5 Barracudas and needlefish (marine)

The great barracuda (*Sphyraena barracuda*) is widely distributed throughout the subtropical and tropical regions of the open oceans. It is 1.8–2.4 m long and very rarely attacks humans. Barracudas, however, may intimidate divers and snorkellers by closely shadowing them. Like sharks, barracudas are attracted to shiny metallic objects and dead fish.

The various species of needlefish pose a more significant threat to humans. Needlefish are slender, possess very long, strong and pointed jaws and reach an average length of 1.8 m. They are most often found swimming in surface waters. At night, they are strongly attracted by bright lights. Cases of fishermen or divers on night expeditions being severely wounded and even killed by jumping needlefish have been reported (Halstead et al., 1990). Needlefish occur in the Caribbean, around the equatorial western African coast and near Japan and are widespread throughout the western Indian Ocean.

11.2.6 Groupers (marine)

Groupers live in the shallow waters of the Indo-Pacific on coral reefs and in sandy areas. Their size (the giant grouper, *Promicrops lanceolatus*, can reach 3 m) means that these generally non-aggressive fish are potentially dangerous. They are territorial fishes, and divers should look out for groupers before entering underwater caves and ensure that an exit is always open should a grouper wish to escape.

11.2.7 Conger and moray eels (marine)

The majority of eels are harmless, although they may attack and inflict fairly deep puncture wounds when provoked. Moray eels (*Gymnothorax* spp.) live in tropical waters on coral reef platforms, where they hide in crevices and holes among the dead coral. Conger eels (*Conger conger*) live in temperate waters of the Atlantic in rocky areas that offer them hiding places inside caves, holes and cracks.

11.2.8 Preventive measures

Preventive measures can be taken by the individual:

- Treat all animals with respect, and keep at a distance whenever possible.
- Avoid swimming at night or in the late afternoon in areas where large sharks are endemic.
- Avoid swimming in shark waters where garbage is dumped.
- Avoid wearing shiny jewellery in the water where large sharks and barracudas are common.
- Avoid attaching speared fish to the body where sharks, barracudas or groupers live.
- Avoid wearing a headlight when fishing or diving at night in needlefish waters.
- Look out for groupers and moray or conger eels before swimming into caves or putting hands into holes and cracks between rocks.

11.3 "Water's-edge" hazardous organisms

As with "in-water" hazardous organisms, attacks by "water's-edge" hazardous organisms, such as alligators, attract a lot of attention; however, the organisms are endemic to certain regions only, and their real public health significance is variable.

11.3.1 Hippopotami (freshwater)

The hippopotamus (*Hippopotamus amphibius*) is an aquatic mammal chiefly inhabiting freshwater rivers and lakes from the Upper Nile down to South Africa. Despite being a herbivore, the hippopotamus is responsible for a significant number of human deaths in Africa. Due to their sudden and violent nature and ability to swim quickly, hippopotami pose a serious threat to humans in the water. They are generally peaceable creatures, and most often a herd will scatter, or at least submerge, at the approach of humans, but attacks are not uncommon. The majority of incidents are due to ignorance of their habits, in particular moving between a group of hippopotami on shore and water.

11.3.2 Crocodiles and alligators (freshwater and marine)

Crocodiles are found in tropical areas of Africa, Asia, the western Pacific islands and the Americas. The majority of species live in fresh water. The largest living crocodiles may exceed 7.5 m in length. Crocodiles normally hunt at night and bask during the day, but might also hunt during the day if food is in short supply.

All crocodiles are capable of inflicting severe harm or causing death to humans. The more dense their populations, the more dangerous are individual crocodiles. The saltwater crocodile (*Crocodylus porosus*) of south-eastern Asia is probably the most dangerous of all the marine animals. It lives mainly in mangrove swamps, river mouths and brackish water inlets, but has been seen swimming far offshore (Halstead et al., 1990). The Nile crocodile (*C. niloticus*) has been rated as second only to the saltwater crocodile in danger to humans (Caras, 1976).

There are only two species of alligator: the Chinese alligator (*Alligator sinensis*) and the American alligator (*A. mississipiensis*). The Chinese alligator, found in the Yangtze River basin of China, is quite small (<2.5 m) and timid and is not considered to be a significant threat to humans. The American alligator, which lives in freshwater swamps and lakes in the south-eastern USA, is larger (up to 6 m in length) and potentially dangerous to humans. Attacks occur infrequently.

11.3.3 Seals and sea lions (marine)

Seals and sea lions are not aggressive towards humans under normal circumstances. During the mating season, however, or when with pups, bulls might turn aggressive and attack intruders. Of particular concern are the Californian sea lion (*Zalophus californianus*), found along the west coast of North America and the Galapagos, and the bearded seal (*Erignathus barbatus*), found on the edge of the ice along the coasts and islands of North America and northern Eurasia (Halstead et al., 1990).

11.3.4 Preventive measures

Preventive measures can be taken by the individual:

- Treat all animals with respect, and keep at a distance whenever possible.
- Avoid swimming in murky brackish water inlets, river mouths and mangrove swamps inhabited by saltwater crocodiles.

- Always try to obtain information from local authorities about the risk from hazardous organisms and ask for their guidance in risk prevention. If so advised, use a knowledgeable guide who can assess risks properly.

11.4 Venomous invertebrates

The effects of invertebrate venoms on humans range from mild irritation to sudden death. The invertebrates that possess some kind of venomous apparatus belong to one of five large phyla: Porifera (sponges), Cnidarians (sea anemones, hydroids, corals and jellyfish), Mollusca (marine snails and octopi), Annelida (bristleworms) and Echinodermata (sea urchins and sea stars).

11.4.1 *Porifera (freshwater and marine)*

Sponges are simple multicellular animals, living mainly in shallow coastal and fresh waters around the world. They either attach to some form of substrate (be it rock, seaweed or a hard-shelled animal) or burrow into calcareous shells or rock. Although most sponges are harmless to humans, examples of toxic sponges are found world-wide. Painful skin irritations, sometimes persisting for many hours, are the most common syndrome. No fatalities are known.

11.4.2 *Cnidarians (marine)*

Cnidarians are relatively simple, with a radially symmetrical body structure. Their body cavity has a single opening surrounded commonly by tentacles equipped with special cells known as cnidocytes. These cnidocytes contain characteristic capsule-like structures called cnidae, which in turn contain a thread that is mechanically discharged upon touch.

Cnidarians are separated into four groups: the Hydrozoa (plume-like hydroids, "fire corals," medusae and Siphonophora), Scyphozoa (free-swimming jellyfish), Cubozoa (box-shaped medusae) and Anthozoa (hard corals, soft corals and anemones). Hydroids and jellyfish possess so-called nematocysts (stinging capsules), which, when the cnidae thread is discharged, penetrate the integument (tough outer protective layer) of their prey and inject a toxin. Sea anemones and true corals, on the other hand, have spirocysts or ptychocysts with adhesive cnidae threads.

1. *Hydrozoa*

Most of the 2700 species of hydrozoa are harmless, but some can inflict painful injuries on humans. Well known examples of these are the sea firs, fire corals and Portuguese man-of-war. Apart from severe stinging cases from the Portuguese man-of-war, hydrozoan stings are not generally life threatening, although the pain can last for several days.

Stinging or fire corals (e.g., *Millepora alcicornis*) have nematocysts that vary in stinging intensity according to species (Sagi et al., 1987). These hydroid corals can cause a painful skin rash. They are generally found together with true corals in warm waters of the Indo-Pacific, the Red Sea and the Caribbean.

The stinging hydroid or fire-weed (*Aglaophenia cupresina*) is a hydroid colony. It resembles seaweed and grows on rocks and seaweeds in the tropical Indo-Pacific. If touched, it causes a nettle-like rash lasting several days (Rifkin et al., 1993).

The Portuguese man-of-war (*Physalia* spp.) is a free-swimming colony of open-water hydrozoans that lives at the sea–air interface. *Physalia* is easily recognized by the prominent floating blue or purple gas-filled bubble that supports the stinging cells on the tentacles and zooids hanging below. The tentacles may reach a length of up to 10 m. Different species of *Physalia* are widespread throughout all oceanic regions, except the Arctic and Antarctic, and may be blown onto beaches in swarms after strong onshore winds. The nematocysts remain active even when beached. Stings by the various *Physalia* species are the most common marine stings known at present. The Atlantic species (*Physalia physalis*) is the most dangerous and has been responsible for some severe stings (Spelman et al., 1982; Burnett et al., 1994) and three deaths (Burnett & Gable, 1989; Stein et al., 1989).

2. *Scyphozoa and Cubozoa*

The number and variety of potentially harmful Scyphozoa and Cubozoa are too numerous to mention here, but the subject has been widely reviewed by Burnett (1991) and Williamson et al. (1996). Williamson et al. (1996) give detailed accounts of the dangerous jellyfish species and describe the harm they can inflict on humans and the recommended treatment for stings from each of the individual species. Although most stings result in only a short-lived burning sensation, some can be dangerous, especially if the swimmer has a severe allergic reaction (Togias et al., 1985) or if the jellyfish is one of those rare species where the stings can be fatal.

The Scyphozoa, or true jellyfish, are typically pelagic and exist for the greater part of their life as medusae. They move by gentle pulsations of the bell, but are frequently driven ashore and stranded by wind and currents. All jellyfish are capable of stinging, but only a few species, particularly *Stomolophus nomurai* and *Sanderia malayensis*, are considered a significant hazard to human health (Mingliang, 1988; Williamson et al., 1996). Species of some genera, such as *Cyanea*, *Catostylus* and *Pelagia*, may occur in large groups or swarms.

The Cubozoa are the most dangerous cnidarians (Fenner & Williamson, 1996; Williamson et al., 1996). They are characterized by a roughly cube-shaped body or bell, with tentacles arising from fleshy extensions in each lower corner of the bell. Several species of box jellyfish have been implicated in human deaths, with *Chiropsalmus quadrigatus*, which causes some 20–50 deaths each year in the Philippines (Fenner & Williamson, 1996), and the Chironex box jellyfish *Chironex fleckeri*, found in summer months in the northern tropical waters of Australia (Baxter & Marr, 1969), being among the most venomous of all marine creatures. A death has also occurred in the south-eastern USA from the box jellyfish *Chiropsalmus quadrumanus* (Bengston et al., 1991). Respiratory failure may occur within a few minutes of being stung by *Chironex fleckeri* (Lumley et al., 1988).

