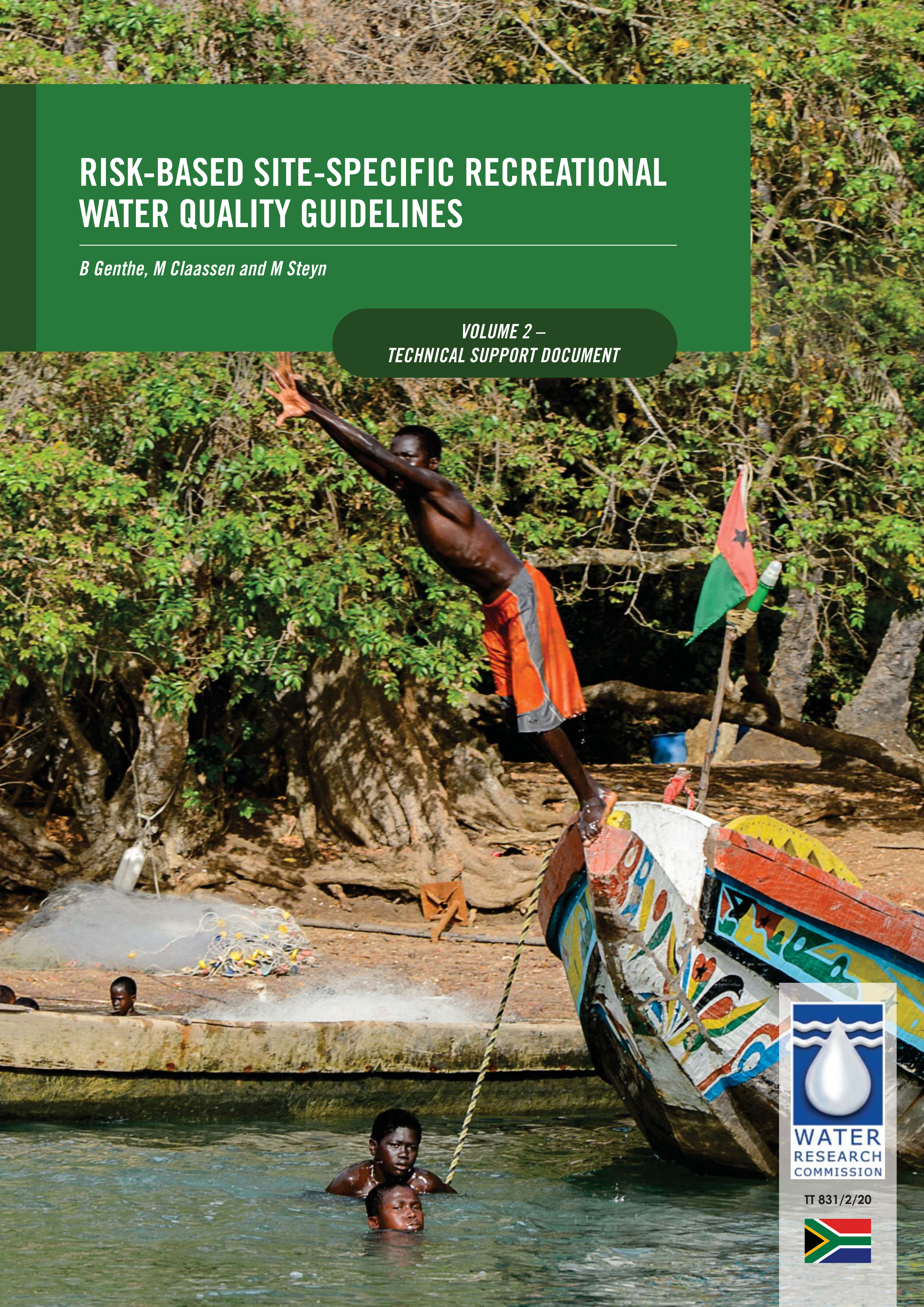
RISK-BASED SITE-SPECIFIC RECREATIONAL WATER QUALITY GUIDELINES

B Genthe, M Claassen and M Steyn

*VOLUME 2 –
TECHNICAL SUPPORT DOCUMENT*



WATER RESEARCH COMMISSION

TT 831/2/20

RISK-BASED SITE-SPECIFIC FRESHWATER RECREATIONAL WATER QUALITY GUIDELINES

VOLUME 2 – TECHNICAL SUPPORT DOCUMENT

Report to the
Water Research Commission

by

B Genthe, M Claassen and M Steyn
Council for Scientific and Industrial Research (CSIR),
Natural Resources and the Environment

WRC Report No. TT 831/2/20
ISBN 978-0-6392-0182-5

August 2020

Obtainable from:

Water Research Commission
Private Bag X03
GEZINA, 0031
orders@wrc.org.za or download from www.wrc.org.za

EXECUTIVE SUMMARY

BACKGROUND

The South African Water Quality Guidelines of 1996 are one of the most widely-used tools in water quality management in South Africa. A Department of Water and Sanitation (then Department of Water Affairs) initiative looking at a needs assessment developed a general philosophy with general specifications recommended for a decision support system for revised water quality guidelines for South Africa. Guidelines should no longer be used simply as trigger values above which something needs to be done and below which water quality can be ignored. While the 2008 Department of Water Affairs initiative looking at a needs assessment identified the need for revision of all the 1996 South African Water Quality Guidelines and the alignment with the 1998 National Water Act, this report focuses on updating the approach to the 1996 South African Recreational Water Quality Guidelines. The 1996 guidelines were based to some extent on a risk philosophy; the updated guidelines proposed follow a risk-based approach. While the scope of the guidelines remains applicable to any inland water used for recreational purposes, an important improvement of the revised guidelines is the site-specific and user-specific nature of the guidelines, allowing greater input and management of water use. In addition, they are available primarily in a software-based decision support system.

AIMS

The general aim of this project was to develop a software-based decision support system (DSS) able to provide both generic and site-specific risk-based recreational water quality guidelines for South Africa. Specific aims were:

i. To develop an intermediate ‘technology demonstrator’ that demonstrates the most important features.
ii. To engage with stakeholders to elicit comment and recommendations.
iii. To maximise synergy with parallel projects on the development of water quality guidelines for other water uses.
iv. To develop a fully-functioning DSS for recreational use.

The project assessed advances in guideline determination, both international and local, to ensure that the guidelines were based on the latest and most appropriate science and practice. The review of the recreational water quality guidelines took into account how suitable water is for recreational water use, and expanded on the 1996 guidelines to address site and user specificity. Water quality guidelines are intended to be protective however they may be over-protective or under-protective at sites with unique conditions.

A four-class classification system based on the current Department of Water and Sanitation (DWS) practice is used to depict water quality for recreational use. This classification system harmonised water quality with a risk-based assessment to determine fitness for use. The “Ideal” fitness for use class for recreational water use for example describes a class where water quality would not impair the fitness of water for its intended purpose. Both the fitness-for-use classification and the risk-based water quality assessment are represented in the DSS output screens depicting an assessment of water quality. The same colour scheme is used to depict the different fitness-for-use classes.

Table 1-1: A generic description of the DWS fitness-for-use classification of water used to determine management class

Fitness-for-use Class	Description
Ideal	A water quality that would not normally impair the fitness of the water for its intended use
Acceptable	A water quality that would exhibit only limited impairment to the fitness of the water for its intended use
Tolerable	A water quality that would exhibit increasingly unacceptable impairment to the fitness of the water for its intended use
Unacceptable	A water quality that would exhibit unacceptable impairment to the fitness of the water for its intended use

The Development Platform

One of the important design criteria stipulated in the project Terms of Reference, is that the Decision Support System (DSS) should make use of open source software. The DSS was created in an Excel-based format using VBA macros.

Defining Risk

According to the World Health Organisation (2017), risk is the likelihood of identified hazards causing harm in exposed populations in a specified time frame, including the magnitude of that harm and their consequences. Two important characteristics of hazards are the health impacts (severity) associated with the substance and the likelihood of significant occurrence (exposure). Combined, these elements determine the risk associated with a particular hazard.

Describing risk consists of answers to three questions:

i. What can happen? (i.e. what can go wrong or hazard identification?)
ii. How likely is it that that will happen?
iii. If it does happen, what are the consequences?

Decisions about defining acceptable risk and tolerable burdens of disease are complex and need to take account of the probability and severity of impact in addition to the environmental, social, cultural, economic and political dimensions that play important roles in decision-making. Despite the complexity, definitions of tolerable burdens of disease and reference levels of risk are required to provide a baseline for the development of health-based targets. Risk is an expression of the likelihood that an undesired effect may occur. The risk is dependent on an agent causing the effect (the hazard), and the subject experiencing the effect (the response). The calculation of risk is a technical/scientific process. Mathematically, it is the product (multiplication) of the likelihood of the subject being exposed to the hazard, and the likelihood that the effect will be expressed if the subject is exposed to the hazard. However, the decision of whether a particular level of risk is acceptable or unacceptable and if it warrants an action, is a value-based decision, which belongs in the policy and management domains.

A technology demonstrator was developed while engaging with project team members of the two parallel water use projects developing guidelines for irrigation and domestic use. The general aim to develop a fully functional software-based DSS able to provide both generic and user- and site-specific risk-based recreational water quality guidelines for South Africa, was successfully completed as described in this report. The DSS is a user-friendly self-contained system based on Excel macros with a manual and supporting information required to run the DSS. Establishing the concepts to design the DSS was a large undertaking and as was experienced with the two parallel projects for domestic and irrigation use, it is anticipated that further refinement is needed for features identified during the course of the project. To ensure uptake by water quality managers, training sessions will be needed, with additional modifications expected to be identified.

ACKNOWLEDGEMENTS

The project team wishes to thank the following people for their contributions to the project.

Name	Affiliation
Dr N Kalebaila	Water Research Commission (Chairperson)
Dr J Molwantwa	Water Research Commission (former WRC Research Manager)
Mrs B Genthe	CSIR (Project Team)
Ms M Steyn	CSIR (Project Team)
Dr M Claassen	CSIR (Project Team)
Mrs P Moodley	Golder Associates
Mrs L Boyd	Golder Associates
Prof. J Annandale	University of Pretoria
Ms LS Mudau	Tshwane University of Technology, Department of Environmental Health
Mr M Vulindlu	City of Cape Town (Scientific Services)
Dr S Jooste	DWS: RQIS
Mr M du Plessis	Independent Consultant
EL Dube	Wits University (Project Team)
Prof. G Nimako	Wits University (Project Team)
Mr Jan Pietersen	Midvaal Water Company
Ms S Janse van Rensburg	Midvaal Water Company
J Dateling	Golder Associates
N Juggath	Golder Associates
Mrs L Coetzee	CSV Water
Mrs S Freese	Independent Consultant
Dr T Ceronio	CSV Water
Ms J Borland	Independent Consultant

The authors would furthermore like to thank the individuals participating in user interaction sessions during the demonstration of the *Technology Demonstrator* which was held in Pretoria, and Stellenbosch during September 2016 for their valuable contributions to enhance the usefulness of the DSS. A special word of thanks is also due to the following individuals who early in 2017 reviewed the draft final DSS and contributed significantly to the identification and introduction of features that improve the usefulness and user friendliness of the final version of the DSS.

Mr Pieter Viljoen	Water Resource Planning Systems, DWS
Mr Geert Grobler	Water Resource Planning Systems, DWS

Many additional international names to be included who have agreed to review the DSS

Jamie Bartram	Editor of WHO water quality guidelines and health risk assessment guidelines
Al Dufour	US EPA and principle researcher and investigator of US recreational water quality guidelines and ingestion volumes

This page was intentionally left blank

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS & ABBREVIATIONS

ADI	Acceptable Daily Intake
BAV	Beach Action Values
BW	Body weight
DALY	Disability Adjusted Life Year
DOC	Dissolved Oxygen Content
DSS	Decision Support System
DWS	Department of Water and Sanitation
EHSA	Environmental Health and Safety Assessment
EHSS	Environmental Health and Safety Survey (EHSS)
GI	gastrointestinal
HACCP	hazard analysis critical control point
HARRNESS	Harmful Algal Research and Response National Environmental Science Strategy
HSE	Health and Safety Executive
IR	intake rate
MAC	Microbiological Assessment Category
MLE	Maximum Likelihood Estimation
NEEAR	National Epidemiological and Environmental Assessment of Recreational Water
QMRA	Quantitative Microbial Risk Assessment
SFRG	Suitability for recreational grade
SIC	Sanitary inspection category
SMCL	Secondary maximum contaminant level
TDI	Tolerable Daily Intake
UF	Uncertainty factors
WHO	World Health Organization
YLD	Years Lived with Disability
YLL	Years Life Lost

GLOSSARY

- **Decision Support System (DSS)** is an information application that can analyse data to allow decisions to be made easier.

- **Quantitative microbiological risk assessment (QMRA)** is the process of estimating the risk from exposure to microorganisms. It is a framework and approach that brings information and data together with mathematical models to address the spread of microbial agents through environmental exposures and to characterize the nature of the adverse outcomes.

- **Acceptable daily intake (ADI)** is defined as the maximum amount of a chemical that can be ingested daily over a lifetime with no appreciable health risk. It is expressed as mg/kg/d.

- **Tolerable Daily Intake** is also the maximum amount of a chemical that can be ingested daily over a lifetime with no appreciable health risk usually referring to pesticide residues or drugs. It is expressed as mg/kg/d.

- Both ADI and TDI have been replaced with the term **reference dose (RfD)** in US EPA risk assessment protocols.

- **The Disability Adjusted Life Year or DALY** is a measure of disease burden where 1 DALY is equivalent to 1 year of healthy life lost. The DALY is calculated using the sum of years of potential life lost due to premature death, and the years of productive life lost due to disability. DALYs are used to measure the combined quantity and quality of life of a population. It is a universal metric that allows comparison of very different populations and health conditions across time.

- **Years of life lost (YLLs**) are years lost due to premature mortality. YLLs are calculated by subtracting the age at death from the longest possible life expectancy for a person at that age.

- **Years lived with disability (YLD)** can be described as years lived in less than ideal health, for example conditions such as influenza, which may last for only a few days, or epilepsy, which can last a lifetime. It is measured by taking the prevalence of the condition multiplied by the disability weight for that condition. Disability weights reflect the severity of different conditions and are developed through surveys of the general public.

- **Hazard analysis and critical control point (HACCP**) is the process whereby potential hazards within a production, storage, and distribution monitoring system are identified and controlled for associated health hazards. It is aimed at prevention of contamination, instead of end-product evaluation.