3. *Anthozoa*

Hard corals can cause abrasion injuries if a swimmer simply brushes against their hard branches. Certain coral colonies also possess stinging nematocysts (*Goniopora*, *Plerogyra*, *Physogyra*), which can leave a rash if touched.

The majority of sea anemones are harmless, except when their tentacles come into contact with delicate parts of the body, such as the face, lips and underarms, resulting in a painful sting. One example is the common intertidal beadlet anemone (*Actinia equina*), found in the eastern Atlantic. More hazardous sea anemones include the hell's fire sea anemone (*Actinodendron plumosum*), found on the shady side of rocks and under coral ledges in the tropical Pacific. A sting from this anemone can cause skin ulcerations lasting for several months. *Triactis producta*, found in the Red Sea, gives painful stings that may later ulcerate (Halstead et al., 1990). A death has occurred after complications following a sting by *Condylactis* species (Garcia et al., 1994).

11.4.3 Mollusca (marine)

Molluscs are found in marine, freshwater and terrestrial environments. They all possess a distinct and well developed head, a muscular foot and a soft, variable-shaped body. Of the aquatic representatives of this large group, only some cephalopods and the cone shells (*Conus*) produce venoms harmful to humans.

All octopi possess two powerful horny jaws, which they can use to bite humans. The bites from the non-venomous (the majority) octopi result in small puncture wounds causing moderate pain. Certain species of octopus, such as the blue-ringed octopus (*Hapalochlaena* (= *Octopus*) *maculosa*) or the spotted octopus (*Octopus lunulatis*), are equipped with venom that aids in the capture of prey. Bites from these species can be deadly (the poisons are neuromuscular, producing muscular weakness and eventually respiratory paralysis) and should be treated with urgency (Williamson, 1987). Both species inhabit shallow coastal waters of the tropical Indo-Pacific and normally show no aggression towards humans. The majority of reported bites have resulted from handling or interfering with the octopi (Flecker & Cotton, 1955; Sutherland & Lane, 1969; Sutherland, 1983).

There are between 400 and 500 species of cone shells, all of them possessing a highly developed venom apparatus. The tropical and subtropical cone shells, *Conus* sp., are usually found in shallow waters along reefs and on or in sandy bottoms. They use their harpoon-like darts carrying the venom supply to catch prey and to discourage predators (Hinegardner, 1958). They often cause intense, localized pain at the site of the injury, accompanied by nausea, vomiting, dizziness and weakness. In more severe cases, victims experience respiratory distress with chest pain, difficulties in swallowing, marked dizziness, blurring of vision and an inability to focus. Fatalities are caused by respiratory paralysis (Flecker, 1936; Kohn, 1958; Endean & Rudkin, 1963; Russell, 1965). Most reported cases are from those organisms being handled.

11.4.4 *Annelids (marine)*

Of the annelids (segmented worms), only some bristleworms, named after two bristle-like setae attached to all their segments, are venomous. Bristleworms live under rocks and boulders. In venomous species, the setae sting; in the Caribbean fire worm (*Hermodice carunculata*), the sting leads to intense pain and a burning sensation.

11.4.5 *Echinoderms (marine)*

Very few of the radially symmetrical adult echinoderms are hazardous to humans. Most common minor injuries are abrasions or punctures acquired from contact with the spines or skin of echinoderms. Examples of venomous species are found only within the starfish and sea urchins.

The crown of thorns starfish (*Acanthaster planci*) is the only venomous starfish and lives on coral reefs in the Indo-Pacific. Its upper surface is covered with many long, sharp and venomous spines, which can inflict painful wounds if handled (Heiskanen et al., 1973). No serious injuries from *Acanthaster* have been recorded.

Sea urchins are found in all oceans, normally located on rocky foreshores and reefs. Most sea urchins can be handled safely, but a few species possess venomous spines or jaw-like pedicellariae capable of delivering very painful injuries (Halstead, 1971). These venomous species tend to be confined to the tropical and subtropical marine regions. Fatal incidents are said to have occurred from handling the flower sea urchin (*Toxopneustes pileolus*) from the Indo-Pacific, the most venomous sea urchin known, but these are difficult to confirm (Hashimito, 1979; Smith, 1977).

11.4.6 *Preventive measures*

Preventive measures can be taken by the individual:

- Always wear suitable footwear when exploring the intertidal area or wading in shallow water.
- Avoid handling sponges, cnidarians, cone shells, blue-ringed octopus, bristle-worms or the flower sea urchin.
- Avoid brushing against hydroids, true corals and anemones.
- Avoid swimming in waters where Portuguese man-of-war are concentrated (often indicated by beached specimens).
- If swimming where jellyfish are prevalent, wear a wet suit or other form of protective clothing, such as the full-length stretch-fitting suits used by divers in tropical waters.

11.5 Venomous vertebrates

Venomous vertebrates deliver their venom either via spines, as with many fish species, or through fangs, as in sea snakes. Injuries caused by venomous marine vertebrates are common, especially among people who frequently come into contact with these marine animals. Potent vertebrate toxins generally cause great pain in the victims, who may also experience extensive tissue damage.

11.5.1 *Catfish (freshwater and marine)*

Catfish are bottom dwellers living in marine, freshwater or estuarine environments. They possess venomous dorsal spines, which can inflict painful wounds even when the fish is dead (Halstead, 1988). The majority of catfish stings result from handling catfish while sorting fish catches. Some species, such as *Heteropneustes fossilis* from India, have been known to actively attack humans, leaving a painful sting (Williamson et al., 1996).

11.5.2 *Stingray (freshwater and marine)*

Stingrays are found in the Atlantic, Indian and Pacific oceans. They are predominantly marine, but the South American river ray (Pontamotrygonidae) lives in fresh water. Stingrays tend to be partially buried on sandy or silty bottoms in shallow inshore waters. Up to six venomous spines in their tails can stab unwary swimmers who happen to tread on or unduly disturb them. All stingray wounds, no matter how minor, should receive medical attention to avoid the risk of secondary infection. Some injuries caused by venomous stingrays can be fatal for humans if the spine pierces the victim's trunk; deaths have been reported for both marine (Rathjen & Halstead, 1969; Fenner et al., 1989) and freshwater (Marinkelle, 1966) species.

11.5.3 *Scorpionfish (estuarine and marine)*

All species of scorpionfish possess a highly developed venom apparatus and should therefore be treated with respect. The estuarine stonefish (*Synanceia horrida*, syn. *S. trachynis*) is the most venomous scorpionfish known and occurs throughout the Indo-Pacific. The reef stonefish (*Synanceia verrucosa*) resembles coral rubble and lies motionless in coral crevices, under rocks, in holes or buried in sand or mud, where divers often mistake it for a rock. The pain associated with stings by a stonefish is immediate and excruciating and can last for days (Williamson et al., 1996). The lionfish and true scorpionfish are also venomous. Deaths have been attributed to stonefish but are very difficult to confirm (Smith, 1957; Cooper, 1991).

11.5.4 *Weeverfish (marine)*

Weeverfish are confined to the north-eastern Atlantic and Mediterranean coasts. All four species (*Trachinus* spp. and *Echiichthys* sp.) contain venomous dorsal and gill cover spines. They are small (less than 4.5 cm) and lie partly buried in sandy bays at extreme low water where swimmers and beach walkers frequently step on them. Weeverfish are regarded by some as the most venomous fish found in temperate European waters (Halstead & Modglin, 1958; Russell & Emery, 1960).

11.5.5 *Surgeonfish (marine)*

Surgeonfish are herbivorous reef dwellers equipped with a sharp, moveable spine on the side and base of the tail. When excited, the fish can direct the spine forward, making a right angle with the body, ready to attack. Large surgeonfish, such as the Achilles surgeonfish (*Acanthurus achilles*) and the blue tang (*Acanthurus coeruleus*) of the warm seas of the western Atlantic, use their spines in defence and cause deep and painful wounds with a quick lashing movement of the tail (Halstead et al., 1990).

11.5.6 Snakes (freshwater and marine)

Poisonous snakes are air-breathing, front-fanged venomous reptiles, and many are associated with both the marine and freshwater environments. Of the 50 species of sea snake, the majority live close inshore or around coral reefs. They appear similar to land snakes, but have a flattened tail to aid in swimming. They are curious, generally non-aggressive creatures, but can be easily provoked to attack. All sea snakes are venomous and can inflict considerable harm if disturbed. White (1995) estimated a worldwide sea snake fatality rate of at least 150 per year.

Of the freshwater aquatic snakes, possibly the water moccasin or cottonmouth (*Agkistrodon piscivorus*) is the most dangerous to humans, the venom attacking the nervous and blood circulatory systems of the victim. The water moccasin is a pit-viper found throughout the south-eastern part of the USA. The species is never far from water and swims with its head well above the surface. When threatened, the snake opens its mouth wide to reveal the almost white lining, which gives it its common name. The species can be aggressive and is densely populated in some areas. Its bite can result in gross tissue damage, with amputations of the affected limb not uncommon (Caras, 1976). Other species of the genus *Agkistrodon* are found throughout North America and south-eastern Europe and Asia.

11.5.7 Preventive measures

Preventive measures can be taken by the individual:

- Always "shuffle" feet when walking along sandy lagoons or shallower waters where stingrays frequent.
- In catfish waters, fishermen should be extremely careful when handling and sorting their catch.
- Suitable footwear should be worn to avoid accidentally treading on weeverfish or stonefish.
- Wear boots in snake-infested areas.
- If possible, carry anti-venom in snake-infested areas.

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CHAPTER 12
Monitoring and assessment

In order to support the attainment of safety in recreational water environments, the responsible management authorities should establish a programme for evaluating existing hazards and monitoring the area for any changes that may occur. Threats to human health may include natural hazards, such as surf, rip currents or aquatic organisms or may have a man-made aspect, such as discharges of wastewater. Comprehensive review of the recreational area and monitoring for any changes enables a responsive strategy to protect public health be implemented.

To provide practical guidance concerning the design and implementation of monitoring programmes for recreational water use areas, WHO developed a book *Bathing Water Monitoring* (Bartram & Rees, 2000). The structure is based upon a framework "Code of Good Practice (COGP) for Recreational Water Monitoring," which is presented in this chapter. The Code was developed through an extensive process of consultation and within the context of cooperation between WHO and the European Commission. The application of the Code under specific circumstances is described in greater detail in the book.

This framework COGP constitutes a series of statements of principle or objectives that, if adhered to, would lead to the design and implementation of a credible monitoring programme. It applies in principle to the monitoring of all waters used for recreational activities that involve repeated or continuous direct contact with a water body. In many circumstances, there are different approaches or methods that can be applied to achieve the objectives stated in the Code. While equally valid in isolation of one another, the adoption of diverse approaches within a single programme may mean that results are not comparable between different locations or enforcement programmes.

The framework COGP provides a linkage to the various health effects associated with recreational waters and incrementally builds up the component parts of a successful programme—key health issues, monitoring and assessment strategies, and principal management considerations.

12.1 Design and implementation of monitoring programmes

12.1.1 Design of monitoring programmes

1. The objective(s) of a monitoring programme or study should be identified formally before the design of the programme and stated prior to data gathering. Ideally objectives would be based on assessment of the frequency and

severity of different adverse health outcomes, with the subsequent monitoring programme designed around those with the greatest public health benefit.

2. Objectives should be described in a manner that can be related to the scientific validity of the results obtained. The required quality of any data should be derived from the statement of objectives and stated at the outset.
3. Where data (such as results from water quality analyses) are to be compared between laboratories or between sites, all available measures to ensure comparability of results should be implemented:
   - A quality assurance programme based on internal controls and external controls (interlaboratory comparisons) is essential.
   - Criteria should be developed for dealing with participating laboratories consistently failing to comply with minimum analytical quality. These should be stated prior to data collection.
4. In designing and implementing monitoring programmes, all interested parties (legislators, nongovernmental organizations, local communities, laboratories, etc.) should be consulted. Every attempt should be made to address all relevant disciplines and involve relevant expertise.
5. The scope of any monitoring programme or study should be defined. This would normally take the form of definition of criteria for inclusion/exclusion of recreational water use areas and preparation of an inventory of recreational water use areas.
6. The catalogue of basic characteristics of all recreational water use areas should be prepared and updated periodically (generally annually)—and also in response to specific incidents—in a standardized format. It should include as a minimum the extent and nature of recreational activities that take place at the recreational water use area and the types of hazards to human health that may be present or encountered. Unless specifically excluded, the list of potential hazards to human health would normally include drowning and injury-related hazards, known or anticipated dangerous aquatic organisms, microbial quality of water and cyanobacteria or harmful algae. Monitoring programmes frequently also address aesthetic aspects and amenity parameters because of their importance to health and well-being.
7. Programme or study design should take account of information derived from the inventory of recreational water use areas and catalogue of basic characteristics, which may require refinement of programme objectives.
8. The logistical planning of any monitoring programme or study should take account of socioeconomic, technical/scientific and institutional capacities, staffing, equipment availability, consumable demands, travel and safety requirements and sample numbers, without compromising achievement of the objectives or scientific validity of the programme or study.
9. The hierarchy of authority, responsibility and actions within a programme or study should be defined. All persons taking part in the programme or study should be aware of their roles and inter-relationships.

10. Staff should be adequately trained and qualified, including with regard to health and safety aspects.
11. Monitoring programmes should include appropriate quality assurance (QA), which does not infringe on health and safety and which covers the integrity of all observation, interview, field sampling and water quality analyses as well as data input, analysis and reporting.
12. A QA Officer should be appointed who reports directly to senior management. The QA Officer should regularly audit all aspects of the operation with special regard to procedures, traceability of the data and reporting.
13. Essential elements of QA programmes include:
    - The writing and implementation of a Quality Manual and Standard Operating Procedures (SOPs). All SOPs should be regularly overhauled and updated as necessary and any deficiencies reported and appropriate remedial action taken.
    - SOPs should include maintenance and updating of inventories and catalogues; methodologies for all major equipment; all sampling and analytical procedures; sample receipt, screening and storage; and reporting.
14. Where samples are taken for laboratory analysis they should be registered on arrival at the laboratory. The applied laboratory procedures should conform to the SOPs defined at the laboratory. Where possible, all analytical procedures should follow defined protocols (e.g., International Organization for Standardization or American Public Health Association protocols). All equipment should be calibrated regularly and the operational procedures submitted to quality control staff in order to guarantee traceability of the data.
15. Laboratory accreditation can form a valuable part of activities relating to analytical quality, e.g., through pursuit of requirements for ISO/IEC 17025.
16. The programme should be evaluated periodically and whenever the general situation or any particular influence is changed. Commitment to support such evaluations should be built into the monitoring programme's design and authorization.

12.1.2 Data collection

17. Collection of data and information should utilize the most effective combination of methods of investigation, including:
    - observation;
    - historical review of deaths, injuries and accidents (including details on lifeguard positioning, number of rescues effected, preventive actions and attendance figures);
    - water quality sampling and analysis;
    - interview of appropriate persons; and
    - review of published and unpublished literature.
18. Frequency and timing of analytical sampling and selection of sampling sites should reflect recreational water area types, use types and density of use, as

well as temporal and spatial variations in the recreational water use area, which may arise from seasonality, tidal cycles, rainfall and discharge and abstraction patterns.

19. Analytical sampling should provide a data set amenable to statistical analysis.

12.1.3 Data handling

20. Data handling and interpretation of results should be done objectively, without personal or political interference.
21. The need for transformation of raw data, before analysis, to meet the conditions for statistical analysis should be agreed upon with a statistical expert before commencing analysis. In addition, procedures should be defined for handling censored data (such as 'less than' and 'greater than' data).
22. Data handlers and collectors should agree on a common format for recording results of analyses and surveys and should be aware of the ultimate size of the data matrix. The preferred approach is to use a database or spreadsheet that allows automatic logical verifications (i.e., only allows entries for certain date and numeric ranges). Forms and survey instruments should be compatible with this format. Likewise, data handlers should agree on a format for the output of results with those responsible for interpreting and presenting the data. Data entry should be double checked to ensure accuracy.
23. Procedures for dealing with inconsistencies such as omissions in records, indeterminate results (e.g., indecipherable characters, results outside the limits of the analytical methods) and obvious errors should be agreed upon in advance of data collection. On receipt from the data collectors, record forms should be examined and the agreed procedure followed. Discrepancies should be referred immediately to the data collector for correction or amendment. Where correction is not possible, resampling is generally the preferred option (with due regard for prevailing conditions); estimates may be preferable to leaving gaps in the record. Such estimates, however, must be recorded as such and the methodology of the estimate outlined.
24. Ideally, arrangements should be made to store data in more than one location and format, to avoid the hazards of loss and obsolescence. At all locations, data should be backed up regularly. Data should be transcribed accurately, handled appropriately and analysed to prevent errors and bias in the reporting.
25. The statistical methodologies should be reviewed by a statistical expert and comments taken into account in finalization.
26. Data should be handled and stored in such a way to ensure that the results are available in the future for further study and for assessing temporal trends.

12.1.4 Data interpretation

27. Data should be interpreted and assessed by experts with relevant recommendations for management actions prior to submission to decision-makers. Interpretations should always refer to the objectives and should also

propose improvements, including simplifications, in the data gathering activities, identifying future research needs and guidelines for environmental planning.

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

12.1.5 Reporting

29. The findings should be discussed with the appropriate local, regional and/or national authorities and others involved in management (including integrated water resource management), such as the industrial development and/or national planning boards.
30. Results should be reported to all concerned parties, including the public, legislators and planners. Any information relating to quality of recreational water use areas should be clear, should be concise and should integrate safety, microbial and aesthetic aspects.
31. In issuing information to concerned parties (the public, regulators, non-governmental organizations, legislators, etc.), it is essential that their requirements are kept in mind.
32. Where specific or extreme events that may threaten public health occur, the competent public health authority should be informed and recommendations should be made to the water user population about the risks of dangerous water conditions or poor water quality (see chapter 13).
33. Reports addressing the quality of recreational water use areas should be accompanied by reference to local and visitor perceptions of the aesthetic quality and risks to human health and safety (see chapter 9).
34. The deleterious impacts of human health hazards and aesthetic pollution and control measures to avoid or reduce such impacts should be introduced into environmental health education programmes in both formal and informal educational establishments.
35. The usefulness of the information obtained from monitoring is limited unless a supportive administrative and legal framework (together with an institutional and financial commitment to appropriate follow-up action) exists at local, regional and international levels.

12.2 Aspects relevant to specific hazards

The following items apply in addition to the general guidance given above in relation to specific hazards. As noted in chapter 1 (Figure 1.2), in order to maximise public health gains management authorities should prioritize according to the hazards having the most serious outcomes. Thus, generally speaking, drowning prevention measures would be prioritized over general beach cleaning. The reader should also refer to the relevant chapters in this volume.

12.2.1 Drowning and injury hazards

1. The catalogue of basic characteristics should include, wherever relevant, hazards such as beach slopes, tides, flows and currents, actual user groups, nearby hazardous areas such as cliffs, shallow waters dangerous for diving, weirs and other such hazards as identified from local knowledge and records of health effects.
2. Information regarding measures to prevent or ameliorate hazard exposure or outcomes, including, for example, lifeguard provision, staff training, signs, emergency telephone numbers, access to first aid, medical facilities, fencing, warning systems for adverse conditions and emergency routes, should be included in the catalogue of basic characteristics.
3. Monitoring and assessment programmes should address those hazards and preventive measures, described in 1) and 2), that are subject to change.
4. When assessing the significance of hazards, account should be taken of the severity and likelihood of adverse health outcomes, together with the extent of exposure.