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

These guidelines for recreational water use are based on a revision of the 1996 South African Recreational Water Quality Guidelines Volume using risk philosophy and site-specific concepts. Although the 1996 guidelines considered risk to some degree; the updated guidelines are more aligned with international best practice and the National Water Act of 1998, following a risk-based approach. While the scope of the guidelines remains applicable to any inland fresh water used for recreational purposes (excluding swimming pools and marine waters), the definition of 'recreation' has been expanded to include social, cultural and religious uses of water resources. This has increased the scope of the 1996 guidelines, where four norms were considered, namely, human health; human safety; aesthetics; and economics. An important improvement of the revised guidelines is the user- and site-specific nature of the guidelines – a widely-recognised limitation of the generic 1996 guidelines. The guidelines are made available primarily as a software-based decision support system (DSS) with three tiers:

- *Tier 1* closely resembles the 1996 generic guidelines (modified where applicable). This tier communicates the minimum requirements to the user taking the most sensitive user into account, highlighting potential problems if these are not met.
- *Tier 2* allows for site and exposure specificity in guideline specified contexts and is facilitated by the DSS. It allows for more specific inputs to be made to provide deeper levels of guideline generation.
- *Tier 3* allows for more detailed site-specific input where possible, using modules of the DSS which allows for modifications, but which requires significant expertise.

There are three main components to the recreational guidelines, namely:

- The DSS, which is a self-contained, user friendly computer program in Microsoft Excel. It has been designed to allow for decision making by a water quality manager. The manager, by knowing the site and through routine monitoring will be able to assess (with help from the DSS) the risk for different recreational activities at a specific site.
- A manual on the structure and functioning of the DSS as well as some of the high-level supporting information contained in the DSS.
- A Technical Support Document that provides background on the current state of knowledge regarding the specific recreational water quality constituents and the approach of the risk-based and site-specific guidelines compared to the previous edition of the guidelines.

1.2 PROJECT AIMS

The general aim of this project was to develop a software-based decision support system (DSS) able to provide both generic and site-specific risk-based recreational water quality guidelines for South Africa. Specific aims were:

i. To develop an intermediate ‘technology demonstrator’ that demonstrates the most important features.
ii. To engage with stakeholders to elicit comment and recommendations.
iii. To maximise synergy with parallel projects on the development of water quality guidelines for other water uses.
iv. To develop a fully-functioning DSS for recreational use.

CHAPTER 2: MANAGING RISKS IN RECREATIONAL WATERS – A REVIEW

2.1 INTRODUCTION

The broad categories of water use recognised in the South African Water Act include the use of water for:

- domestic purposes
- industrial purposes
- agricultural purposes
- recreational purposes, and lastly
- aquatic ecosystem health also needing to be protected

The water quality requirements of these form the basis on which the water is judged. The approach used to develop the water quality guidelines for recreational use was that the guidelines should serve as a source of information and support for decisions as to the safety of the water according to its intended use. Using this, water resource managers should be able to make judgements about the fitness for use of water for different recreational purposes. The guidelines are applicable to any inland water that is used for recreational purposes, namely rivers, streams, canals, dams, ponds and other impoundments. Recreational use of marine water is dealt with in the South African Water Quality Guidelines for the Marine Environment published by the Department of Environmental Affairs (DEA, 2012) and water quality of swimming pools in the Norms and Standards for Environmental Health in South Africa (DOH, 2013) published by the Department of Health.

2.2 USER GROUPS AND RECREATIONAL WATER ACTIVITIES

User groups have been defined according to the activity which in turn was previously defined according to the level of contact expected to result from the activity, providing only 3 different levels of contact, namely full-, intermediate- or non-contact. The current DSS takes into account the following user groups based on their activity which will influence their contact with the water:

- Recreational swimming
- Competitive swimming
- Water-skiing
- Boardsailing
- Canoeing
- Boating
- Fishing
- Onshore activities
- Baptism

Most of these activities involve full contact, whereas previously water-skiing, canoeing and fishing were considered as intermediate contact. Each activity is dealt with according to the amount of water people are expected to be exposed to through ingestion, inhalation or dermal contact according to research studies from international literature. Competitive and recreational swimming provides a more likely ingestion of water and in many cases of recreational swimming includes large numbers of children who are more susceptible to health effects. Competitive open water swimming events are included as a separate user group as it is known that competition swimmers often ingestion much larger volumes of water compared to recreational swimming due to wave action caused by wind, incorrect breathing style or through behaviour of fellow competitors forcing water to be swallowed, as some examples. Water-skiing, canoeing and angling also involves a high degree of water contact, whereas paddling and wading involve relatively little water contact. Angling is a common and popular recreational use of inland waters, often involving direct exposure to water standing in the water for long durations and indirect exposure through the handling of fishing lines and fish. Since most fishing is practised from the shoreline, the risk of exposure to bilharzia is of special importance. The range of activities requires that some discretion is used in applying the guideline. A more stringent approach is used where water contact is relatively extensive, whereas a less stringent approach can be adopted if water contact is infrequent and minimal. Religious activities such as full immersion baptisms are now included as a user activity as accidental ingestion may occur with fairly large volumes of water ingested during the immersion.

Population groups, such as the very young, the elderly, the immunocompromised, and tourists, are normally more susceptible to local endemic pathogens and, thus, may be at higher risk to swimming-associated disease. Children are at higher risk because of their swimming behaviour ingesting more water and their immature immune systems. This is dealt with in the DSS at tier 2 which allows volumes of accidental water ingested to be changed according to circumstances. Visitors and tourists may be at higher risk because they have not been previously exposed to local pathogens.

Non-contact recreation encompasses all forms of recreation which do not involve direct contact with water. It includes activities such as picnicking and hiking alongside water bodies and scenic appreciation of water by those residing or holidaying on the shores of a water body. These activities concern themselves predominantly with the scenic, spiritual and aesthetic appreciation of water. The economic, spiritual and cultural value of recreational water bodies is often closely related to scenic appreciation and not on the chemical or microbial water quality constituents. Included in this category, are the non-contact recreation activities associated with trail running, mountain biking and other similar activities.

2.3 HAZARD CHARACTERISATION

2.3.1 Overview

Recreational water users may experience a range of impacts as a result of changes in water quality. These have been categorised as follows:

- Health impacts (short term and long term)
    - waterborne diseases (gastroenteric diseases)
    - skin and ear infections
    - carcinogenic risk
- Human safety
    - poor visibility
    - profuse plant growth
    - benthic microbial and/or algal growth
- Aesthetic impacts
    - changes in water taste, odour or colour
    - discolouration and staining
    - objectionable floating matter
    - nuisance plants

The water quality problems and issues listed are often recognised in association with the constituents that cause them. Constituents that may cause problems for recreational activity in water include those that can affect human health, safety, aesthetics, and economic impacts and therefore the following constituents are included in the guidelines:

- pH
- Odour
- Floating matter and refuse
- Nuisance plants
- Clarity
- Algae – chlorophyll-a and cyanotoxins
- Microbial contamination – *E. coli*, and possible human pathogenic microorganisms
- Chemical irritants
- Bilharzia

2.3.2 Human health impacts

2.3.2.1 Waterborne diseases

The water body used for full contact recreational activities may be the source of infectious diseases as a result of microbial contamination. Such diseases may be contracted either by ingestion of contaminated water; through contact with the skin, especially mucous membranes; or through inhalation of water droplets. Depending on the type of waterborne disease and on the physical health of the person infected through full contact recreational activities, the person may either recover completely from the disease, or suffer permanent harm or damage from the disease, or if severe enough may die as a result of it. Remedial measures, such as removing or controlling the source of contamination, may either eliminate or mitigate the effects of infectious diseases. Banning any form of full contact recreation in a contaminated water body will have an immediate reduction in the likelihood of contracting waterborne diseases from the affected water body.

2.3.2.2 Skin and ear infections

Through contact with the skin or penetration of the ear, microbiologically or chemically contaminated water may cause skin and ear infections and irritations. Such infections may be chronic or acute, depending on the nature and source of the contamination. Depending on the nature of the infection and the organ affected, the effects of such infections may be permanent or a person suffering from such an infection may recover completely. The use of ear plugs by participants in full contact recreational activities may prevent or reduce infections of the outer and/or middle ear.

2.3.2.3 Gastroenteric diseases

Waterborne gastroenteric diseases may be contracted from the ingestion of water contaminated with pathogenic faecal organisms or polluted by algal toxins or other chemical pollutants. Depending on the nature of the contaminants and the mode of contamination, the effects of waterborne gastroenteric diseases are chronic or acute. Participants involved in recreational activities suffering from gastroenteric disorders as a result of contact with contaminated water usually recover fully from the effects of such diseases following treatment. The effects of waterborne gastro-enteric diseases may be ameliorated or prevented by regular medical check-ups, particularly if the water is known to be contaminated or polluted.

2.3.2.4 Carcinogenic risk

Long-term exposure to water contaminated or polluted with known or potential carcinogens can give rise to carcinogenic problems for participants of full contact recreational activities. The effect of exposure to such contaminants is chronic. The effects of carcinogenic diseases are irreversible and may be fatal in some cases. In other cases, the effects may be controlled, although causing undesirable chronic disorders. Identification of the sources of carcinogenic pollutants and remedial steps to eliminate these sources may remove the problem, and therefore eliminate the effects. Early diagnosis and appropriate medical treatment may alleviate or ameliorate carcinogenic effects in affected participants.

2.3.3 Human safety

2.3.3.1 Poor visibility

High suspended solids load derived from silt and/or organic debris, as well as dense algal blooms may reduce visibility within the water body to such an extent that underwater hazards may not be visible, creating dangerous situations for swimmers and divers. The effects of poor visibility are usually acute. Some rivers and impoundments have permanently low visibility due to the nature of the substrates they drain, or because of the source of their feed water and turbulence in the impoundment. In other cases, visibility in a body of water may be drastically reduced temporarily as a result of flash floods carrying with them high silt loads. In naturally turbid impoundments and rivers, or water bodies where visibility is temporarily adversely affected, the effects of poor visibility are usually irreversible. In terms of human safety, accidents arising from diving into invisible, submerged objects or shallow waters very often end tragically in irrecoverable paralysis of limbs, viz. paraplegic or quadriplegic. Little can be done to mitigate poor visibility in naturally turbid waters. However, in waters with usually good visibility, diversion weirs to bypass turbid water past specific recreational sites may help to retain high visibility levels until the turbid slug has passed. Local warnings of dangers that may be encountered in a particular water body may help to prevent costly accidents.

2.3.3.2 Profuse plant growth

Profuse macrophytic plant growth in impoundments or along river banks, while possibly aesthetically pleasing, may provide hazardous situations for participants of full contact recreational activities as a result of snagging and entanglement. Application of herbicides to eradicate or control macrophytic plant growth in impoundments or along river or stream margins will eliminate or ameliorate hazardous situations for full contact recreational water users. However, the use of herbicides may cause skin irritations or the release of toxins from the decaying plants causing gastroenteric diseases. In addition, the use of herbicides could lead to contact with skin and ingestion via full and intermediate contact recreation, causing water quality problems ad possible carcinogenic risks.

2.3.3.3 Benthic microbial and/or algal growths

As a result of heavy microbial, fungal or algal growths, especially those organisms secreting abundant gelatinous matrices, submerged substrates (e.g. rocks, concrete, and wood) may become very slippery, posing a threat to human safety. While the conditions giving rise to benthic microbial, fungal or algal growths are usually chronic, the effects of these growths are usually acute. Participants in full contact recreational activities who have suffered mishaps as a result of such growths may recover fully. Participants involved in intermediate contact such as fishermen may slip on rocks as a result of algae growth resulting in permanent damage. The effects of benthic microbial, fungal and/or algal growths may be mitigated to a certain extent in impoundments through mechanical or biocidal treatment programmes. Such biocidal treatment programmes may not be effective in flowing waters. Caution, however, should be exercised when biocides are used as these may give rise to skin irritations or to the release of toxins from the dying organisms.

2.3.4 Aesthetics

2.3.4.1 Undesirable or bad odours

Unpleasant or bad odours can arise from a number of sources, such as rotting of dead vegetation, contamination of the water bodies by domestic sewage and other industrial effluents containing substances such as phenolic compounds and other volatile organic pollutants, and/or microbial action that releases hydrogen sulphide. The effects of undesirable or bad odours can be chronic if the conditions producing them last for a long period of time or may be acute if due to a sudden occurrence or accident (e.g. chemical spill, rotting or decaying plants or animals). The effects of bad odours can be eliminated or ameliorated by locating and identifying the source and implementing measures to treat the offending condition or chemical substances emitting the odour.

2.3.4.2 Discolouration and staining

Both naturally-occurring and industrially-produced inorganic and organic compounds can discolour water bodies, producing aesthetically displeasing conditions and/or staining of equipment and clothing worn in the pursuit of full contact recreational activities. The effects of naturally-occurring substances causing discolouration and/or staining are generally chronic, while the effects of industrially-produced substances are often acute. Once stained or discoloured, the effects on equipment or clothing are irreversible. Damaged articles may be recovered, repainted or re-dyed to improve their aesthetic appearance. Undesirable discolouration of a water body or staining of equipment arising from industrially-produced colouring substances may be eliminated by identifying the source of the offending compound/s and instituting measures. Little can be done to mitigate staining or discolouration by naturally-coloured waters.

2.3.4.3 Objectionable floating matter

The presence of floating and shoreline litter and other floating matter of human and natural origin detracts from the aesthetic enjoyment of water bodies. Submerged refuse also presents a danger to full contact recreational water users. Such floating matter consists of waste oil and grease, plastic containers and bags, bottles, cans, metal containers and domestic refuse. Some objectionable floating matter may also be generated naturally through decaying vegetation, raw sewage. Although it may be difficult to achieve in some instances, education in environmental awareness may result in the decrease of dumping of litter in or near water bodies. Organised campaigns to clean up the environment, both terrestrial and aquatic, may reduce the amount of objectionable floating matter.

2.3.4.4 Nuisance plants

Nuisance plants are those that render water bodies aesthetically displeasing or give rise to discomfort for full contact recreational water users. Such plants may give rise to unsightly or odorous substances, and if present in large numbers, may constitute a hazard to human health and safety. For example, heavy blooms of *Microcystis aeruginosa* are not only a health hazard due to the phytotoxins they produce when they decay but give rise to foul odours and unsightly masses of decaying vegetation, which can form a thick

crust covering the water surface, thereby eliminating any light penetration. The effects of nuisance plants are usually seasonal, often persisting for a long time after the growth period of the nuisance plant.
The effects of nuisance plants are reversible and may be achieved naturally through seasonal variations, or by means of mechanical, chemical or biological control programmes. The effects of nuisance plants may be mitigated by either exploiting environmental factors to change growth conditions, making them unsuitable for the growth of the nuisance plant, or by mechanical, chemical or biological control programmes to reduce or severely limit the growth of these plants.

2.3.4.5 Poor visibility

High suspended solids load derived from silt and/or organic debris, as well as dense algal blooms, may reduce visibility within the water body to such an extent that underwater hazards may not be visible, creating dangerous situations leading to damage of equipment of participants in intermediate contact recreational activities. The effects of poor visibility are usually acute. Some rivers and impoundments have permanently low visibility due to the nature of the substrates they drain, or because of the source of their feed water and turbulence in the impoundment. In other cases, visibility in a body of water can be drastically reduced temporarily as a result of flash floods carrying with them high silt loads. In naturally turbid impoundments and rivers, or water bodies where visibility is temporarily adversely affected, damage to equipment can occur. Damaged parts or equipment will need to be repaired or replaced. Little can be done to mitigate poor visibility in naturally turbid waters. However, diversion weirs bypassing specific recreational sites may help to retain high visibility levels in such sites until the turbid slug has passed. Local warnings (notice boards) of hidden dangers that may be encountered in a particular waterbody may help to prevent costly accidents or damage.

2.3.5 Economic impacts

Public perceptions on the quality of recreational waters play a huge role in the enjoyment of recreational activities. Litter, bad smells or poor visibility may cause a loss in tourist days or in recreational activities. It may affect fishing activities or recreational sporting events (e.g. MTB challenges), etc. A loss in these activities could have an economic cost to the event being cancelled or not well attended or economic activities associated with venues where the recreational activities would be held such as pop up cafés or restaurants, selling of foods and drinks, etc. might be affected as a result of low numbers taking part in recreational activities at the specific site. Floating matter or large numbers of nuisance plants might cause damage to canoes or equipment. In addition, there is also an economic cost related to the health impact such as injuries and infections, bad media coverage (image/ brand) and long-term impacts in closure of recreational facilities. Costs to monitor the specific sites more frequently or repeatedly will also increase. Pitois et al. (2017) discussed the impact of cyanobacterial presence on the possible expansion of the aquaculture industry. Decaying cyanobacterial blooms could result in oxygen depletion and fish kills but also affect the growth and taste of some fish preventing the marketing of such fish.

In an assessment reported by WHO (2003) economic effects attributed to the loss of use of the environment for recreational purposes were calculated to include the following:

- 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 considered is the health care cost associated with beach litter (Philipp, 1991; Walker, 1991; Anon, 1994).

2.4 MANAGING RISKS AND MONITORING OF RECREATIONAL WATERS

2.4.1 Managing risks of recreational waters

Internationally, the roles and responsibilities for the safe management of recreational waters will differ depending on the national, provincial and local legislation. The authority responsible for the day-to-day management of the recreational water area requires the most extensive up to date knowledge of the area and this authority would be in the best potion to take the necessary actions to ensure the safety of recreational users. As a first step, the Canadian Guidelines for Recreational water use (Health Canada, 2012) as well as the WHO (2003) Guidelines for Safe Recreational Water Environments and the WHO (2009) Addendum to Guidelines for Safe Recreational Water Environments, highlighted that *stakeholder cooperation* is required for the effective management of recreational water. These stakeholders include government, service providers, local businesses and industry, facility managers as well as users. Stakeholders need to be aware of their roles and responsibilities in the safe management of recreational waters. Internationally, the historical reactive management strategies relying on *compliance monitoring* alone has been substituted by the *multi-barrier management approach* that focuses on the identification and control of water quality hazards and their associated risks as the best strategy for the protection of public health from risks associated with recreational waters.

2.4.2 The multi-barrier approach

The multi-barrier approach is a preventative risk management approach that consists of an integrated system of procedures, actions and tools that collectively reduce the risk of human exposure to recreational water quality hazards. The approach became known as the “Annapolis Protocol” (WHO, 1999). The WHO suggests the combination of a sanitary inspection and microbial measurement approach to classify recreational waters. During the development of the WHO Guidelines for Safe Recreational Water Environments which involved an expert consultation co-funded by the US EPA (held in Annapolis, USA) the “Annapolis Protocol” (WHO, 1999) was adopted. This protocol describes an approach to classify recreational waters that combines a sanitary inspection and microbial measurement to evaluate and regulate faecal pollution. It also suggests real-time public health protection by making use of other relevant information. With this approach regulation is now expanded from a retrospective numerical compliance to include real-time management and public health protection.

The success of having barriers in place across all identified areas of management (e.g. monitoring, source protection, communication) rather than focusing on a single barrier has the following benefits:

- more effective public health protection;
- improved recreational water management (operational plans can be specifically tailored to address an area’s individual needs and resources);
- improved public communication (leading to better public understanding of key concepts and the public’s role in ensuring recreational water safety); and

- better management of emergencies (potential water quality hazards are understood and plans are in place to address the problems effectively).

Additional elements of the multi-barrier approach include (Figure 2-1):
1) An Environmental Health and Safety Survey,
2) Compliance Monitoring,
3) Public Awareness and Communication,
4) Public Health Advice and
5) Hazard Control Actions.

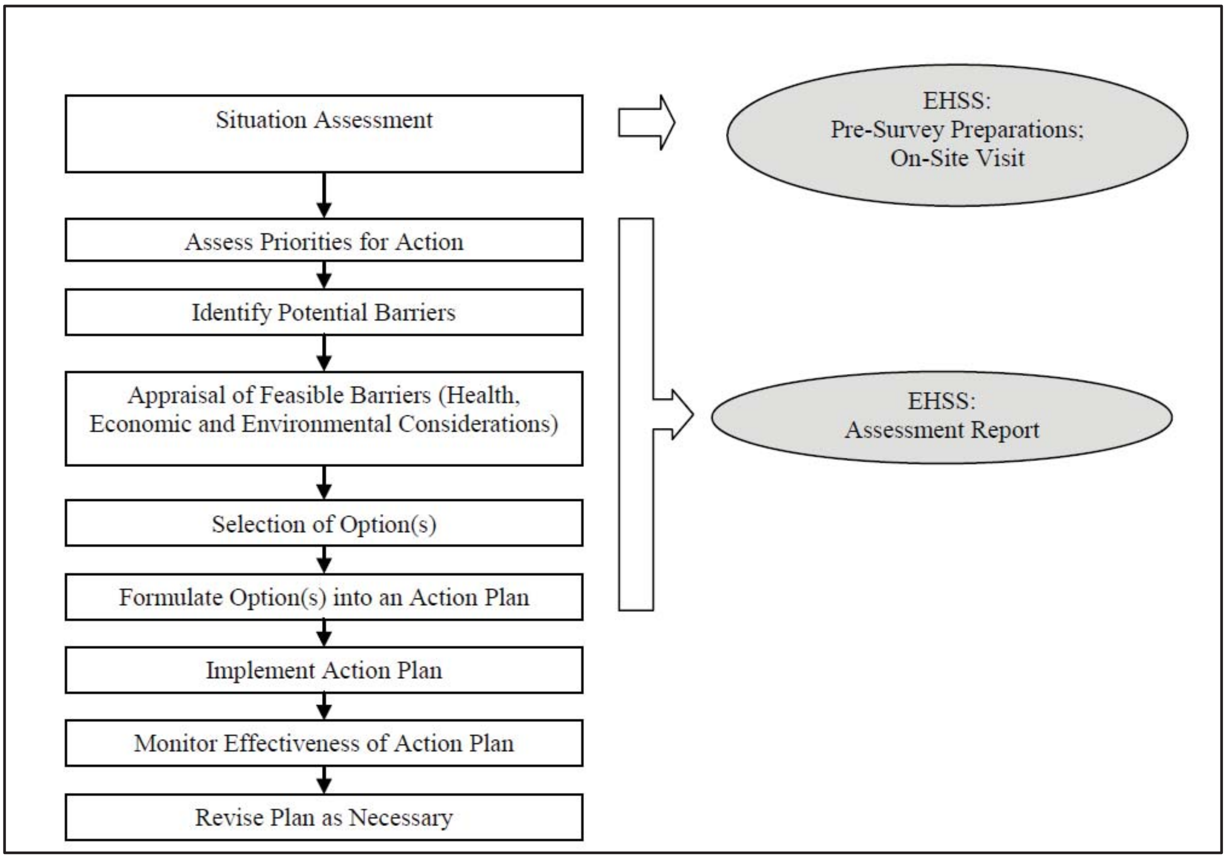


Figure 2-1: Sequence of events for multi-barrier strategy for recreational waters (Source: Codd et al., 2005)

2.4.2.1 Environmental Health and Safety Survey (EHSS)

The EHSS survey forms the basis for designing and implementing an effective risk management plan for recreational water. It usually consists of three phases: pre-survey preparations, the on-site visit and the assessment report. The EHSS involves an extensive search for, and assessment of, existing and potential water quality hazards (e.g. biological, chemical or physical) and the associated risks to the public. The EHSS provides the responsible authorities with the information necessary to make sound risk management decisions and to develop and maintain an effective recreational monitoring program. The flow chart from Codd et al., 2005 suggests a possible sequence of events when designing and implementing a multi-barrier strategy for recreational waters. This could be adjusted to develop national, provincial or local operational plans. In South Africa it would typically form part of the Integrated Water Resources Management Approach to water resources management nationally. Within this management approach, catchment management plans should inform the authority of the existing and potential hazards and associated risks to recreational water users. These plans are further informed by national initiatives such as the national microbial monitoring program, the eutrophication hot spot assessment, etc.

2.4.2.2 Compliance monitoring

To date, compliance monitoring has formed the backbone of recreational water quality management. Generally, the aim of compliance monitoring is to identify existing water quality hazards and to maintain a record of changes that may occur (e.g. due to seasonality, rainfall events, industry outflows). Monitoring is a broad concept and can serve many functions. It can be used to:

- determine whether water quality meets the Guidelines
- identify the impacts of water quality events;
- demonstrate long-term water quality trends;
- support EHSS findings or identify gaps;
- verify that barriers (e.g. notifications, corrective actions) are put in place;
- verify that these barriers are operating effectively.

To be effective, the monitoring plan should incorporate information from the EHSS, taking into consideration recommendations regarding areas of concern. Proper monitoring and accurate reporting are essential for assessing and communicating information on the level of safety of recreational waters. Decisions regarding the areas to be monitored, choice of indicators and monitoring program design will be made by the appropriate regulatory and management authorities.

The monitoring program should at least contain detailed information on the following:

- the parameters to be analysed;
- the locations at which samples are to be collected; and
- the times and frequencies of sample collection.

Understandably, each recreational water area will be unique and have different characteristics and operational considerations. The authority responsible for managing each area would have the necessary information from the EHSS to inform the design and implementation of the monitoring program for each recreational water area. These plans should consider the specific needs and conditions of the area as well as the types of users and recreational activities practised (e.g. swimming, initiation, picnic), as well as any additional relevant historical information.

2.4.2.3 Frequency of microbial sampling

Decisions regarding the frequency of water samples collected for microbiological analysis should be made by the appropriate local or regional authority. Bartram and Rees (2000) as well as international guidelines for recreational water such as WHO (2003), Health Canada (2012) and Australia (NHMRC, 2008) provides guidance on some of the factors to be considered when selecting sampling frequency. Table 2-1 shows the microbial monitoring schedule recommended by the WHO (2003). The microbiological water quality of a recreational water body can be affected by a number of factors such as point and non-point sources of contamination, time of day, weather conditions). The US EA noted that significant day-to-day and same-day variations have been documented and that this is the cause of the most uncertainty when trying to estimate the water quality for a recreational area over a given time period (Health Canada, 2012). While increased frequency of sampling will provide additional information, even daily sampling does not guarantee more certainty in estimating the next day’s water quality. Additional samples will however allow the authority to detect persistent water quality problems and help them to make an informed decision regarding the suitability of an area for recreational purposes.

Table 2-1: Recommended microbial monitoring schedule (WHO, 2003)

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

2.4.2.4 Public awareness and communication

Based on our Constitution, the public have the right to participate in safe, enjoyable recreational water activities and therefore needs to be informed of the quality of recreational areas and the associated facilities. This includes notification of any existing water quality hazards. Service providers and responsible authorities have a responsibility to inform and educate the public and provide adequate warnings about any hazards relevant to their recreational water areas. This could be done by posting of signs at recreational sites warning users of potential health risks (e.g. bilharzia area, cyanobacterial blooms) or similarly indicating that the area is safe for recreational use. Signs should be highly visible to the public and easily understood and not open to misinterpretation. Usually these signs should include a statement identifying the health or safety risk as well as recommended actions to be taken. The name of the issuing authority and relevant contact information should also be provided.

2.4.2.5 Public health advice

Communication and consultation with the public health authority form an essential part of the risk management process. In case of an incident, health officials can play a key role by providing advice and determining what actions need to be taken. Local public health authorities should be promptly notified of any situation that threatens the health or safety of recreational water users.

2.4.2.6 Hazard control actions

The physical actions intended to reduce the impact of microbiological, chemical or physical water quality hazards on a particular recreational water site is numerous and site specific, which falls outside the scope of this document. Internationally, authorities consult published text on topics such as storm water management, wastewater treatment and other types of resources for further information to address the specific issue. Water quality issues can cross over multiple boundaries (e.g. health, environment, agriculture, municipal infrastructure), and require cross-sectoral collaboration. Consult with experts on the topic, or the area, to identify actions that have been successful elsewhere.

2.5 REVIEW OF INTERNATIONAL EXAMPLES OF RISK BASED RECREATIONAL WATER QUALITY GUIDELINES

2.5.1 Overview

International examples of risk based Recreational water quality guidelines were reviewed to evaluate their relevance and application in the South African context. The World Health Organisation (WHO) guidelines, as well as the recreational water quality guidelines of New Zealand, Australia, US EPA and Canada were considered. These guidelines had two objectives:

- to provide guidance on the safety of recreational water from a public health perspective and
- to provide guidance to provincial and local authorities on the management of recreational

2.5.2 World Health Organisation (WHO)

The WHO Guidelines for Safe Recreational Water Environments consists of two volumes (Volume 1: Coastal and Fresh Water and Volume 2: Swimming Pools, Spas and similar Recreational Water Environments). The broad scope of these guidelines also describes in-water (e.g. snakes, sharks) and water's edge (e.g. crocodiles and hippo's) hazardous organisms. In addition, it discusses hazards from venomous organisms, dangerous aquatic organisms, disease vectors and other health impacts as a result of heat, cold, and sunlight.