12.2.2 Microbial water quality assessment and sanitary inspection

5. Sanitary inspection should be undertaken as a necessary adjunct to microbial water quality analysis to identify all real and potential sources of microbial contamination. It should assess their impact on the quality of the recreational water use area and water user health. During inspection, the temporal and spatial influences of pollution on water quality should receive full consideration.
6. An exhaustive sanitary inspection should be carried out immediately prior to the principal bathing season. Inspections of specific conditions should be conducted in conjunction with routine sampling during the bathing season. Pertinent information should be recorded on standardized checklists and used to update the catalogue of basic characteristics. If a problem is identified, it may be necessary to collect supplementary samples or information to characterize the problem.
7. Visual faecal pollution or sewage odour should be considered a definite sign of elevated microbial pollution, and necessary steps should be taken to prevent health risks to bathers.
8. SOPs for sanitary inspections, water sampling (including depth) and analyses should be well described to ensure uniform assessments.
9. Sample point location and distance between each should reflect local conditions (overall water quality, recreational usage, predicted sources of faecal pollution, temporal and spatial variations due to tidal cycles, rainfall, currents, onshore winds and point or non-point discharges) and may vary widely between sites.
10. Sterile sample containers should be used for microbiological samples. Scrupulous care should be taken to avoid accidental contamination during handling

and sampling collection. Every sample should be clearly identified with time of collection, date and location.

11. A sampling depth relevant for the exposure of concern should be selected and adhered to consistently in order to allow comparison between locations.
12. Samples should be kept in the dark and maintained as cool as possible within a chilled insulated container and delivered to the laboratory promptly after collection. Samples should be analysed as soon as possible and preferably within 8 h of collection. Sample storage is recommended not to exceed 24 h at 5 °C.
13. Additional information should be collected at the time of sampling, including water temperature, weather conditions, water transparency, presence of faecal material, abnormal discoloration of the water, floating debris, cyanobacterial or algal blooms, flocks of seabirds and any other unusual factors. All information should be recorded on standardized checklists.
14. Local and national conditions should be taken into account when selecting appropriate microbial indicators.
15. The influence of specific events such as rain on the recreational water use areas, especially in relation to the duration of the peak contamination period, should be established and prior agreed procedures implemented.
16. Extreme events such as epidemics and engineering and natural disasters may require additional measures to ensure there is no additional risk associated with recreational water use areas.
17. The procedures to be used for transformation of raw data to meet the statistical requirements should be agreed upon with the statistical expert prior to analysis. The most usual need is to transform bacterial counts to logarithms and to convert their approximately lognormal frequency distribution to normality.
18. When unexpectedly high microbiological results are obtained, resampling should be undertaken to help determine whether this was due to sporadic events or persistent contamination. In the latter case, the source of pollution should be established and appropriate action taken.

12.2.3 Cyanobacteria and algae

19. Monitoring of recreational water use areas should be sufficient to identify risk of blooms, taking into account actual or potential accumulation of toxic cyanobacteria and algae.
20. Sampling points should be located to represent different water masses (stratified waters, waters coming from river mouths, etc.) in the investigation area and the sources of nutrients (discharges, upwellings, etc.). Possible transport mechanisms of toxic phytoplankton should be considered, wind induced accumulations of scum should be identified and sampling schemes should be arranged accordingly.
21. In areas of high risk, sampling for algae should be carried out at least weekly. During development of blooms, sampling should be intensified to daily.

22. Monitoring of toxicity (using bioassays, chemical or immunological procedures) is justified only where reason exists to suspect that hazards to human health may be significant. In such cases, long-term information on phytoplankton populations (toxic, harmful and others) should be collected where appropriate.
23. Analyses of toxins should be undertaken only where standard, replicable and reliable analyses can be performed.
24. Where conditions are such that monitoring is considered essential, temperature, salinity (in marine coastal areas), dissolved oxygen, transparency, presence of surface water stratification, phytoplankton biomass (chlorophyll), surface current circulation (transport of algae) and meteorological patterns such as seasonal rainfall, storms and special wind regimes should be considered.

12.2.4 Other biological, physical and chemical hazards

25. Monitoring for other locally important hazards is justified only where reason exists to suspect that hazards to human health may be significant. Such occurrence may be highly localized.
26. Only where standard, replicable and reliable analyses may be undertaken for known parameters should such analyses be undertaken.
27. Approaches to the assessment of the significance of locally important hazards will depend on the type of hazard and should take account of their magnitude and frequency, severity and occurrence of health effects, and other local factors.

12.2.5 Aesthetic aspects

28. Selection of aesthetic pollution parameters for monitoring should take into account local conditions and should consider parameters such as surface accumulation of tar, scums, odours, plastic, macroscopic algae or macrophytes (stranded on the beach and/or accumulated in the water) or cyanobacterial and algal scums, dead animals, sewage-related debris and medical waste.
29. Assessment of aesthetic pollution indicators should take into account the perception and requirements of the local and any visiting populations in reference to specific polluting items as well as the feasibility of their monitoring.

12.3 Progressive implementation of monitoring and assessment

To protect health it is necessary to develop monitoring orientated towards hazards to human health in response to public health priority. This will normally mean that several aspects (beach safety, pollution control, etc.) will be developed in parallel. There are different levels of monitoring (as there are with management, see chapter 13), although each level deals with each of the major hazard groups (as outlined in Table 12.1). Typically, monitoring proceeds through local activities in isolation

TABLE 12.1. LEVELS OF MONITORING IN RELATION TO RESOURCE REQUIREMENTS[a]

Level	Basic information /visit rate	Accident hazards	Microbiological parameters	Cyanobacteria and algae	Other
Local (no national organization)	Local action comparable to basic level, in some locations only.	Local action comparable to basic level, in some locations only.	Local action comparable to basic level, in some locations only.	Local action comparable to basic level, in some locations only.	Local action comparable to basic level, in some locations only.
Basic (no access to equipment or staff resources at national level; limited local resources)	At least one pre-season visit; creation of a catalogue of basic characteristics; all recreational waters registered, but more–used and higher–risk beaches inspected and monitored.	Annual inspection for identification of any hazards and interventions (e.g., signs, warning systems).	Inspection for faecal pollution or sewage odour; delimitation of high risk areas; initial screening of microbial indicator parameters for primary classification; internal quality control at laboratories; at least one sample a month once the recreational water is classified.	Inspection for scum, type and transparency.	Register of local special problems.
Intermediate (limited access to resources both local and national level)	Comprehensive cataloguing and timetabling of visits; additional visits during peak seasons (e.g., monthly); greater proportion of recreational waters monitored.	Periodic verification of interventions during bathing season; central capacity for incident investigation.	Identification and cataloguing of potential sources of contamination; all recreational waters at primary classification; monthly sampling; additional sampling and investigation of unexpected peak values; reclassification scheme initiated; investigation of rain effects and design of preventive measures; internal quality control at laboratories; occasional inter-laboratory comparison studies.	Phosphate analysis (freshwater) Chlorophyll a (freshwater) where bloom events probable.	Check on local information availability; active warning and management response.
Full (no significant resource limitations)	Additional visits during peak seasons (e.g., fortnightly or weekly); complete cataloguing, including updating for each recreational area; all beaches with significant use monitored.	Central register of recorded incidents; decentralised capacity and procedure for incident investigation.	Additional microbiological parameters if necessary; possible reclassification investigated where indicated; internal and external quality controls regularly operated; convergence among participating laboratories.	Toxicity detection and toxin analysis capacity if necessary (not routine); remote sensing methods where relevant.	Chemical monitoring (for appropriate parameters).

[a] adapted from Bartram & Rees, 2000.

of any national or regional framework through basic, intermediate to full scale monitoring.

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

12.4 References

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ISO/IEC 17025 (1999*) General requirements for the competence of testing and calibration laboratories*. International Organization for Standardization, Geneva, Switzerland.

CHAPTER 13

Application of guidelines and management options for safe recreational water use

Recreational use of inland and marine waters is increasing in many countries worldwide. These uses range from whole-body contact sports (where there is a significant risk of water ingestion), such as swimming, surfing and slalom canoeing, to non-contact activities, such as fishing, walking, birdwatching and picnicking. Although these activities can benefit health, they may also be associated with adverse health outcomes, as described in previous chapters. These possible adverse health outcomes result in the need for guidelines that can be converted into locally (i.e., nationally or regionally) appropriate standards and associated management of sites to ensure a safe, healthy and aesthetically pleasing environment. The management interventions that may be required to ensure a safe recreational water environment include compliance and enforcement measures, application of control and abatement technology, public awareness and information initiatives and public health advice, which are best brought together in an integrated management framework (summarised in Figure 1.4). This chapter brings together the conclusions of the management strategies and options discussed in previous chapters.

13.1 Application of guidelines

Recommended guidelines for a number of hazards and associated risks to public health have been outlined in preceding chapters. The guidelines and recommendations range from identifying the need for providing advice to the public (chapter 3) to numerical guidance levels (chapter 8) to a system of classification (chapter 4). Chapter 1 and several other chapters have emphasized the need to adapt these guidelines to suit local circumstances.

Guidelines are intended to be flexible and should be adapted to suit regional, national and/or local circumstances by taking into consideration socio-cultural, environmental and economic conditions. An initial assessment of issues and priorities can, for example, include an assessment of the number of drownings or serious injuries sustained (i.e., severe health effects) in comparison to, say, cases of mild illness as a result of bathing in microbially contaminated water (see Figure 1.2). Initial assessment would preferably be complemented by a risk-benefit approach (qualitative or quantitative) and in some circumstances a full cost-effectiveness or cost-benefit analysis may be undertaken. The outcome of such analyses should inform the process of standards development and the measures that are put in place to implement the standards.

The agency responsible for health will take a leading and coordinating role in the application of guidelines. However, the health authority should ensure the active participation of the other key stakeholders as outlined in chapter 1 (Figure 1.3). A wide variety of elements of legislation and regulation may contribute to ensuring and/or improving the safety of the recreational water environment. Not all are relevant or appropriate to all types of hazard and the balance among them will depend on the nature of the hazards of priority concern for human health. Experience suggests that overall health protection is most effective when a number of complementary mechanisms are employed. The potential "actors" and functions involved in improving safety are outlined in Table 13.1.