In addition to the guidelines, a practical guide to monitoring of bathing waters has been produced including recommendations of analytical methods to be used. In 2009 an addendum (WHO, 2009) was published with changes and updates to the 2003 guideline document. The "Annapolis Protocol" (WHO, 1999) on which the WHO (2003) guidelines are based, describes a new approach to evaluation and regulation of faecal pollution in that it suggests the combination of a sanitary inspection and microbial measurement approach to classify recreational waters. It also suggests real-time public health protection by making use of other relevant information. With this approach regulation is now expanded from a retrospective numerical compliance to include a real time management and public health protection. While the public health risk associated with recreational water activities will be mostly due to microbial microorganisms, chemical and physical hazards are also considered. Exposure assessment will be most important here as different levels, frequency of contact and events will determine the possible risk. WHO based their guidelines on safe drinking water quality guideline levels stating however that the risks associated with chemical and physical hazards must be seen in relation to the other risks at these specific sites – in other words, numbers of injury or death due to drowning as well as microbial risk.

The WHO (2003; 2009) guidelines are risk-based making use of Quantitative Microbial Risk Assessment (QMRA) to indirectly estimate the human health risks by predicting illness or infection rates (based on densities of particular pathogens in recreational waters, assumed rates of ingestion and appropriate dose-response models for the exposed population (US EPA, 2007; Boehm et al., 2009). See Section 4.3 of this guideline for supplementary information. Although the differences between exposure to chemical agents and pathogenic microorganisms are widely acknowledged, the conceptual framework for chemical risk assessment in Figure 2-2 has been commonly employed for assessing the risk associated with exposure to pathogenic microorganisms. Since application of QMRA to recreational water use is constrained by the current lack of specific water quality data for many pathogens and the varying prevalence of specific pathogens from the contributing population with potential seasonal changes, the WHO (2009) suggests as a first step, a general Screening Level Risk Assessment (SLRA). The SLRA aims to identify and prioritise where further data collection and quantitative assessment is most needed.

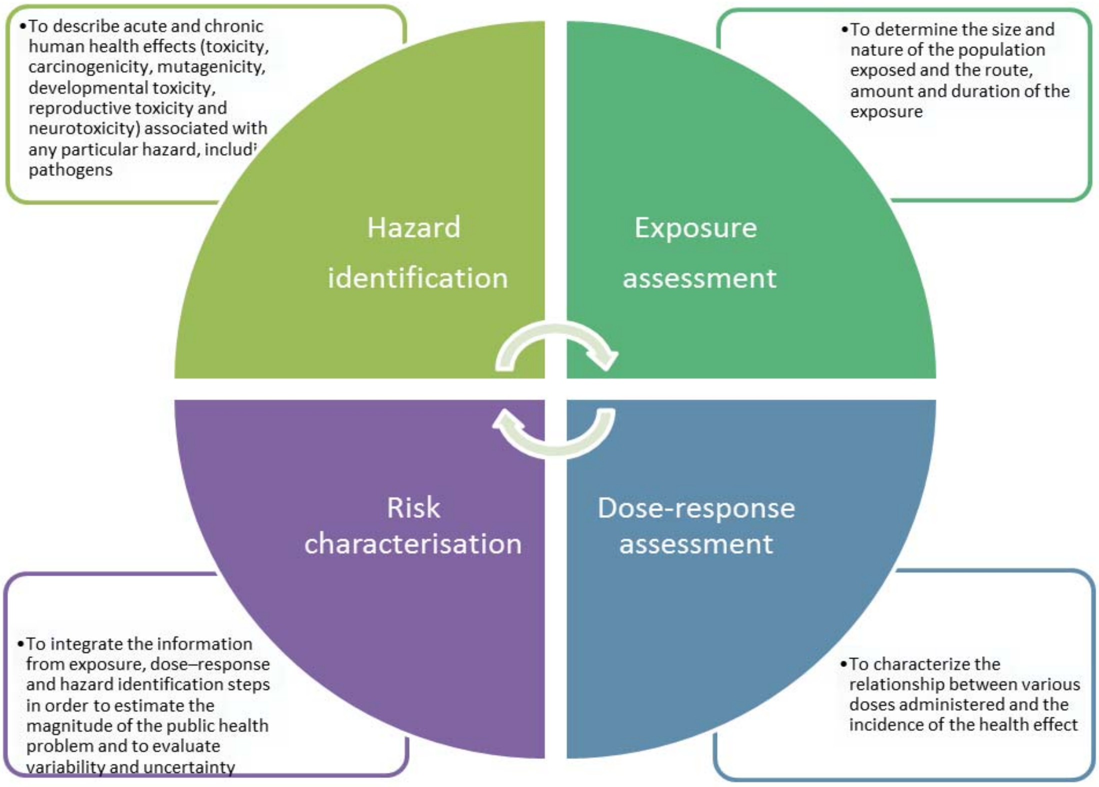


Figure 2-2: Risk Assessment Paradigm (Adapted from WHO, 2003)

In employing the chemical risk framework to carry out a SLRA, representative pathogens for viral, bacterial and parasitic protozoan pathogens (reference pathogens) are used to conservatively characterize each pathgen group. Despite the somewhat limited array of microorganisms and exposed sub-populations for which dose-response relationships have been estimated, there is a sufficient array of reference pathogens to at least undertake a SLRA. Table 2-2 provides a list of reference pathogens for each of the pathogen groups (WHO, 2009).

Table 2-2: Reference pathogens for pathogen groups

Pathogen group	Reference/Surrogate pathogens	Reference
Enteric viruses	rotavirus, adenovirus, norovirus	Haas et al., 1999; US EPA, 2005; Teunis et al., 2008
Enteric bacteria	*Salmonella enterica* (various serotypes), *Campylobacter jejuni*, *E. coli* O157:H7	
Protozoan parasites	*Cryptosporidium parvum*, *Giardia lamblia*	

* Based on WHO, 2009 – this has since been updated in later WHO QMRA documents. See Chapter 4 of this guideline.

Total risks from each of the pathogen groups are first calculated by making use of reference pathogens to allow for conservative risk estimates of exposure. The results of the SLRA can help to indicate an order of magnitude estimate of risk. It can also indicate where further data is 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 does not account for either person-to-person transmission of disease or immunity. Table 2-3 shows an example of risk estimates based on various reference pathogens and different exposure scenarios.

An alternative method to the SRLA approach exists which is far more comprehensive as it allows for population-based data regarding person-to-person transmission as well as immunity. This approach is known as disease transmission or dynamic models (Eisenberg et al., 1996; Soller, 2002), Application of the disease transmission modelling approach however proof limited as it requires substantially more epidemiological and clinical data than SLRA.

The QMRA should therefore be an iterative process and should be based on stochastic models (using distributions rather than point estimates) to better account for the inherent variability as well as the uncertainty in parameter values. In cases where uncertainty is high and risk estimates are unacceptable, further research should be suggested, with re-running of the QMRA model. From a management perspective, a SLRA could however still help to identify certain key risk areas with uncertain QMRA values and initial point estimates.

The risk of infection or illness from exposure to pathogenic microorganisms is subject to many uncertainties. Caution is therefore required in interpreting the results of a QMRA. QMRA is however a very valuable tool in estimating risks based on various scenarios in order to manage risks. Even in the absence of epidemiological evidence or at very low levels, QMRA can still explore risks and assist with managing public health at recreational water sites.

Table 2-3: Risk estimates for different weather scenarios (WHO, 2009)

Reference pathogen	Scenarios				
		Different amounts of rainfall			
	1)Dry weather	2)Management Trigger (9.9 mm previous night)	3)Substantial event (40 mm); followed by 3 days recovery	4)Large event (180 mm); Epilimnion displaced, five days recovery	5) Bather shedding[b]
Cryptosporidium	2.5×10^{-6}	1.9×10^{-4}	8.1×10^{-5}	**1.6×10^{-3}**	9.3×10^{-5}
Giardia	3.8×10^{-7}	7 2.9×10^{-5}	1.2×10^{-5}	2.4×10^{-4}	2.8×10^{-6}
Rotavirus	2.3×10^{-8}	1.8×10^{-6}	7.4×10^{-7}	1.4×10^{-5}	**9.2×10^{-2}**
Enterovirus	6.9×10^{-11}	5.2×10^{-9}	2.2×10^{-9}	4.3×10^{-8}	3.5×10^{-4}
Salmonella	2.3×10^{-11}	1.8×10^{-8}	7.4×10^{-10}	4.6×10^{-9}	-
Campylobacter	2.7×10^{-3}	**2.1×10^{-3}**	8.6×10^{-5}	**5.4×10^{-4}**	-
[a] Infection probabilities close to, or exceeding, the proposed benchmark probability range (0.5-2 x 10-3) are shown in **bold**.					
[b] Shedding risks were calculated separately to risks from run-off.					

2.5.3 New Zealand

The New Zealand guidelines "Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas" (2003) makes use of a combination of qualitative risk grading at catchment level which is then supported by direct measurement of faecal indicators. In addition, they provide "alert and action" guideline levels for surveillance throughout the bathing season. The guidelines are defined based on a tolerable risk rather than no risk and makes use of a three-tier approach (using a "traffic light" colour grading). The guidelines consist of two components. The Sanitary Inspection Category (SIC) gives a measure of a water body's susceptibility to faecal contamination. The second component is the Microbiological Assessment Category (MAC) which makes use of historical microbiological results to give an idea of water quality over time (seasonal changes, etc.). The combine approach is called the "Suitability for Recreation Grade" (SFRG) which describes the general condition of a site at any given time based on risk and indicator numbers. This is depicted in Figure 2-3 below. The grading determines the need for ongoing monitoring and from a public health perspective tells whether the water is suitable for recreation. These guidelines state the monitoring protocol for recreational waters in New Zealand and are used by the Ministry and regional councils to report on the state of the Environment.

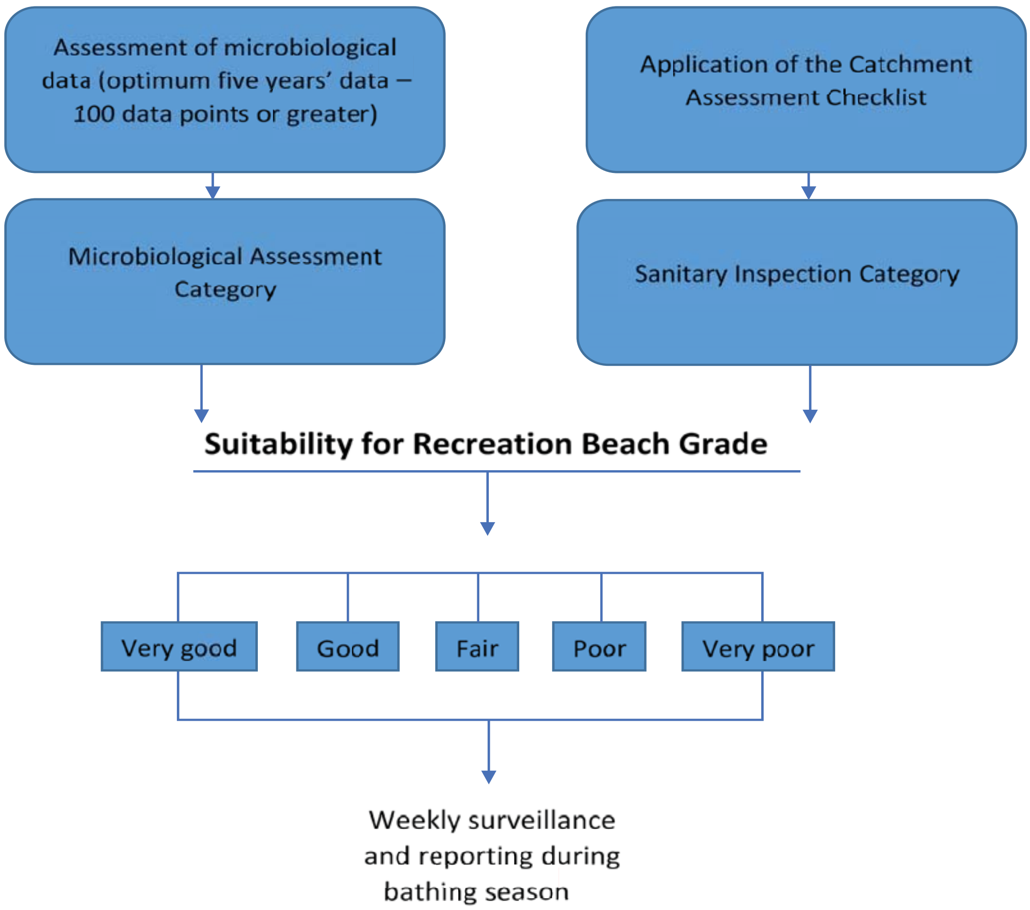


Figure 2-3: Suitability for Recreation Grade (SRG) described in Recreational Guidelines of New Zealand, 2003

2.5.4 Australia

The Australian guidelines follow a preventative approach to management of recreational waters. These guidelines focus on local assessment and management of hazards or factors that may lead to hazards. Similar to other guidelines it provides information on site-specific influences on the quality of recreational waters in addition to the numerical information on the level of contaminants which in turn is used to:

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

According to these guidelines, the development of a monitoring program that provides a real-time indication of recreational water quality is key to this preventative approach. It suggests a three-level (tiered) monitoring system, with each of the major hazard groups being dealt with at each level of monitoring. Similar to the New Zealand Traffic light approach, the three suggested levels range from green to amber to red or from surveillance to alert to action mode. This document uses a grading concept where the water body is classified according to it suitability for recreational use (based on level of contamination, etc.) and is consistent with the WHO (2003) and New Zealand (2003) guidelines. It also adopts the “Annapolis Protocol” for recreational waters, based on analysis of long-term data.

The approach developed in the Annapolis Protocol relies on identifying surrogate indicators of increased risk and taking action to manage those risks. Examples are then given of the higher risk of infection experienced immediately following rainfall events and an appropriate management approach might be to advise the public not to use the specific site for a particular time (one or two days after the rainfall event). For example, rainfall causing increased run-off into a water body and consequently influencing pathogen contamination could be used as a surrogate indicator of increased risk. The preventive risk management framework (Figure 2-4) includes elements of ISO 9001 and hazard analysis critical control point (HACCP) methods.

This guideline document discusses the difficulty, costs and impracticality of measuring the level of all contaminants in the water directly. Instead, it describes a catchment level hazard assessment approach and how these hazards affect the quality of the water. In addition, it realises the importance of site-specific data such as a local rainfall event, pump station failure, etc. in managing recreational sites. It acknowledges the use of surrogates such as the case with microbial indicators instead of pathogenic microorganisms is based on a tolerable risk of illness. These guidelines do not make provision for culture specific activities. The Australian Guidelines as well as the WHO Guidelines (Addendum 2009) recommends the use of a screening level risk assessment versus population-based transmission models (these require lots of epidemiological and clinical data).