TABLE 13.1. EXAMPLES OF ACTORS AND FUNCTIONS THAT MAY BE EXERCISED IN MANAGING RECREATIONAL WATER ENVIRONMENTS FOR SAFETY

Example of authority or activity	Comments
Facility operator/service provider	Agencies developing facilities or providing services may be responsible for the safety of those locations, or this may be seen as an element of 'duty of care' or 'due diligence'. Recreational water-specific requirements may include the establishment and implementation of a 'safety plan' (in consultation with other stakeholders, including agencies responsible for safety and health—see section 13.2). This would normally include an assessment of hazards, including reference to user groups; a programme for monitoring and assessment; a water safety plan (which would include 'normal' and 'incident' circumstances and include a communication strategy to stakeholders).
National authority responsible for public health	Responsible to maintain and update national standards, e.g., recreational water quality standards, including sampling regimes and methods, analytical methods, analytical quality control and inter-laboratory comparisons, reporting. Maintenance of lists of national recreational water use locations. Surveillance of injury and illness in the community.
Local authority responsible for public health	Authority and responsibility to advise local facility developers/service providers and municipalities on public health aspects of the activities and resources under their supervision. Authority and responsibility to intervene when made aware of imminent or actual severe threat to public health at a recreational water location, including advising against use for a determined period or until safe conditions are re-established.
Authority responsible for safety	May be multiple and some may be non-governmental (e.g., lifesaving federations). Often responsible for development and implementation of voluntary codes of good practice (e.g., for lifeguard qualifications and activities). The fact that they are voluntary does not reduce their importance and they may be a major aspect of safety promotion.
Local tourism body	Provision of information to the public.
Certification agencies	The certification process is used to verify that devices (such as life belts) meet a given level of quality and safety based on agreed standards.
Recreational water/facility user	Exercise informed choice and take personal responsibility (e.g., use of sunscreen, avoiding excess alcohol).

In regulatory monitoring programmes factors, such as frequency of inspection and/or sampling, analytical methods, data analysis, interpretation and reporting, sample site selection and criteria for recreational water use areas will generally be defined by the regulatory agency and should take account of the principles outlined in chapter 12.

Box 13.1 uses the implementation of the recreational water quality classification system (outlined in chapter 4) to illustrate points to be considered in adaptation of guidelines to specific, locally-appropriate regulatory provisions, as it is potentially the most complex.

BOX 13.1 GUIDELINE ADAPTATION (USING THE RECREATIONAL WATER QUALITY CLASSIFICATION SYSTEM AS AN EXAMPLE)

The principal requirements that would need to be incorporated into provisions would normally include:

1) The definition of "water user" or "bather", "recreational water" and, if the use is seasonal for the majority of users, "bathing season".
2) The establishment of a water quality classification system based on:
   a) defined statistics from microbial water quality assessment;
   b) defined levels of the probability of the sewage pollution of the recreational water (with the assessment to be based on inspection of the conditions during the defined bathing season);
   c) defined means to combine a) and b) to provide a broad classification of risk to public health.
3) The obligation upon national/regulatory authorities to maintain a listing of all recognized recreational water areas in a publicly accessible location. This would, typically, be the same location as used to inform the public of the recreational water classification.
4) The establishment of procedures, responsibilities and authority for progressively updating 2a) and 2b) in light of new scientific information and developments.
5) The definition of responsibility for:
   a) establishing a water safety plan (including "posting" to warn of poor water quality, monitoring and sanitary inspection) and its implementation (e.g., local authority, private facility manager or service provider, lifeguard association, etc.);
   b) independent surveillance, including recreational water classification (e.g., local government, public health body, environment agency/authority);
   c) provision of information to the public (e.g., public health body, local authority, local tourism body);
   d) interpretation of the significance of "exceptional circumstances" (e.g., public health body).
6) The obligation to act. This would include:
   a) the requirement that on detection of conditions potentially hazardous to health, or uncharacteristic of the location, to immediately consult with the public health body and inform the public as appropriate;
   b) a general requirement to strive to ensure the safest achievable recreational water use conditions, including implementation of measures in order to improve classification of recognized recreational water areas by available means (including pollution control and abatement) and the discouragement of the use of locations that present an especially high risk (i.e., the worst classification category);
   c) encouragement of advisory action at times of high risk of disease at locations where water quality deterioration is sporadic and predictable. Where such action can be shown to be effective, this should be taken into account in the classification scheme outlined in 2).

Most of the factors outlined in Box 13.1 will apply to the derivation and adaptation of any recreational water standard. In addition to illustrating the application of guidelines, Box 13.1 also highlights the importance of the multiple stakeholders (see Figure 1.3) involved in the process of adapting and applying guidelines and standards.

13.2 Recreational water safety plan

One way in which all the potential hazards outlined in previous chapters can be brought together, on a location specific basis, is through a recreational water safety plan. As outlined in Table 13.1 this would include an assessment of locally relevant hazards (including reference to user groups), a programme for monitoring and assessment and a management plan, which would detail both normal and incident (or exceptional) circumstances. It is suggested that such a safety plan is adapted from a country or regionally specific generic plan which could include a hazard rating scheme and also an overall recreational water rating, as outlined in chapter 2. The advantage of adapting a generic plan is that all recreational water areas in a specific area would then be rated against the same scale, improving informed personal choice.

13.3 Compliance and enforcement

"Watchdog" institutions responsible for the programmed process of monitoring quality indicators—i.e., sampling, measurement and subsequent recording of various characteristics (e.g., governmental environmental agencies/local authorities, with analysis being carried out by hospitals, public health or university laboratories)—should assess the conformity of recreational water areas to local or national standards. In those countries where it is difficult to achieve guideline objectives, central and local governments may set interim standards to ensure a progressive improvement towards local regulatory limits and possibly to desirable conditions.

13.3.1 Responsibility for risk management

Risk management is the making of decisions on whether or not risks to well-being are acceptable or ought to be controlled or reduced, based on evaluation of risks together with the identification and application of preventative or control strategies. The making of these judgements involves value judgements of some kind, whether a formal evaluation of costs of detriment from the hazard and the benefits of improvements or a subconscious personal evaluation.

Responsibility for managing risks in water recreation takes place at two distinct levels:

- society regulators, through central and local government and providers of recreational facilities; and
- participants in the activities, whether personally or collectively (see section 13.5).

The regulatory functions in risk management are very much the same as in other systems where public health and well-being are involved, such as drinking-water supply and food hygiene. They involve a devolvement of responsibilities downward and of reporting upwards. Responsibilities for monitoring may be devolved to an environmental agency or to local authorities, with analysis being carried out by hospital, public health or university laboratories. Local authorities may own or control access to public beaches and recreational water areas and thus fall into the category of provider. This role should be independent of a local authority's responsibility for public health (e.g., closing beaches and other recreational facilities deemed hazardous to health and safety). This latter responsibility is a well-defined role of a local authority's department of environmental health, the local medical officer for environmental health or equivalent. Central government and local authorities have a responsibility for informing the public about health issues in water recreation (Table 13.1).

13.3.2 Regulatory compliance

A number of problems affect the application of regulatory compliance and restrict the usefulness of this approach. For example, a marginal failure in water quality may be due to one of a number of contributing pollution sources. In the case of microbial quality, it is frequently the case that a number of sources—which may include riverine discharge, sewage, storm outflows, solid waste and agriculture—may all contribute and may be the responsibility of different authorities (hence the usefulness of an "umbrella" type of management framework, such as that provided by ICAM). A further problem concerns the issue of temporal variation. While most regulatory regimes require compliance based on a proportion of time, periods of high risk may be brief and either undetected by such regimes, which exposes the public to increased risk, or overestimated, thereby condemning an otherwise safe location. Finally, it should be recalled that legislation generally applies to specifically designated areas, e.g., government-defined bathing beaches, rather than to all potential recreational water use areas. Special interest groups and users of less-frequented locations may not be properly protected under such regimes.

An alternative approach to assessing regulatory compliance as a failure of a recreational water to achieve a certain water quality is provided by the "obligation to act" stipulation outlined in Box 13.1 and Section 4.7.3. This requirement would mean that failure to respond to the detection of conditions potentially hazardous to health would lead to non-compliance rather than the measured water quality (for example) falling below a certain measure.

The role of regulatory compliance is not, however, restricted to pollution control and may successfully be extended to the implementation of policy regarding areas suitable for development and provision of minimum facilities and supervision by local operators—for instance, in terms of lifeguards (see Appendix A) and first aid facilities.

There are two kinds of regulatory action. *Local action* consists of improvements to facilities to eliminate hazards and thereby to reduce risks. Examples are the construction of sewage treatment works and long sea outfalls to reduce contamination of the sea with sewage or designating areas to be used for waterskiing, which do not conflict with bathing. *Policy implementation* (regional, national or international) usually takes the form of creating standards or guidelines to control risk. Inherently, standards provide a means of judging whether conditions are acceptable or not and, therefore, whether improvements are needed. They also provide a means of identifying whether intervention to reduce exposure is required, such as through provision of public advice, closing areas etc. Purpose-designed programmes of monitoring (see chapter 12) and analysis must accompany them, which provide information on quality.

13.3.3 *Enforcement*

Enforcement is an essential component of the regulatory system. Strong enforcement of a regulatory approach, however, may also focus attention on the high cost of, for example, pollution control intervention, and in some cases it has been argued that this is disproportionate to the public health benefit obtained. Again, an "obligation to act" regulation may minimise this problem. As point 6b) in Box 13.1 suggests, a general requirement to ensure the safest achievable recreational water use includes the discouragement of use of inappropriate or very polluted sites and not just pollution control measures.

Pollution control measures are most effectively deployed within a wider context of ICAM (see Box 13.2). In order to be effective, standards, guidelines and codes of practice must address the root causes of hazards. For example, medical waste found on a beach should be cleared, but sourcing it and preventing ongoing contamination is the prime consideration.

13.3.4 *Monitoring and reporting*

One purpose of guidelines, standards and regulations should be to promote improvement, and thus monitoring and enforcement should focus upon this. Proper information and positive incentives are often more effective ways to achieve improvement than the implementation of sanctions.

Results of monitoring programmes should be made readily available to participants in a timely manner, so that they can make informed decisions on using the facilities, and to regulators, so that they can take decisions with facility owners to carry out needed improvements. The public is also entitled to receive the results of monitoring so that individuals can choose whether or not to visit a particular beach or recreational water (see section 13.5 and Box 9.2).

13.4 Control and abatement technology

As health risks in certain environments become apparent (because of either changing risks or improved detection), responsible institutions (e.g., water companies, agricultural agencies, beach or recreational facility managers and so on) should identify the causes and put in place measures to combat the risks. Detection of health risks should be objective, e.g., based on systematic surveys. Implementation of remedial action should be in accord with an integrated management framework as outlined earlier and may include the control and abatement of pollution discharges with respect to the various levels of sewage treatment (chapter 4), control of agricultural runoff (chapter 8), fencing of dangerous areas (chapter 2), beach cleaning (chapters 2 and 6), provision of lifeguards (chapter 2 and appendix A), etc. Zoning and use separation can also be simple, but effective, control measures (chapter 2).

In terms of pollution control and abatement technology, the *required* design criteria for an intervention would result in a low to intermediate health risk, while the *preferred* design criteria would result in a minimal or low health risk (Figure 1.4).

Within an integrated planning process, tools (such as environmental health impact assessment, environmental audits and quality standards) can be designed and enforced. Stakeholders including industrial representatives should be involved in the discussion throughout the whole process to ensure that priority concerns are taken into consideration and that the proposed tools are generally acceptable, which would facilitate compliance. A development plan would also include land use plans, overall legislation and regulation and could advocate the use of such tools as economic instruments to manage the recreational waters.

13.4.1 Health impact assessment

Planning for the development of new recreational water projects or for the upgrading of existing ones offers ample and timely opportunities to incorporate human health considerations. A health impact assessment (HIA) provides the method and procedures to ensure such incorporation in a systematic, comprehensive and focused manner. The HIA approach considers changes in environmental and social determinants of health resulting from development. Both types of health determinants are relevant in the context of recreational water projects. HIA should be linked to the environmental assessment, but must maintain a distinct profile.

The rationale for HIA is firstly economic. It allows design options and management measures to be integrated into the project rather than relying on strengthening health services or the need for subsequent remedial action to be implemented at a generally higher cost. Such an after-the-fact remedial approach is undesirable, because it usually signifies a transfer of hidden costs to the health sector. HIA will also contribute to improving the health status in the project area. It aims to identify not only adverse health effects but also health opportunities. The measures recommended on the basis of the HIA should be designed to take into account inequities in health status and to overcome a disproportionate burden of exposure to health risks of vulnerable groups.

HIA starts by setting boundaries and priorities, a process known as scoping and screening. In recreational water projects, the physical boundaries for HIA will often coincide with the project boundaries, but they may stretch beyond, to include communities downstream from a project on a river system or further along the coast, depending on prevailing currents. HIA is a predictive exercise, and it should, therefore, not only include communities currently inhabiting the project area, but also groups of people that may enter and settle temporarily or permanently. In recreational water projects, these may include temporary labour employed during the construction phase, new staff that have come to work at the recreational facilities and the project's target group itself: people who come to use the recreational facilities. Within these groups, those with particular vulnerabilities should be identified.

HIA should cover the full range of health issues potentially affecting these different groups: accident and injury, communicable diseases, non-communicable diseases, malnutrition, and psycho-social disorders. In the case of recreational water projects, it is likely that the screening process will result in a health focus on two major groups:

- accidents and injury
  - — hazards and risks to construction workers related to increased traffic and transportation once the project becomes operational;
  - — accidents and injury due to tourists' engagement in high-risk activities (whitewater rafting or scuba diving, for example) or their increased exposure to natural risks (shark attack, snake bite, jellyfish sting).
- communicable diseases
  - — mainly waterborne (and foodborne) diseases associated with a deterioration of water quality;
  - — water-related vector-borne diseases, because of ecosystem changes resulting in the increased breeding of mosquitoes and other insect vectors. Such changes include hydrological changes, biodiversity loss and an increased air humidity.

    (There may also be an impact on respiratory infections (non water pollution related), sexually transmitted infections and HIV/AIDS. There are, however, no design, engineering or water management measures that can help prevent these.)

There may be other health issues associated with recreational water development such as, increased risks of excessive UV exposure due to sunbathing, psycho-social effects especially among indigenous communities in the project vicinity or malnutrition among groups primarily depending on fisheries that are adversely affected by the project. There is, however, little that improved environmental management can do about such problems, with the exception, perhaps, of the last example.

Screening and scoping should lead to a decision concerning the need for a full HIA. A number of countries have legislation in place that contains criteria with minimum values only, about which an impact assessment is required. Some authorities have also advocated sentinel health monitoring to identify health impacts of development projects.

HIA results in a package of recommended measures to safeguard health or mitigate health risks, as well as health promotional activities. In recreational water projects, the resulting environmental management plan will aim to tackle the risks resulting from changes in the environmental determinants of health; moreover, regulatory measures, including financial instruments such as taxes or subsidies, will deal with risks resulting from social change.

Environmental management may involve permanent and capital-intensive measures often of an infrastructural nature. In the context of recreational water projects, this may include:

- wastewater treatment plants;
- systems of dykes, sluice gates, pumps, weirs and other hydraulic structures to optimize hydrological features;
- construction of pipelines to drain or desalinate coastal lagoons where mosquitoes breed; and
- protection of water storage ponds and tanks.

Environmental manipulation aimed at eliminating health risks is a recurrent action. Cleaning aquatic weeds that may harbour vector insects or snails from water bodies is an example.

Some remedial measures may themselves need an assessment for their possible environmental and health impacts. This is particularly true for the chemical control of insect vectors of disease using residual insecticides. Indoor residual spraying poses risks to the members of the spray team. Larviciding introduces the insecticides into the environment at large, where it may disrupt ecosystems and enter the food chain.

Once an action plan based on the HIA recommendations has been initiated, monitoring is a critical component. It should ensure compliance with the agreed design, construction and management changes. It should also follow the health status of the various groups to identify any unexpected health issues arising.

13.5 Public awareness and information

Awareness raising and enhancing the capacity for informed personal choice are increasingly seen as important factors in ensuring the safe use of recreational water environments and an important management intervention. They act both directly (i.e., users are less likely to choose an area that is known to be less safe or to practise unsafe behaviours, so that overall exposure of the population, and hence adverse health outcomes, will be reduced) and indirectly (the exercise of preference for safer environments may induce competition between resorts/destinations based upon relative safety and encourage investment in improvements). In order that these contribute to improved safety, it is essential that the public is generally aware and that information is available, comprehensible, delivered in a timely manner and standardized to enable comparison between alternative locations.

The general public has to rely on information about safety, hazards to health and well-being and facilities as it is able to gain from the news media, local authority notice boards, environmental groups and tourist publicity, as well as its own perceptions. Local NGOs, the tourism industry and local authorities contribute to the distribution of information brochures, the training of consumers in safe conduct and practice, the posting of warning notices, the zoning of dangerous areas and provision of lifeguards. In so doing, they need to translate data gathered by scientists and technicians into understandable and user-friendly messages. The media is also a powerful tool in awareness raising and information dissemination.

Awareness raising is of particular importance among certain specialist user groups and should concern both the hazards that they may reasonably encounter together with the hazards that they may present to other users. With the increasing use of recreational water areas by multiple user types (e.g., beaches used for swimming, jetskiing and sailboarding), this is of particular importance. Clubs and other user group associations have a special role to play in this regard.

Participation in leisure activities is essentially a voluntary activity. Committed participants may choose to belong to clubs and, in turn, clubs may be affiliated to regional and national organizations, which promote development of the sport at the highest national and international levels and issue rules and codes of practice to clubs and the wider membership. Clubs may own facilities and stretches of water. In general, the level of organization shown in Table 13.2 will ensure that club members enjoy the advantages of well maintained facilities, training in proficiency and personal safety and knowledge and awareness of hazards. The degree of development of this structure is dependent upon economic factors and the degree of commitment of participants to the development of their sport.

Participants can control risks actively by acting on knowledge provided to them in the form of guidance, codes of good practice, rules, training and information on the existence of local hazards (such as poor water quality, strong tidal currents, the existence of wrecks underwater and so on).

TABLE 13.2. PUBLIC AWARENESS INFORMATION: ORGANIZATIONAL LEVELS AND RESPONSIBILITIES

Participant	Expert advice	Regulator
National sports organizations Issue codes of practice and newsletters for membership, regulate competitive sport, promote training. International liaison.	**Public health body** Provide public health information. Liaise with user groups and media to disseminate appropriate health messages.	**Central government** Legislate standards, publish results of national monitoring, conduct national health surveillance, involved in finance of capital improvements.
Affiliated clubs Informing members of codes of practice, setting rules of conduct for members, supervising organized events, promoting high standards of performance, providing training.	**Professional institutions, experts** Current awareness of health and safety issues, legislation, research. Liaison with, and expert representation on, government committees and national sports organizations.	**Local authorities and government agencies** Monitoring, reporting results to central government, displaying results to public. Giving information on health. Enforcing public health measures, closing facilities if conditions are hazardous to health.
Club members Responsible to club for conduct and act on club's advice, in addition to making their own value judgements.	**National and international lifesaving federations** Lobby group. Dissemination of safety information.	**Providers of facilities** May be local authorities (public facilities) owners or service providers, including clubs with their own facilities. Adopting and implementing local codes of operational practice, providing safety facilities, preparing a recreational water safety plan, carrying out improvements. Publicizing facilities and results of monitoring.
General public Make own value judgements from personal awareness and knowledge.		