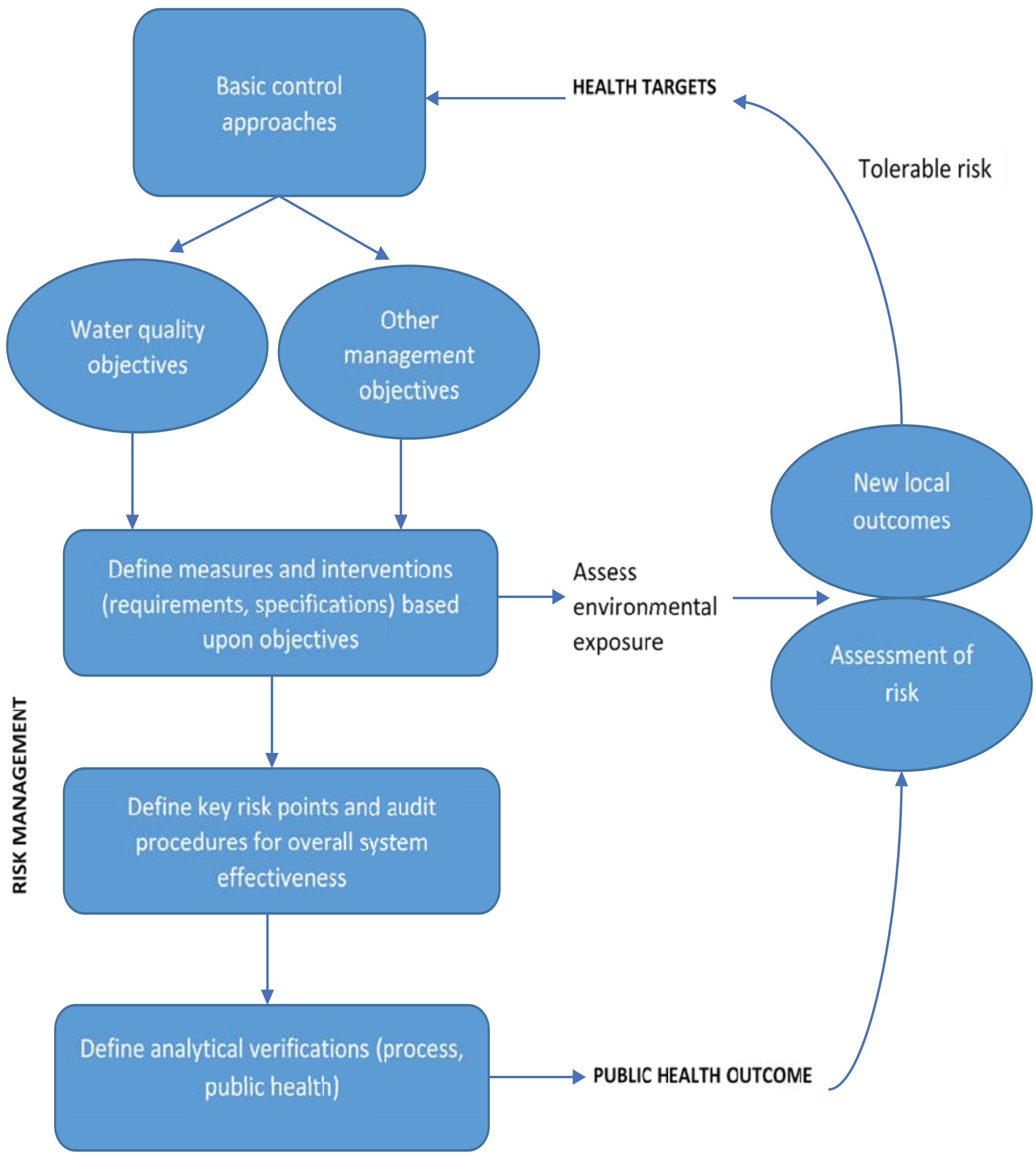


Figure 2-4: Preventative Risk Management Approach (adapted from Bartram et al., 2001)

2.5.5 US EPA

The US EPA published Recreational Water Quality Criteria for the protection of human health (Table 2-4). It recommends a QMRA approach but made use of extensive epidemiological data and human illness rates to determine acceptable risk levels. These criteria are suggested and only once adopted by the states does it have regulatory impact. The states can then modify these to reflect site-specific conditions, while having enough scientific proof to be credible and protective of the user community. No discrepancy is made between different exposure intensities which are different to guideline development and risk-based approaches to date. It recommends two sets of criteria set out to protect primary contact recreators and then site-specific modification are allowed. Modifications to the recommended criteria are contained in the Water Quality Standards Handbook (US EPA, 2012).

Table 2-4: US EPA 2012 recommended Recreational water quality criteria

<table>
<tr><th rowspan="2">Criteria Elements</th><th colspan="2">Estimated Illness Rate (NGI): 36 per 1,000 primary contact recreators</th><th rowspan="6">OR</th><th colspan="2">Estimated Illness Rate (NGI): 32 per 1,000 primary contact recreators</th></tr>
<tr><th colspan="2">Magnitude</th><th colspan="2">Magnitude</th></tr>
<tr><td>Indicator</td><td>GM (cfu/100 mL) [a]</td><td>STV (cfu/100 mL) [a]</td><td>GM (cfu/100 mL) [a]</td><td>STV (cfu/100 mL) [a]</td></tr>
<tr><td>Enterococci – Marine and fresh</td><td>35</td><td>130</td><td>30</td><td>110</td></tr>
<tr><td>OR</td><td></td><td></td><td></td><td></td></tr>
<tr><td>E. coli
- fresh</td><td>126</td><td>410</td><td>100</td><td>320</td></tr>
<tr><td colspan="6">Duration and Frequency: The waterbody GM should not be greater than the selected GM magnitude in any 30-day interval. There should not be greater than a ten percent excursion frequency of the selected STV magnitude in the same 30-day interval</td></tr>
</table>

[a] EPA recommends using EPA Method 1600 (U.S. EPA, 2002a) to measure culturable enterococci, or another equivalent method that measures culturable enterococci and using EPA Method 1603 (U.S. EPA, 2002b) to measure culturable *E. coli*, or any other equivalent method that measures culturable *E. coli*.

Faecal contamination in recreational waters is associated with an increased risk of gastrointestinal (GI) illness and less often identified respiratory illness. Indicator organisms indicates the possible presence of pathogens and therefore potential risk of disease. Based on epidemiological evidence, either Enterococci or *E. coli* could be reported on for marine waters, while *E. coli* was recommended for fresh waters. The US EPA criteria comprise of both a geometric mean (GM) and a statistical threshold values (STV). The EPA recommends a GM value that corresponds to the 50th percentile and a STV value that corresponds of the 90th percentile of the same water quality distribution, in other words having the same level of public health protection. Reporting on a GM alone is not sensitive enough to reflect spikes in water quality and therefore EPA suggests use of both the GM and STV criteria values.

The GM and STV criteria values set by the US EPA is the maximum amount of the pollutant that is allowed in a water body to ensure safe recreational activities. The US EPA further states that this should be determined over a 30-day period by states (even though a longer time period might provide a better indication of catchment water quality, longer term monitoring might conceal some pollution events). This 30-day duration will therefore allow for more frequent sampling and picking up peak pollution events. Additionally, the US EPA recommends that the magnitude (GM and STV values) may not be exceeded for more than 10% of the set duration (in this case 30 days). Apart from the GM and STV values, EPA expects states to make a management decision based on two different illness rates.

In addition to these criteria the US EPA provides additional information in the form of Beach Action Values (BAV) are the “do not exceed” values to use in notifications and guidance on managing such waters by means of predictive modelling and sanitary surveys. BAV corresponds to the 75^{th} percentile of the Enterococci and *E. coli* water quality distributions. A single sample above the BAV could trigger a recreational site notification. For the first time US EPA also provides values for qPCR determination of Enterococcus spp. in fresh and marine water bodies.

2.5.6 Canada

The recreational guidelines from Canada follow a multi-barrier risk management strategy to reduce the risk of human exposure to recreational water quality hazards. The basis of this preventative management approach is an “Environmental Health and Safety Survey” (EHSS) (HACCP approach) to identify the actions or procedures needed to put in place as barriers (e.g. beach clean-up, improvement of the management plan, monitoring). The EHSS approach is depicted in Figure 2.1 earlier in this document. These guidelines provide for primary (e.g. swimming, wading) and secondary (e.g. canoeing, fishing) recreational activities and considers risks from;

- pathogenic microorganisms
- a result of injury or illness as a result of physical and chemical quality of recreational water.

In the Canadian Guidelines, inorganic chemicals pollutant levels were low and heavy metals were found in concentrations below that for drinking water quality. Ingestion would be the primary route of exposure although skin absorption was also considered a route of uptake, inorganic chemicals posed such a low risk that it was not further considered in the recreational guidelines. These guidelines recommend *E. coli* for fresh water and enterococci for marine recreational waters. The guidelines provide a Geometric Mean (GM) as well as a single-sample maximum concentration for *E. coli* in fresh recreational waters.

Aspects such as temperature of water and pollutants that could influence the aesthetic characteristics of recreational waters are also discussed. These are also included in the supplementary information in Chapter 4-7 of this document. It outlines a risk management approach and includes parameters for bacterial indicators, risks resulting from cyanobacteria and their toxins as well as emerging issues related to faecal pollution of beach sand and microbial source tracking. Exposure to inorganic chemical contaminants is not considered a significant health risk for recreational water users Health Canada (2012) Organic chemicals such as chlorophenol can cause taste and odour problems at concentrations below toxic levels, and were included to satisfy aesthetic objectives.

2.6 SUMMARY

This guideline document describes the constituents included in recreational water quality assessments and the DSS. Considerations that are essential but cannot be included in a DSS risk-based guideline are usually dealt with through water safety plans and IWRM approaches used in other countries. For instance, in Australia recreational use of some water bodies may be restricted for a number of days during or after large rainfall or flood events. The information presented in the box below is provided for contextual purposes, with some aspects discussed presented in more detail in the body of the document.

Note: The World Health Organisation (WHO) states that while the public health risk associated with recreational water activities will be mostly due to microbial microorganisms, chemical and physical hazards are also considered. Exposure assessment will be most important here as different levels, frequency of contact and events determine the possible risk. The WHO based their recreational water quality guidelines on safe drinking water quality guideline levels.

The US Environmental Protection Agency (US EPA) published recreational water quality criteria for the protection of human health (2012) which makes use of extensive epidemiological data and human illness rates to determine risk levels. They recommend two sets of criteria to protect primary contact users and site-specific modification are allowed. In addition to these criteria they provide additional information in the form of Beach Action Values (BAV) to use in notifications and guidance on managing recreational waters by means of predictive modelling and sanitary surveys.

The recreational guidelines from Canada follow a multi-barrier risk management strategy to reduce the risk of human exposure to recreational water quality hazards. They make use of a preventative management approach to identify the actions or procedures needed to put in place barriers to pollution.

The Australian recreational water quality guidelines also make use of a preventive risk management framework which includes elements of ISO 9001 and hazard analysis critical control point (HACCP) methods. They describe a catchment level hazard assessment approach and how hazards affect the quality of recreational water. The importance of site-specific data such as a local rainfall events, pump station failures, etc. in managing recreational sites is emphasised.

New Zealand recreational water quality guidelines consist of two components. The Sanitary Inspection Category (SIC) which gives a measure of a water body's susceptibility to faecal contamination and a second component, namely the Microbiological Assessment Category (MAC) which makes use of historical microbiological results to give an idea of water quality over time (seasonal changes, etc.).

CHAPTER 3: DEVELOPMENT OF SOUTH AFRICAN RISK-BASED WATER QUALITY GUIDELINES FOR RECREATIONAL WATER USE

3.1 INTRODUCTION

The use of water for recreational purposes is common to all consumers. The term *recreational water*, as used in these guidelines, refers to all inland fresh water resources used for recreational purposes (excluding swimming pools and marine waters). As *recreational water* is used for a wide variety of activities, it follows that the type of quality requirements for such water represents a synthesis of the needs for various activities, and that a wide spectrum of problems may be encountered where water does not meet requirements.

Water used for recreational purposes can originate from impoundments such as dams, from rivers and streams, or from ground water via boreholes. Recreational water in South Africa spans a wide range, including water of high quality to more polluted surface water. Both water quantity and quality may be affected by seasonal droughts or floods. Water quality is changing and is predicted to continue changing as a result of climate change effects. Increased heavy precipitation is predicted in the eastern part of the country and drier weather is predicted in the west. Increases in severe flooding events in certain regions are expected.

The majority of wastewater treatment works are not in compliance with relevant legislation on water quality for the majority of wastewater effluents according to the required national standards. This adds to the pressures on recreational water users. With the decline in wastewater treatment and increase in temperatures through climate change, an increase in eutrophication and associated algal blooms has occurred and is expected to continue.

3.2 RECREATIONAL WATER USES

With cultural and religious activities included in the revision of the recreational guidelines, an understanding of the potential exposure needs to be understood. The DWS commissioned a study on the cultural and religious uses of water using regional case studies from South Africa through the UCT Environmental Evaluation Unit (DWS, 2005). Numerous uses were identified where exposure to water could occur, with attempts at understanding the extent of exposure.

A summary of these activities is provided in Table 3-1. Baptism and initiation ceremonies are the major activities that would result in exposure to water to be considered in recreational water quality guidelines.

Table 3-1: Cultural and Ritual Water Uses (Source DWS, 2005)

Type of activity / use	Extent and scale of such use	Preferred sites
Baptism	Water source mostly natural sources* Extent water is used at source Scale very little/no water is extracted	Preferred sites for baptism include: • rivers, • springs, • lakes, • dams, and • streams
Initiation ceremonies	Water source – only natural sources* Extent – water is used on-site Scale – very little water is extracted	Preferred sites for initiation include • rivers, • lakes, and • streams Areas used by initiates for bathing should be isolated.
Final resting place for the deceased	Water source – only natural sources* Extent – water is used on-site Scale – very little/no water is extracted	Preferred sites include; • rivers, • streams, and • lakes
Ablution	Water source – treated water** Scale – water is used on site Extent – Water is extracted	No preferred sites. Water is adequate for ablution. Approximately 5L of water[27] per person is required for ablution.
Rituals (rainmaking)	Water source – Both natural and treated water sources Extent – water may be used on-site or a small amount collected and taken away Scale – Water is extracted	Water is collected from rivers and/or waterfalls believed to possess strong water spirits. Unable to determine the quantity of water used
Rituals (cleansing)	Water source – Only treated water** Extent – Water is extracted	<5l of water is used to clean utensils used for rituals.
Medicinal uses	Water source – natural sources* Extent – Water is extracted	Generally, <5l of water is extracted
Livestock farming	Water source – natural sources* Extent – Water is extracted	Unable to determine the quantity of water used
Source of food	not applicable	Unable to determine the quantity of water used

*Natural sources include springs, rivers, lakes and streams.

** Refers to treated tap water. Generally, water used for household and domestic purposes.

[27] General Secretary of the Jamiet Ulama – KZN Council for Muslim theologians (2005)

3.3 NEED FOR RISK-BASED GUIDELINES RECREATIONAL WATER USE GUIDELINES

Water quality guidelines provide a means of assessing water quality in a resource (at a chosen time or period) so that its fitness for use can be established (at a location during a time period). “Risk based” guidelines simply allow the suitability of the water to be interpreted in terms of risk of specific adverse effects. Primarily, the risk refers to the probability of adverse effects to the identified immediate user of the water, i.e.

- Humans and animals using drinking water
- Crops and soils being irrigated
- Aquatic ecosystems in which water may flow
- Industrial users

Secondly, in some specific instances the risk may also include the consideration of the probability of adverse effects to users downstream of the primary user. This is particularly so when it may be difficult to control subsequent contamination of the water resource directly after the primary user. The basis for the developing the water quality guidelines for recreational use will inevitably be those for domestic use. However, they will be modified according to the nature of the exposure, including full contact (in which digestion may occur) partial contact and non-contact recreation. The current definition of recreational use is terms of DWS policy now extends beyond sport, leisure and tourism. Using water for recreational purposes now include uses such as personal or commercial activities as well as activities which contribute to the general health, well-being and skills development of individuals and society. This therefore includes social, cultural and religious uses of water resources. The quantitative nature and extent of risk should inform the complete process of water quality guideline development, guideline definition and description, and guideline use more explicitly. So that the guidelines will then be more:

- Scientifically defensible;
- Transparent to all concerned; and
- Practical and usable to not only those managing our water resources but also those using the water.

3.4 HAZARD CHARACTERISATION AND WATER QUALITY CONSTITUENTS FOR THE RECREATIONAL WATER QUALITY GUIDELINES

Table 3-2: Key issues and related water quality constituents considered in the water quality guidelines

Aspect	Key issues	Related water quality parameter	Indicator
Biological	Diarrheal causing bacteria and organisms; pathogens which pose. adverse health affects	Algae Human and animal pathogens	Cyanobacteria *E. coli* Enteric viruses such as norovirus
Chemical	Chemicals which cause skin irritation when people are submerged or partially merged in water. A minor issue is the consumption of small amounts of water during	Chemical irritants All chemical and constituents considered in domestic water quality guidelines including; Metals, nutrients, radio-active and other organic contaminants.	

Aspect	Key issues	Related water quality parameter	Indicator
	merged and partially merged incidents.		
Physical	Water is physically unpleasant, unsafe to swim in.	pH odour floating matter and refuse nuisance plants clarity	

Table 3-3: Summary of Parameters included in Recreational Water Quality Guidelines

Parameter	Considerations	Tier 1 Guidelines
E coli	Based on risk of illness through accidental ingestion – volumes according to activity – >3-5% illness rate	< 42/100 mL
E coli (representing pathogens: Norovirus infection)	Based on ingestion volumes according to activity – <0.1% illness rate per annum from multiple exposures – equivalent to < 0.0001 DALY pppy	Ingestion dependent
Algae as Cyanotoxins	Adverse health effects caused by cyanotixins used to establish guideline value based on protecting children (20 kg) and 100 mL accidental ingestion	< 8-10 ug/L
Algae as chlorophyll a	Chlorophyll a is the preferred indicator for algal biomass to provide an indication of potential problems based on epidemiological evidence.	≤ 10 ug/L
Bilharzia	Bilharzia is a health risk only in the northern and eastern parts of South Africa. Monitoring of bilharzia parasites is not practical, with control through avoidance with intermediate host snails. No snails capable of acting as the intermediate host of the bilharzia parasite should be present in waters used for recreation.	No numerical value – geographical distribution according to snail
pH	The pH of water does not have direct health consequences of recreational users except at extremes values – very low or very high values. pH has revelvance for direct immersion in water. Low pH can cause skin irritation and burn eyes . High pH appears to be more linked to skin irritation.	5.0-9.0
Clarity	To protect users from accidents/injury the clarity should be sufficient to see subsurface hazards and able to estimate depth of waterbody.	Secchi disk visibile at 1-2 m
Odour	Although the odours themselves may not be toxic, their association with decaying material indicates something that is best avoided as the material causing	No numerical value

Parameter	Considerations	Tier 1 Guidelines
	the odour can represent a health risk. The effects of undesirable or bad odours can be chronic or acute. Objectional odours should be absent.	
Nuisance plants	Nuisance plants can endanger the safety of and impinge on the physical comfort of recreational water users. Excessive plant growth can obstruct the view of swimmers and obscure underwater hazards. Evaluation of the nuisance value of aquatic plant growth is essentially qualitative and subjective and no methods of measurement are applicable.	No numerical value
Chemical irritants	Recommended that exposure from organic chemicals are lower than those recommended for drinking water purposes not pose a significant threat to human health. Exposure is typically 1/10th of that via drinking water ingestion. Some contaminants may need to be monitored in the future if new data becomes available. These new and emerging contaminants may include compounds increasingly used and found in the environment, such as fire retardants and endocrine disrupting compounds.	No numerical value

3.5 RISK QUANTIFICATION USING THE THREE-TIERED APPROACH

3.5.1 A decision support system (DSS) for evaluating fitness for use and recreational water quality requirements

The DSS is a risk-based software tool developed with a human health risk understanding of the different exposure scenarios and likely levels of contact (e.g. full-contact, intermediate contact and non-contact recreation) and likely exposure to different volumes of water (e.g. ingestion, skin contact, inhalation) reported in international literature and likely associations with health impacts. The desktop tool to determine risk for recreational water use contains a landing (or welcome) page followed by an “Activities” page where recreational activities and specific exposure scenarios are selected (Figure 3-1 and 3-2).

Figure 3-1: Decision Support System startup page

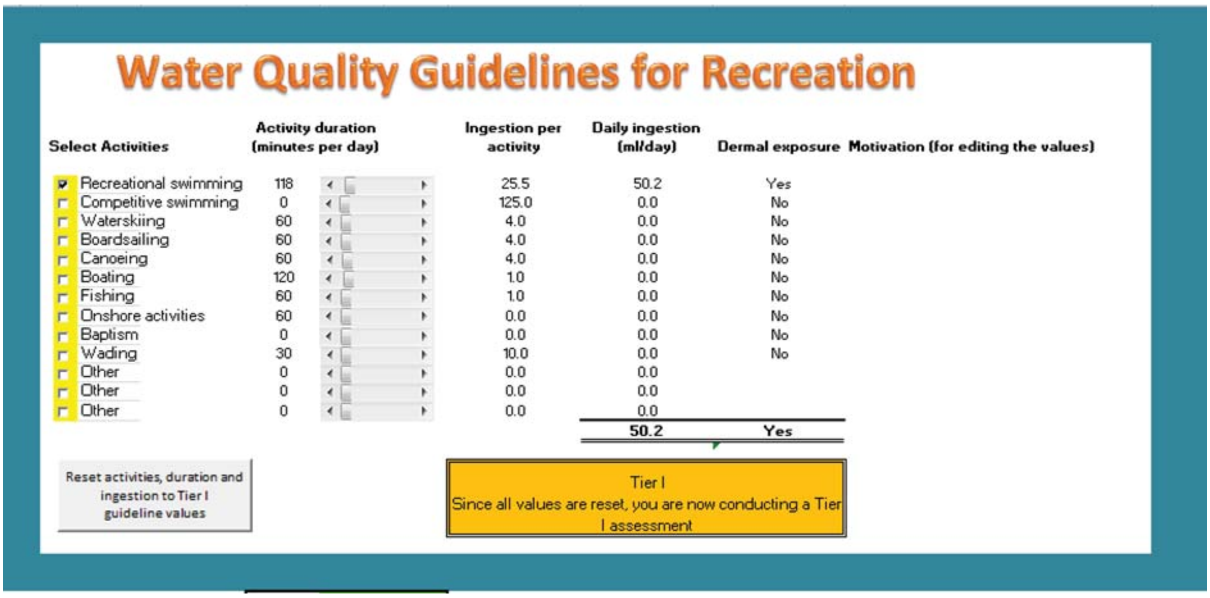


Figure 3-2: Decision Support System Activities Page

3.5.2 The three-tiered approach

In line with the original terms of reference, three tiers are presented for recreational water quality guidelines.

3.5.2.1 Tier 1

The water quality guidelines are generic and applicable in the absence of site-specific information. These guidelines are similar to the 1996 water quality guidelines. A water safety planning process is followed for identifying the hazards, and risk calculations will be made with generic risk assumptions. The following information is included (based on domestic water quality guidelines)

- A full description of the hazard
- The guideline range (may be more than one depending on exposure assessment)
- The basis of the guideline derivation (data used, its quality, reliability of method, safety factors, etc.)
- Guidelines in other countries (literature comparison)
- References

3.5.2.2 Tier 2

The water quality guidelines in this tier incorporate site and scenario specific considerations that influence the fitness for use of a particular water quality constituent. The calculations for site/scenario specific considerations include one or combinations of the following:

- Refined exposure parameters – higher or lower exposure or dose situations based on recreational activity which includes cultural or social practices and may differ from that described in Tier 1
- Acclimatization of users to extended or high volumes of a constituent which can include whether users have knowledge of a water body that might be classified with a high risk as a result of clarity, or if natural water bodies have low pH values such as many rivers in the Western Cape.
- Sensitive sub-populations, for example informal communities and high HIV-infection areas are taken into consideration in tier 1 values in most instances, but with some exceptions, as it is not possible to examine water for all possible opportunistic pathogens. Some pathogens that may be naturally present in the environment may be able to cause disease in vulnerable subpopulations. If water used by such persons for recreational purposes contains sufficient numbers of these organisms, they can produce various infections of the skin and the mucous membranes of the eye, ear, nose and throat. These organisms are not pathogenic for healthy individuals but can easily infect individuals with decreased immunity. Examples of such agents are *Pseudomonas aeruginosa* and species of *Flavobacterium*, *Acinetobacter*, *Klebsiella*, *Serratia*, *Aeromonas* and certain non-tuberculous mycobacteria (WHO, 2017).
- Location from point source water quality impacts – for example wastewater treatment works or mining activities
- User density
- Recreational use during or after large rainfall or flood events.

3.5.2.3 Tier 3

The final tier refers to site and scenario specificity not catered for in the previous tiers.
Collected date, site and scenario specific information and sophisticated models will be needed to determine the fitness for use water quality constituents in very specific cases. The third tier will not be provided for in the envisaged DSS, but it will allow for assessment and objective setting. This tier requires specialist input and data interpretation.

3.5.3 Performing risk calculations using the DSS

The DSS can be used to evaluate the fitness for use as well to set water quality objectives for specific sites. This data is built into the DSS to allow water resource managers to assess likely risks or fitness for use at specific sites based on different recreational activities. Most illnesses resulting from contaminated recreational water result from the accidental ingestion of the water. Table 3-4 provides a summary of the volumes of water reported in international literature associated with specific recreational activities. These range depending on the type of contact, from full contact swimming to canoeing, fishing, playing, wading, etc., but also making provision for competitive swimming (e.g. Midmar mile, Iron Man competition, Triton X Trail run series). Aspects such as vulnerable sub-populations are able to be included in the DSS at a tier III level if new data becomes available relating to area specific susceptibilities of the population.

Table 3-4: Volumes of water ingested in association with specific recreational activities according to exposure studies

Activity	Volume ingested	Reference
Canoeing	4 mL/h	Sunger and Haas, 2015
Boating	1 mL/h	
Fishing	1 mL/h	
Wading	10 mL/h	
Playing	12 mL/h	
Swimming	25 mL/h	
Swimming – men	27-34 mL /event	Schets et al., 2011
Swimming – women	18-23 mL/event	
Children	31-51 mL/event	
Swimming – children	47 mL/event	Evan's et al., 2006
Swimming males	30 mL/event	
Swimming females	19 mL/event	
Limited contact	3-4 mL	Dorevitch et al., 2011
Swimming	10-15 mL	
Children	37 mL	Dufour et al., 2006, 2017
Adults	16 mL	
Competitive swimmers	125 mL	
Wading	10 mL/h	US-EPA ,2000

Estimates of water ingestion are based on international studies that have attempted to measure this, using a combination of approaches. Dufour et al. (2006) determined the amount of water swallowed during swimming activity by measuring the amount of ingested cyanuric acid in pools disinfected with chloroisocyanurates. The chloroisocyanurates decomposes slowly to release chlorine and cyanuric acid. Cyanuric acid passes through the body un-metabolised. Fifty-three recreational active swimmers participated in the study. Their urine was collected for the next 24 hours. Cyanuric acid was measured in pool water and urine samples to calculate the volume of pool water ingested while swimming. Results of the study indicate that adults ingest about half as much water as children during swimming activity. The average amount of water swallowed by children and adults was 37 mL and 16 mL, respectively. This study allowed the measurement of the actual volumes of water swallowed during swimming activity.

Estimates of water ingestion for common restricted exposure recreational activities such as canoeing, fishing, kayaking, motor boating and rowing are limited. Dorevitch et al. (2011) assessed the water ingestion for these activities making use of self-reporting estimates in combination with cyanuric acid measurements in pool and urine samples. The results obtained from the combined tests were used to derive translation factors to quantify self-reported estimates in open water environments. Mean estimates of water ingestion during limited contact recreation was 3-4 mL. Only a limited number of studies have looked at assessing limited contact exposures. Dorevitch *et al.* (2011) found swimmers ingested water more frequently and in larger average volumes than canoers and kayakers, who in turn ingested water more frequently and in larger volumes than those who wade/splash or fish.

Canoers and kayakers who do not capsize ingest water as often and in similar amounts to those who fish or wade/splash. Canoers and kayakers who do capsize swallow less frequently and in reduced volumes compared to swimmers. Schets et al. (2011) also made use of a combined approach of self-reporting and measurements of volumes of mouthfuls to transform categorical data to numerical data of swallowed volumes of water. Sunger and Haas (2015) made use of a number of studies reported in the literature to estimate low contact exposure events using the method of maximum likelihood estimation (MLE). Using site specific water quality data and a QMRA model to look at variability from all input parameters, including non-swimming (low contact) exposure scenarios to predict total health risks, they found that activities contributing most to the risk of gastro-intestinal illness at creeks were wading and playing (81%), while fishing was the potential risk contributor (65%) at rivers.

Time spent exposed to water differs according to the type of recreational activity. Time spent swimming is typically reported as minutes/month. The amount of time was based on 2 key studies reported in the US EPA Exposure Factors Handbook (US EPA, 2011).