Increased public awareness regarding recreational water use and health is likely to lead to a number of direct benefits where the principal factor leading to accident or disease is individual error of judgement. This may be the case regarding a number of accident hazards, including, for example, diving into shallow water or overestimating swimming abilities. Increased awareness may also lead to greater availability of rescue and lifesaving skills among the general and water user population. The objective of awareness-raising activities is not only to raise the individual's ability to correctly appraise the risk but also to raise the level of confidence of the public that the issue is being addressed and monitoring measures are being undertaken.

Personal perceptions of pollution are most influenced by sight and odour, while physical danger is often based on a visual assessment. Choice of venue is strongly influenced by the availability of appropriate water conditions and areas most suitable for the activity (Cutter et al., 1979). The general public is therefore largely reliant on effective risk management.

One important tool used by associations and governments to enhance the public's capacity for informed personal choice is beach grading or award schemes. For example, since 1987, the Foundation for Education and Environment in Europe has attributed a quality label (in the form of the "Blue Flag") to European beaches and also to marinas. The Blue Flag award takes into account water quality, as well as restrictions on dogs, toilet facilities and so on. It encourages coastal municipalities to improve the public awareness of both visitors and residents.

Government authorities are also developing effective incentive systems. The tourism industry is increasingly conscious of the need to promote safety and environmental concerns and now sponsors "green quality labels". In addition, users and sports participants may develop schemes, such as that used to assess the conditions of surfing areas initiated by a surfers' association.

Although such schemes can improve public awareness and act to inform public choice, a lack of coherence and compatibility among award schemes may undermine their effectiveness and credibility. Issues related to such schemes are discussed in greater detail in Box 13.2.

13.6 Public health advice and intervention (including prevention and rescue services)

Public health advice is a key input to public awareness and informed personal choice, be it with regard to avoiding excessive UV exposure (chapter 3), being aware of what precautions to take against leptospirosis (chapter 5) or malaria (chapter 11) or knowing that an area is unsafe for swimming (chapter 2).

Public health advice and intervention includes response to short-term incidents and breaches of standards. When a guideline or standard is exceeded, the authority responsible for public health should determine if immediate action is required to reduce exposure to the hazard and whether measures should be put in place to prevent or reduce exposures under similar conditions in the future.

BOX 13.2 GRADING AND AWARD SCHEMES

A number of international and national award/grading schemes for water use areas (most commonly beaches) that include safety-related information have been developed. International examples include the Blue Flag (which is the most popular in Europe) and Coastwatch programmes. In addition, many countries also have one or more national equivalents. In the United Kingdom, for example, there are a number of other rating schemes in use, including the Seaside Awards, Good Beach Guide and Beachwatch. These schemes are used at a variety of recreational-water environments, ranging from large-scale resorts to undeveloped rural beaches. Award schemes can have a large influence on tourism (e.g., the beach award schemes in the USA) (Leatherman, 1997) and, as a result, are generally seen as desirable by local authorities and agencies responsible for tourism.

These schemes were designed to inform the public about a recreational area's quality so that users and potential users can make an informed choice regarding the area. Nevertheless, it appears that confusion exists about the implications associated with these schemes (Williams & Morgan, 1995). They are used to:

- give consumers information about water quality so that they can make informed choices about holiday destinations and assess risks when bathing in coastal waters;
- advise businesses that operate nearby and that want to reduce the risks caused by adverse publicity about poor water quality; and
- help resort managers and local authorities that wish to ensure that there are common standards and a common system for measuring those standards (Nelson et al., 1999).

In some of these programmes, however, human health concerns comprise only a small component, or it is possible for areas that present a significant public health risk to receive a high grading if other facilities are good or extensive. Such approaches are likely to undermine the contribution of informed personal choice to the promotion of user safety. In general, health-related aspects in such schemes should assume a dominant character in classification if there is any likelihood that users will interpret them as indicating safety.

A specific problem that is commonly encountered in the development of award schemes is that information may not be comparable between locations. For example, it may be difficult to generate comparable information on microbial water quality because of problems with interlaboratory comparability; where such information is locally generated, it may be difficult to ensure the impartiality of laboratories and surveyors. At an international scale, differing legislation, practice and interpretation between countries compound such problems.

The success of award schemes in terms of informing the public depends upon active information dissemination as well as the required technical interventions. While comparison of different locations constitutes an important part of the information required for improved personal choice, active information dissemination at a local level and related to short-term changes is also necessary. For example, in some recreational water use areas, changes in local conditions may be extreme or rapid, such that areas are unsafe for physical or quality reasons. Such areas require "posting" and also information dissemination where a beach is unsafe at certain times—for instance, because of weather conditions or because of local water quality changes. Ideally, the requirement for such information dissemination should constitute an important part of award schemes.

Available evidence suggests that many hazards associated with the recreational use of the water environment are of an instantaneous or short-term nature. Drowning has been associated with offshore winds carrying inflated toys and buoyancy aids away from the coast. In the case of water quality, certain beaches or areas are known to register increased pollution under certain conditions, relating to tide, wind direction or rainfall, for example. In eutrophic fresh water, wind may be associated with the accumulation of cyanobacterial "scums" in some areas, which may present a special hazard to children who are tempted to play in the scum material. Whenever such conditions occur and constitute a risk to public health, short-term advisory notices may be considered necessary, and the decision to place such notices should be based upon public health considerations. This approach may, through low-cost measures, enable safe use of areas that might otherwise be considered inappropriate for recreational use. Examples of conditions that may result in a severe health outcome and thus merit a public health advisory and levels at which they may be implemented are summarised in Table 13.3. Specific conditions require definition on a location by location basis depending upon local circumstances and the user groups and activities typically undertaken (a white water canoeist, for example, may be actively seeking river flood conditions).

TABLE 13.3. CONDITIONS THAT MAY MERIT INTERVENTION BY SAFETY OR PUBLIC HEALTH AUTHORITIES

Hazard	Examples of conditions meriting immediate action
Drowning	High surf conditions Development of a strong rip current Dam release of water on an impounded river
Microbial	Presence of human sewage (e.g., due to a pipeline breakage) 95% percentile value of intestinal enterococci/100ml greater than 500 (or greater than 200 if source mainly human faecal pollution) in consecutive samples. Presence of a large outbreak of faecal-oral illness in the local community (especially if the agent is resistant to sewage treatment processes and has a small infectious dose)
Algal and cyanobacterial	Presence of scums or detection of 100,000 cells/ml
Chemical	Chemical spill or significant contamination
Dangerous aquatic organisms	Presence of organisms associated with human fatalities such as sharks, hippopotami, crocodiles, alligators or box jellyfish (for example) close to the recreational area.

Prevention and rescue services can also be considered to fall within this intervention. Provision of lifeguards (see Appendix A) is a highly visible measure that may contribute to safety in various ways: by directly assisting in prevention of drowning (rescue, resuscitation), by assisting in injury prevention (e.g., advising users not to enter dangerous areas) and by playing a more general educational role (concerning water quality hazards and exposure to heat, cold or sunlight, for example).

13.7 Operating within an integrated coastal area management framework

One way in which all the relevant stakeholders can be brought together is through the establishment of an integrated management system for marine and freshwater recreational areas based on the concept of integrated coastal area management (ICAM), as outlined in chapter 1 and Box 13.3.

BOX 13.3 INTEGRATED COASTAL AREA MANAGEMENT

An integrated coastal area management (ICAM) framework is a "continuous and dynamic process that unites government and community, science and management, sectoral and public interests in preparing and implementing plans for the protection and development of coastal systems and resources" (GESAMP, 1996).

The main premises of ICAM are:

- Natural resources are finite, and their use must be allocated prudently.
- The functional integrity of the resource systems must be protected.
- Resource management involves changing human perceptions and behaviour.
- Resolution of multiple-use conflicts needs a holistic approach through policy, management and technical innovations.
- Planning and management processes are dynamic and should respond to ecological and socioeconomic conditions and evolve with time.

Ideally, ICAM seeks to address all activities and resources within a defined area. Thus, the need for and requirements of such economic and social activities, including fisheries, non-renewable resource extraction, waste disposal, agriculture and aquaculture, tourism, recreation, transportation and development, should be considered.

ICAM involves comprehensive assessment, the setting of objectives and the planning and management of coastal systems and resources. It also takes into account traditional, cultural and historical perspectives and conflicting interests and uses. The individual elements and some of the main linkages of the ICAM framework are shown in Figure 13.1.

ICAM is an iterative and evolving process for achieving sustainable development (UNCED, 1992) and continuous management capability that can respond to changing conditions. As such, the framework permits integration of the various needs and requirements for the coastal area and coordination of the actions, whether preventive or remedial. Integration relates to both vertical (levels of government and NGOs) and horizontal (cross-sectoral) coordination among stakeholders whose actions influence the quality/quantity of water-based resources reflected in the planning and management strategies.

Continued

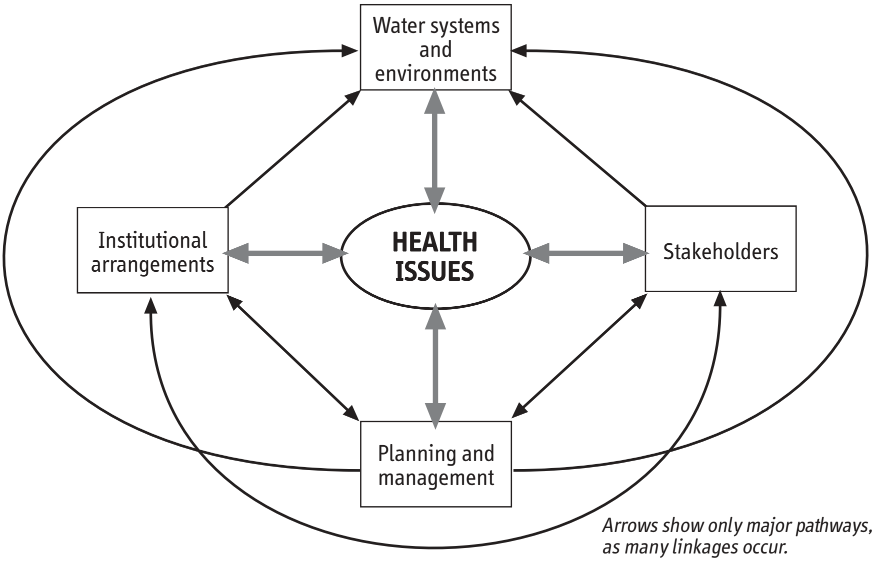

FIGURE 13.1. A SCHEMATIC VIEW OF THE INTEGRATED MANAGEMENT OF RECREATIONAL WATERS

An ICAM programme can be directed to one or more types of coastal areas, which can extend from coastal mountain watersheds to offshore coastal boundaries, and can also encompass river catchment areas.