3.6 DETERMINING ACCEPTABLE RISK

3.6.1 What is meant by ‘acceptable risk’?

Risk is generally taken to be the probability of injury, disease, or death under specific circumstances (WHO, 2001). In the course of deriving risk-based guidelines, different risks are presented for different users. The subject of what constitutes an acceptable risk is an extremely complex issue and must be handled from a policy perspective. Descriptions of tolerable burdens of disease relating to water are typically expressed in terms of specific health outcomes such as maximum frequencies of diarrhoeal disease or cancer incidence. However, these descriptions do not consider the severity of the outcomes. The various hazards that may be present in water are associated with very diverse health outcomes with different impacts ranging from mild diarrhoea to potentially severe outcomes such as typhoid, paralysis or cancer. A common “metric” can be used to quantify and compare the burden of disease associated with different water-related hazards, taking into account varying probabilities, severities and duration of effects.

The metric used by the WHO to evaluate public health priorities and to assess the disease burden associated with environmental exposures is the disability-adjusted life year, or DALY. The World Health Organization has used DALYs to be able to aggregate different impacts on the quality and quantity of life and to be able to focus on outcomes and not only potential risks. DALYs can be used to define tolerable burden of disease and the related reference level of risk and therefore support public health priority setting. Some international practices are presented in the next section. Acceptable risk is very location-specific and for this reason it plays an important role in adapting guidelines to suit local circumstances, where local stakeholder involvement is vital. This is relevant and comes into play with the Tier III guidelines.

A 10^{-5} risk of developing cancer represents 1 chance in 100,000 associated with environmental contaminants and has evolved into a target risk (Cotruvo, 1988) and is in line with WHO guidelines for drinking water quality. It is generally thought that where practical, an excess lifetime cancer risk of 10^{-5} for carcinogenic risks over a lifetime is acceptable (WHO 1993). Similar approaches have been adopted elsewhere and for other risks. In the UK, for example, the Health and Safety Executive (HSE) adopted levels of (un)acceptable risk based on the probability of an individual dying in any one year:

- 1 in 1000 as the 'just about tolerable risk' for any substantial category of workers for any large part of a working life.
- 1 in 10,000 as the 'maximum tolerable risk' for members of the public from any single non-nuclear plant.
- 1 in 100,000 as the 'maximum tolerable risk' for members of the public from any new nuclear power station.
- 1 in 1,000,000 as the level of 'acceptable risk' at which no further improvements in safety need to be made.

Putting the burden of chemical contamination into context, in South Africa, our current risk of developing cancer is approximately 1 in 4 (or 0.25) with international estimates of background levels of environmental contaminants contributing between 1 in 1000 and 1 in 100 of this risk (Kelly & Cardon, 1991). Even with data that is not up-to-date, a perspective of relative risk contributions is provided. Risks resulting from exposure to microbial pathogens cannot be dealt with in the same way as risks resulting from exposure to chemicals. Microbial infections may occur if people are exposed to pathogens, which may result in illness. The US EPA use Giardia as a reference organism for drinking water guidelines and require the microbial risk to be less than 1 infection per 10,000 people per year. However, the illness rates associated with their Recreational Water Quality Criteria are 32 and 36 gastro-intestinal illnesses per 1,000 primary contact users, or an average of 3.4 gastro-intestinal illnesses per 100 users (U.S. EPA, 2012). For recreational water the EU bathing water directive prescribed an acceptable risk of illness associated with bathing in surface water of 3-5%, which are similar to the US EPA (2012) recreational water quality guidelines.

3.6.2 Disability-adjusted life years (DALY) as a measure of acceptable risk

The concept of tolerable disease burden (acceptable risk) was set out in the fourth edition of the Guidelines for Drinking Water Quality or GDWQ (WHO, 2011). The guidelines defined the tolerable burden of disease as an upper limit of 10^{-6} disability-adjusted life year (DALY) per person per year. One DALY per million people a year roughly equates to one cancer death per 100 000 in a 70-year lifetime and was the benchmark often used in chemical risk assessments (WHO, 2004). This level of health burden is equivalent to a mild illness such as watery diarrhoea with a low fatality at an approximately 1 in 1000 annual risk of disease to an individual, which is equivalent to a 1 in 10 risks over a lifetime (WHO, 1996; Havelaar & Melse, 2003[i]). Although many waterborne pathogens may lead to gastroenteric symptoms, the duration and severity of illness and likelihood of long-term sequelae[1] vary between pathogens. Pathogens that lead to the greatest burden of disease should be given priority when managing water safety. Disability Adjusted Life Years (DALYs) is as a system of measurement used by the WHO to translate the disease burden to a general health burden per case of illness. It combines the burden of mortality and morbidity (non-fatal health problems) into a single number. The DALY accounts for the years lived with a disability (YLD) plus the years of life lost (YLL) due to the hazard.

[1] Sequela can be described as an after effect of a disease, or disease arising from a pre-existing disease.

The disability severity is assigned a weight ranging from zero, representing perfect health or no disability, to one, representing the most severe disability, or death. A “tolerable” risk of 10^{-6} DALY per person per year allows for the loss of 365 healthy days in a population of one million over the course of one year which is the DALY limit one excess case of cancer per 100 000 people ingesting treated drinking-water over a 70-year period. The DALY measurement system is described in greater detail in the GDWQ (WHO, 2011 & 2017). Using the same limit, in terms of DALY, but milder outcome of self-limiting diarrhoea is equal to 1 excess case of diarrhoea per 1000 population per year (1 in 1000). The DALY is calculated as the product of the probability of each illness outcome with a severity factor and the duration (years). Calculation of the DALY contribution per infection is made using the formula:

$$DALY = YLL + YLD$$

Where:
YLL = years life lost;
YLD = years lived with a disability standardised with a severity weight. YLD = number of cases, multiplied by the average duration of the disease and the weight factor that reflects the severity of the disease on a scale from 0 to 1.

3.6.3 Tolerable burden of waterborne disease

According to the WHO (2017) a tolerable burden of waterborne disease from drinking water is suggested as 10^{-6} DALY per person per year. The estimated disease burden associated with mild diarrhoea at an annual risk of 1 in 1000 or 0.1% is approximately equal to 10^{-6} DALY per person per year. This high level of protection is needed for drinking water but it may not be seen as applicable to recreational exposure to water.

A discussion paper by Mara et al. (2010) suggests a lower DALY such as 10^{-5} or 10^{-4} DALY pppy as “more realistic, yet still consistent with the goal of providing high-quality, safer water and encouraging incremental improvement of water quality”, and it is lower than the current diarrhoeal disease incidence of 0.7 pppy.

3.7 SETTING TOLERABLE RISKS FOR RECREATIONAL WATER QUALITY

3.7.1 Overview

According to Hunter and Fewtrell (2001)[ii] a risk can be acceptable if it falls below a level that is already tolerated. For recreational water the EU bathing water directive prescribed an acceptable risk of illness associated with bathing in surface water of 3-5%, similar to the US EPA (2012) recreational water quality guidelines which historically allow a risk of illness of 3.6%. The US EPA sets a tolerable risk of less than 1 in 10 000 people per year (a 10^{-4} risk) from drinking-water (Regli et al., 1991[iii]) however it has been argued that based on background rates of gastrointestinal disease in the general population, that even a risk of 10^{-3} of infection per person per year would be too low (Haas et al., 1991). Global health data, presented by WHO (2006), shows that adults overall experienced 0.2 episodes of diarrhoea per year compared to young children in developing countries who experienced an average 4.7 diarrhoeal episodes per year (equal to a 4.7 yearly risk).

3.7.2 Hypothetical Disease Burden estimates for different water-borne pathogens

Examples presented by the WHO (2016) of the DALYs for different waterborne pathogens are provided in Table 2-2. Similar DALYs per 1000 cases could be anticipated as a result of Norovirus infections with later sections showing calculations. It is important to include the variability (natural dispersion in a system, such as pathogen concentrations in a river) and uncertainty (lack of understanding and/or inability to measure) in all steps of the risk characterization. The DALY concept provides a tool to evaluate and compare health risks from a specific environment for a specific population and behaviour and for comparing with other health risks of daily life. Both person- and pathogen-specific variations in the course of gastroenteritis may lead to different health outcomes.

Table 3-5: Example of Hypothetical Disease Burden estimates for different water-borne pathogens (Source WHO, 2016)

Pathogen	Disease burden per 1 000 cases		
	YLD	YLL	DALY
Cryptosporidium	1.34	0.13	1.47
Campylobacter	3.2	1.4	4.6
Shiga-toxin producing E coli	13.8	40.9	54.7
Rotavirus			
High income countries	2.0	12	14
Low income countries	2.2	480	482
Hepatitis A virus			
High income countries	5	250	255
Low income countries	3	74	77

3.7.3 Fitness for use classification of water quality

A four-class classification system based on the current Department of Water and Sanitation (DWS) practice was used to depict water quality for recreational use (Table 3-6). This classification system harmonised water quality with a risk-based assessment to determine fitness for use. The “Ideal” fitness for use class for recreational water use for example describes a class where water quality would not impair the fitness of water for its intended purpose. Both the fitness-for-use classification and the risk-based water quality assessment are represented in the DSS output screens depicting an assessment of water quality. The same colour scheme is also used to depict the different fitness-for-use classes.

Table 3-6: A generic description of the DWS fitness-for-use classification of water quality

Fitness-for-use Class	Description
Ideal	A water quality that would not normally impair the fitness of the water for its intended use
Acceptable	A water quality that would exhibit only limited impairment to the fitness of the water for its intended use
Tolerable	A water quality that would exhibit increasingly unacceptable impairment to the fitness of the water for its intended use
Unacceptable	A water quality that would exhibit unacceptable impairment to the fitness of the water for its intended use

SUPPORTING INFORMATION

NOTE:

CHAPTERS 4- CONSISTS OF SUPPORTING INFORMATION ON BIOLOGICAL, CHEMICAL AND PHYSICAL HAZARDS AND SELECTION OF PARAMETERS FOR THE SOUTH AFRICAN RISK BASED RECREATIONAL WATER GUIDELINES

CHAPTER 4: BIOLOGICAL ASPECTS

4.1 MICROBIAL WATER QUALITY FOR RECREATIONAL ACTIVITIES

According to numerous studies, recreational water exposure is associated with an increased risk of acute gastroenteritis (Prüss A, 1998; Soller et al., 2016, Ashbolt et al., 2010, Dufour et al., 2006, 2017, and more[iv]). Epidemiological studies investigated mainly gastro-intestinal symptoms, eye infections, skin complaints, ear, nose and throat infections and respiratory illness resulting from exposure to water via swimming. In prospective studies for swimming in polluted waters, Stevenson in 1957 determined that there was a relationship between the amount of pollution as measured by faecal indicator bacteria in the water and the disease rate in swimmers (Figure 4-1). Swimmers are more likely to experience gastrointestinal, highly credible gastrointestinal, ear, eye, skin, respiratory and total illness than non-swimmers.

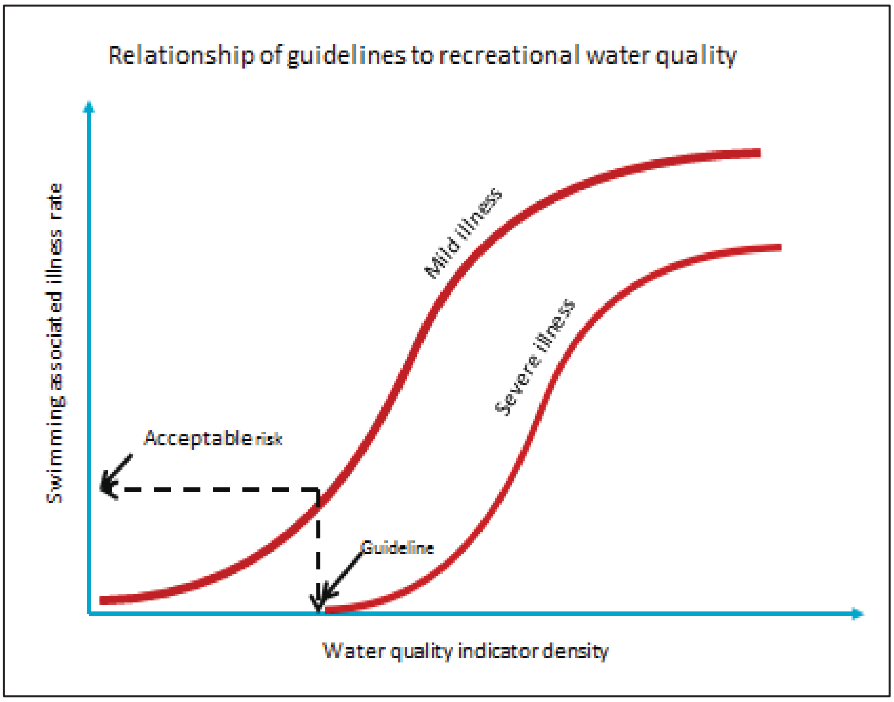


Figure 4-1: Relationship of water quality indicators and swimming associated illness rate (from Cabelli et al., 1983[v])

Epidemiological studies were carried out in both marine and fresh water over the previous 6 decades. All studies assessed water quality by measuring indicator microorganisms, usually bacteria of faecal origin. In 19 of 22 studies examined in the review of epidemiological studies of illness rates and recreational water, Prüss (1998) concluded that 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, with gastrointestinal symptoms the most frequent health outcome for which significant dose-related associations were reported. Most studies reviewed by Prüss (1998) also suggested that symptom rates were higher in lower age groups. It is not feasible to measure the presence and levels of all possible pathogens in recreational water. The studies used different indicators, the most commonly used being enterococci, *Escherichia coli* and faecal coliforms. Regression relationships were characterised and are discussed in more detail.

The epidemiological studies have resulted in various correlations found between health outcomes (numbers of illness per 1000 persons) and water quality, which can be summarised using the amount of *E. coli* or enterococci present. Scientific advancements in microbiological, statistical, and epidemiological methods have demonstrated that enterococci and *E. coli* are better indicators of faecal contamination than the more general indicators that were previously used, namely, total coliforms and faecal coliforms. Faecal contamination in recreational waters is associated with an increased risk of gastrointestinal (GI) illness and less often identified respiratory illness.