Management options may vary, for example, from educational projects to construction work or from no-cost actions to heavily funded development. The exact package of management options to reduce or eliminate health hazards and risks related to recreational water uses will be driven by the nature and severity of the health impacts.

Based on assessment of risk, three levels of response may be considered:

- The basic response should guarantee that an ICAM management framework is established to prevent the occurrence of significant adverse health outcomes and facilitate the implementation of remedial actions. This could include the dissemination of minimum public awareness messages, the establishment of an integrated recreational water committee with participation of various stakeholders and the development of a streamlined monitoring programme.
- The expanded response would provide an enhanced institutional setting with more sophisticated legislation and increased participation of stakeholders in the development and implementation of solutions, targeted intervention to areas prone to health hazards, rapid response when problems are identified, and a greater public awareness activity together with the mobilization of local NGOs to support the effort.

- The full response would ensure a comprehensive package of management options with a clear strategic plan for implementation of the various interventions and establishment of an integrated coastal area/recreational waters management system, which would, in turn, develop appropriate tools (legislation, incentives, economic instruments, participation, etc.).

These three levels of response correspond to the assessed level of health risk in a recreational water area and should be complemented by the corresponding levels of monitoring outlined in chapter 12. Levels of response apply both at progressive national implementation and that appropriate to specific local circumstances.

A basic response may suffice in an area that is rarely frequented, with little or no record of health effects due to recreational activities and with no development plans to alter the nature and use of the recreational water zone in the medium term. The response should ensure that a potential danger situation can be dealt with effectively and immediately. The expanded and full levels of response would need to be adapted to local conditions, taking into consideration past occurrences and likely trends. Preventive actions are effective in areas with good general awareness levels, which have available resources and no imminent health danger and threats. Remedial actions would be required to minimize existing negative health effects. Usually a combination of the two would be selected, with respect to local conditions, availability of resources and valuation of the danger and impacts. The selection of level of response is clearly also linked to the availability of funding, technical support and advice.

Four major management interventions were identified in chapter 1. These comprise compliance and enforcement, control and abatement technology, public awareness and information (this includes support for informed choice, such as clear recreational water grading/award schemes) and public health advice and intervention (including prevention and rescue services). Some activity in each of these areas is possible and advisable at all three levels of response in terms of national implementation.

13.8 References

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APPENDIX A
Lifeguards

This annex draws upon the extensive experience of the International Life Saving Federation (ILS)[1] and comments received during the preparation of these Guidelines. It relates to people who are trained and positioned at recreational water sites to protect water users and who may be paid or voluntary. They may be referred to as lifesavers, lifeguards or given some other title. For simplicity, the term lifeguard has been used throughout this annex. The following sections outline points for consideration when setting up or running a lifeguarding scheme.

A.1 Lifeguard qualifications

Lifeguards are generally responsible for observation of a beach or recreational water area to anticipate problems and identify an emergency quickly, carry out rescues, give immediate first aid, communicate with swimmers and recreational water users, enforce regulations where appropriate, promote awareness of specific and general hazards and report incidents.

Lifeguards should have appropriate training and hold a suitable current qualification. This would normally be from an appropriate and recognized training and assessment agent. Lifeguards should, for example, be competent in lifesaving methods, swimming and the most current methods of resuscitation. Requalification should be undertaken at regular intervals, and practical rescue and resuscitation skills should be practised frequently. Both fitness and technical knowledge are required. Good practice would generally require that records be kept of all training and qualifications and be available for inspection.

Lifeguards should have locally-specific knowledge concerning the presence of natural and artificial features, the topography of the area, tides and currents, hazards posed by local animals, the distance to qualified medical assistance, hazards and risks, public relations, crowd management and local operating procedures.

Minimum standards for the training of lifeguards have been proposed (http://www.ilsf.org).

A.2 Lifeguard observation points

Lifeguard observation points must have a clear and unobstructed view of the area of supervision, including both the water and the beach. Lifeguard observation points

[1] The ILS is a non-profit confederation of major national lifesaving federations worldwide.

are ideally elevated (the higher the better, within reason) and provide the lifeguard with protection from the elements. These are often referred to as lifeguard "towers". They should provide adequate space to allow the lifeguard to stand and move while observing the water and a place for necessary rescue and first aid equipment. The design of a lifeguard observation point should include a way to respond on foot to a rescue without breaking observation of a swimmer in distress.

Lifeguard observation points should be placed to allow observation of the area under control. At coastal recreation areas, they should be placed as close to the water edge as practical at high tide and may be moved at intervals with the changing tide, so that they will be close to the water edge at all tidal stages. Where a beach is divided by a jetty or other obstacle to clear observation, each part should ideally be independently observed.

A.3 Lifeguarding equipment

Lifeguards on duty should be easily identifiable at a distance, in a manner that sets them apart from others at the beach, such as by a uniform. To properly perform their duties, lifeguards require appropriate rescue equipment. The most basic rescue device is a rescue float. The most common of these are tubes of flexible closed-cell foam rubber and buoys of hard plastic. Other examples of basic lifesaving equipment are the rescue board (a surfboard adapted for rescue), binoculars and swim fins. Lifeguards are frequently involved in first aid and need to be appropriately equipped for this work. Lifeguards are often be provided with a telephone or radio for communication. As record keeping is necessary, report forms should normally be provided.

More advanced rescue equipment can be useful. Rescue craft have proven effective in offshore rescue of swimmers, boaters and others. While costly, they receive a high degree of public support. They are most frequently deployed in areas of dense use or particular hazard. For effective use of rescue craft, good communication linked to rapid deployment is important. In some cases, the provision of a motor vehicle may also be appropriate.

All equipment should be inspected frequently and replaced or repaired as necessary.

A.4 Lifeguarding policies

Lifeguard organizations should develop written "standard operating procedures". These would contribute to the water safety plan (section 13.2) and should contain details on risk assessment, a plan of the recreational water (outlining hazards, access points, vantage points and blind spots, information points, zones, positioning of public rescue equipment and protective features), supervision requirements (e.g., lifeguard provision, rotation systems, qualification, surveillance levels and daily routines) and the duties of other recreational water staff.

An "emergency action plan" should be formulated to guide lifeguards in handling emergencies that can be reasonably anticipated. It should provide step-by-step procedures for each member of the team: rescue management, continuity of supervision during rescue, communication procedures during an incident (both within the team and with external agencies), aftercare and peer support.

Lifeguard levels of performance should be established and incorporated within the policies.

A.5 Lifeguard duty period

Lifeguard supervision should be maintained during times of significant use. Sufficient regular breaks should be incorporated into duty periods. When on duty, lifeguards should not perform other tasks that might detract from observation.

Warning signs should be posted if lifeguard service is interrupted, and the beginning and end of this period should be communicated with, for example, megaphones and signs.

A.6 Lifeguard staffing levels

Lifeguard staffing levels should be appropriate to the use of the area of responsibility and provide for public safety in a manner consistent to ensure safety. Responsibility should not be left with a single individual. Lifeguards work more effectively in teams. These teams should ideally be managed through a central administration capable of providing necessary relief, backup and resources.

Two primary factors influence the staffing level needs for lifeguards: attendance and risk. Attendance typically varies according to season, day of the week, weather and other factors. Risk can vary according to surf, rip current intensity (which is usually directly related to surf), wind (which may enhance surf size), water temperature and other factors. The number of lifeguards staffing a beach area should be adequate, regardless of fluctuations in attendance and risks. The provider of lifeguard protection must therefore either adopt a system to effectively vary staffing according to fluctuations or set a consistent staffing level aimed at the highest levels of attendance and risk. Most lifeguard providers address this via a mix of the two. That is, they set regular staffing levels somewhat below the level needed to address the highest levels of risk and attendance, but somewhat above the average levels. Then, they develop a system to enhance staffing levels when unexpected crowds and/or risks present themselves. Varying staffing levels by day of the week is also common in areas where attendance fluctuates predictably.

People in distress in the water rarely wave or call for help, being panicked and occupied in trying to keep themselves afloat, and even nearby swimmers are often unaware of the problem. Thus, lifeguard vigilance is of key importance. It is a tremendous challenge to maintain concentration in the face of the monotony of watching swimmers for extended periods of time. Training may help, but does not eliminate normal human reactions to boredom. Regular breaks are therefore important and may also be necessitated by the environment in which lifeguards operate, which may be hot and/or windy. Lifeguards must consume generous quantities of fluid to prevent dehydration and assist with concentration. Breaks allow for simple human needs along with relief from prolonged periods of scanning and physical inactivity.

A.7 References

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The World Health Organization's (WHO) new *Guidelines for Safe Recreational Water Environments* describes the present state of knowledge regarding the impact of recreational use of coastal and freshwater environments upon the health of users – specifically drowning and injury, exposure to cold, heat and sunlight, water quality (especially exposure to water contaminated by sewage, but also exposure to free-living pathogenic microorganisms in recreational water), contamination of beach sand, exposure to algae and their products, exposure to chemical and physical agents, and dangerous aquatic organisms. As well, control and monitoring of the hazards associated with these environments are discussed.

The primary aim of the Guidelines is the protection of public health. The Guidelines are intended to be used as the basis for the development of international and national approaches (including standards and regulations) to controlling the health risks from hazards that may be encountered in recreational water environments, as well as providing a framework for local decision-making. The Guidelines may also be used as reference material for industries and operators preparing development projects in recreational water areas, as a checklist for understanding and assessing potential health impacts of recreational projects, and in the conduct of environmental impact and environmental health impact assessments in particular.

ISBN 92 4 154580 1

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