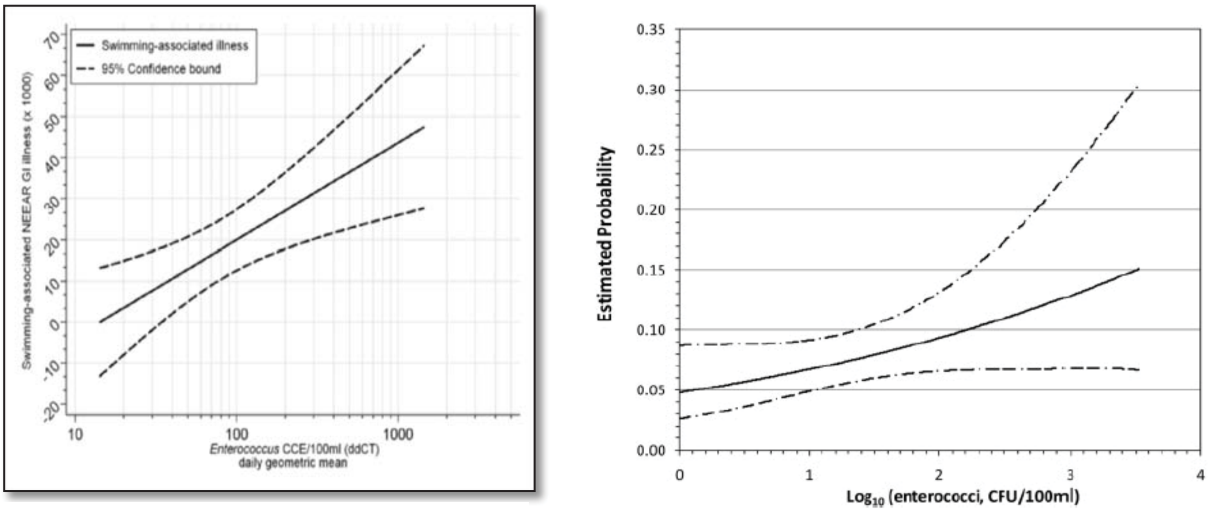
4.1.1 *E. coli* and enterococci: illness rate

Epidemiological studies conducted by the US EPA indicated that levels of *E. coli* in fresh water were correlated to the occurrence of swimming-related gastric illness. Correlation and regression analysis were used to determine the correlation coefficients and the slope of the linear regression equation for each indicator. The best correlation coefficient (r) was obtained with *E. coli* (r = 0.80) followed by enterococci (r = 0.74). Various regression equations for gastrointestinal illness and faecal indicators (*E. coli* and enterococci) are shown in Table 4-1. What is evident is that the regression equations differ according to the symptoms examined, the definition of symptoms used, and the indicator organism.

Table 4-1: Regression Analysis for faecal indicator numbers and swimming associated illness

Regression equation – Swimming associated symptoms vs Faecal indicator	**Reference**
Swimming-associated total gastro-intestinal GI = 5.09 + 24.19 Log enterococci Swimming-associated total gastro-intestinal GI = 15.73 + 7.37 Log *E. coli* Swimming-associated highly credible gastro-intestinal GI = 0.2 + 12.17 Log enterococci Swimming-associated highly credible gastro-intestinal GI = 5.88 + 6.30 Log *E. coli*	Cabelli, 1983[vi]
Seasonal risk of gastro-intestinal GI per 1000 persons = 9.42 (log E coli/100 mL) – 11.74	Health Canada (2012) based on Dufour (1984)[vii] study
Swimming-associated risk gastro-intestinal = 23.73 (log qPCR cce enterococci /100 mL) – 27.31	US EPA, 2012 NEEAR study[viii]

Based on the U.S. EPA's regression analysis of epidemiological data (Dufour, 1984), Health Canada estimated that using the guideline values for the recommended indicators of faecal contamination for fresh and marine waters will correspond to a seasonal gastrointestinal illness rate of 1-2% (10-20 illnesses per 1000 swimmers) (Figures 4-2A and B). A study reported by Wiedenmann et al. (2006)[ix] observed a relationship between the observed rates of illness and measured concentrations of *E. coli*, enterococci, *Clostridium perfringens* and somatic coliphages and proposed guidelines values of 100 *E. coli*/100 mL, 25 enterococci/100 mL, 10 somatic coliphages/100 mL and 10 *C. perfringens*/100 mL. However, as described by Health Canada (2012) the rates of swimmer illness compared to those of the control group were not statistically significant until *E. coli* concentration ranges approached or exceeded 200 *E. coli*/100 mL. The US's EPA and CDC study, the "National Epidemiological and Environmental Assessment of Recreational Water" (NEEAR) looked at the epidemiological studies post-1986, concluding that scientific advancements in microbiological, statistical, and epidemiological methods showed that culturable enterococci and *E. coli* were better indicators of faecal contamination and that combining routine *E. coli* monitoring alongside actions, procedures and tools to collectively reduce the risk of swimmer exposure to faecal contamination in the recreational water environment represents the most effective approach to protecting the health of recreational water users.



A

B

Figure 4-2: (A) Dose response with 95% confidence intervals between gastro-intestinal illnesses and enterococci levels, (B) From Fleisher Skin symptom and enterococci

Note: Therefore, *E. coli* is used as the indicator of faecal contamination in the South African Water Quality Guidelines for recreational use and the accompanying DSS as an indicator of microbial pathogens, recognizing that levels of *E. coli* are usually higher than those of microbial pathogens.

4.1.2 Norovirus

Norovirus causes about 18% of acute diarrhoeal disease globally with similar proportions in high- and low-income settings (Lopman et al., 2015). As a result, norovirus is used as the reference pathogen for viruses in this guidance[x]. Norovirus is a common pathogen in children with diarrhoea in Africa, with a high number of asymptomatic children[2]. In Southern Africa, a peak in Norovirus infections was observed in the spring/early summer time (September-November) while in Malawi it was experienced at the end of the rainy season. According to research reported by Matson et al. (2017)[xi] antibody response showing exposure to Norovirus rises during childhood and results with more than 90 percent of young adults being sero-positive, showing they have been exposed to Norovirus. However, immunity is not long lasting, and reinfection can occur over time. Exposure to a diversity of norovirus strains may result in repeat infections (Johnston et al., 1990)[xii].

4.2 RISK ASSESSMENT AS A TOOL TO MANAGE WATER QUALITY

The risk-based approach was first adopted by WHO as the Stockholm Framework providing a conceptual approach to assess water quality hazards and managing the risks associated with these (Bartram et al., 2001[xiii]). A range of approaches to manage health risks resulting from water quality are available as recommended by the WHO (2016) and involve different levels of risk assessment. These include:
1) the most basic sanitary inspections,
2) a semi-quantitative risk assessment making use of a risk matrix and
3) the most detailed quantitative microbial risk assessment method.

4.2.1 Sanitary inspection

Sanitary inspections involve on-site visual evaluation of conditions at or in the vicinity of the water supply that may lead to an unsafe supply, often making use of checklists to help identify the most common issues that could cause contamination or other hazard into a system. This simple and effective tool was developed for small water supplies (WHO, 1997) and is now recommended as part of Water Safety Plans for small supplies (WHO, 2012b, 2014b). Sanitary inspections help in the identification of the most important causes and pathways of contamination and control options.

Figure 4-3: Sanitary inspections

4.2.2 Risk matrix

The risk assessment approach makes a qualitative or semi-quantitative evaluation of the likelihood that a hazardous event will occur and the severity or consequence of the hazard and combines them into a risk score or risk rating. The risk matrix approach has been applied as a simple way to evaluate the range of different water quality risks.

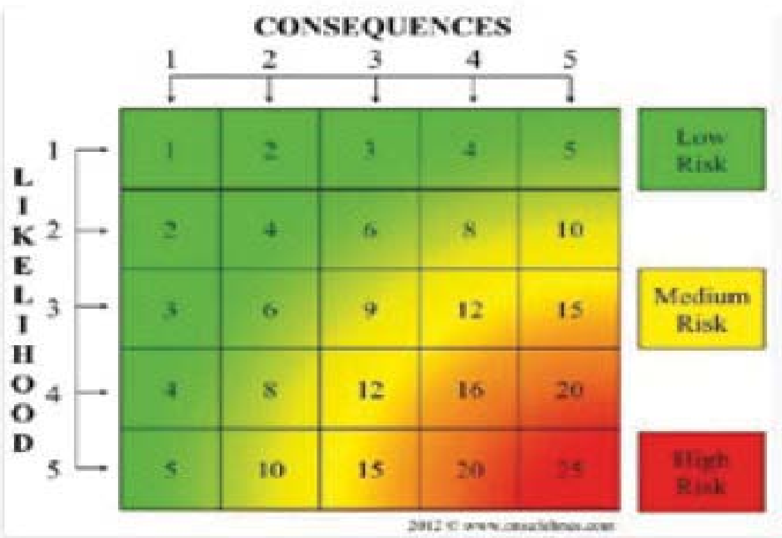


Figure 4-4: Risk Matrix

4.2.3 Quantitative Microbial Risk Assessment (QMRA)

A quantitative risk assessment approach that combines scientific knowledge about the presence and nature of pathogens, their routes of exposure to humans and the possible health effects is combined into a single assessment that allows evidence-based, proportionate and transparent management of the risk of waterborne infectious disease transmission. QMRA has developed as a scientific discipline over the last two decades and has been embedded in the WHO water-related guidelines (WHO, 2003, 2006a&b, 2017[xiv]). Pathogens might be at concentrations too low to be detected and still pose a risk to public health (Signor & Ashbolt, 2006[xv]; Smeets et al., 2007[xvi]). Microbial risks are therefore often assessed by modelling within a QMRA process (example, Figure 4-5).

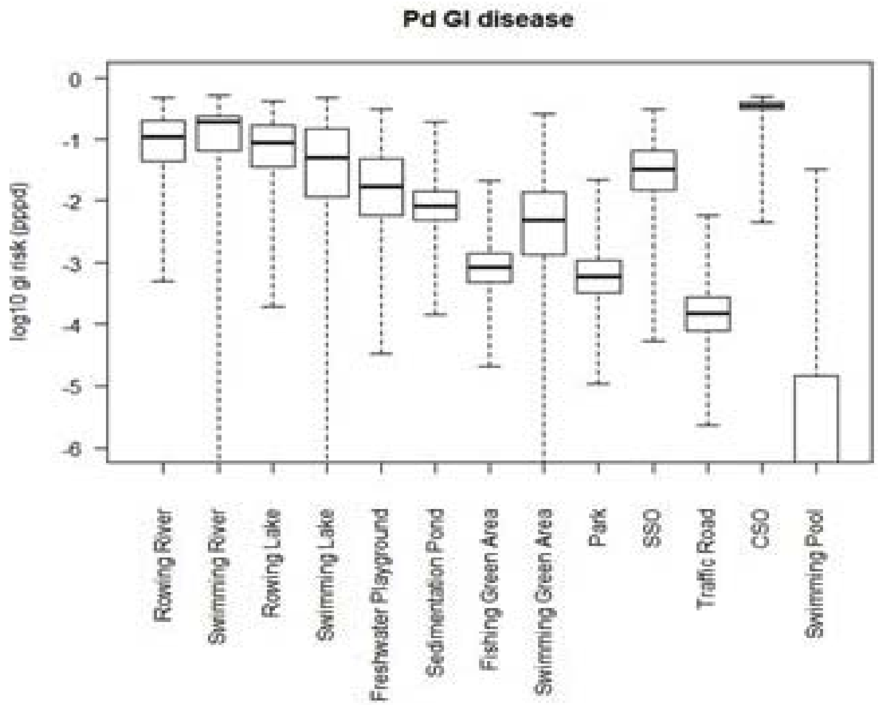


Figure 4-5: Quantitative Microbial Risk Assessment (QMRA)

Pathogen monitoring data from surface water sources may have a large number of non-detects even when the water sources are known to be influenced by faecal sources. This is often due to the event-driven nature of microbial loading and the limitations of small monitoring data sets to capture these events. Modelling the pathogen concentration in faecal sources, followed by hydrologic modelling of contamination events, may therefore provide more useful information for QMRA than relying on monitoring data alone (Ferguson et al., 2007; Ashbolt et al., 2010; Sokolova et al., 2015)[xvii]. Generally, water-transmitted pathogens include viral, bacterial and protozoan pathogens. These microorganisms may result from sewage effluents; the recreational population using the water (which can be directly from faecal material or shedding as a result of immersion in water); livestock (cattle, sheep, etc.); industrial processes; farming activities; domestic animals and wildlife. These pathogens are represented by Norovirus (virus), Campylobacter (bacterial) and Cryptosporidium (protozoa) (Mara and Bos, 2010)[xviii]. These groups of pathogens differ in their ability to survive in the environment. Viruses are the smallest of the waterborne pathogens and are unable to multiply outside the host cell. They are more resistant to environmental inactivation than most pathogenic bacteria and have a lower infective dose.

Outbreaks of acute gastrointestinal with an unknown aetiological agent occur frequently, however the symptoms of the illness suggest the agents are of viral origin. Serological data from studies looking at children experiencing swimming associated gastroenteritis found norovirus to be the more likely cause of the enteritis (WHO, 1999). The number of microorganisms (dose) that may cause infection or disease depends on the specific pathogen, 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[xix]). The types and numbers of pathogens in the environment will differ depending on the incidence of disease and carrier states in the contributing human and animal populations and the seasonality of infections. As a result, numbers will vary greatly in different communities and times of year. A general indication of pathogen numbers in raw sewage is given in Table 4-2 to provide an indication of sewage as a contribution to surface water quality (Modified from WHO Guidelines for Safe Recreational Water Environments, 2006).

Table 4-2: Quantities of organisms present in wastewater as an indication of contribution to surface water quality (Modified from WHO Guidelines for Safe recreational Water Environments, 2006)

Organism / Pathogen	Numbers in sewage / 100 mL
Bacteria	
Campylobacter	10^4-10^5
Clostridium perfringens spores	6×10^6-8×10^8
Escherichia coli	10^6-10^7
Faecal streptococci	5×10^3-4×10^5
Salmonella spp	0.2-8.0×10^3
Shigella spp	0.1-1×10^3
Virus	
Poliovirus	180-5×10^5
Rotavirus	4.0×10^2-8.5×10^4
Adenovirus	1.15×10^5 (gene copies[xx])
Norovirus	4×10^3 (gene copies[xxi])
Hepatitis viruses	5.1×10^1 (gene copies[xxii])
Parasites	
Cryptosporidium parvum oocysts	0.1-39
Giardia lamblia cysts	12.5-3.0×10^4

Various approaches have been used, and continue to be used, for a monitoring philosophy. Outbreaks may occur even in water of high quality (outbreaks can occur despite compliance to guideline values) illustrating the need for a more sophisticated conceptualisation of risk. Ashbolt et al. (2010) discuss how bathers themselves may contribute to pathogen loads in a recreational waterbody through viral or pathogen shedding. For example, rotaviruses may be shed at an amount of 10^{10}-10^{12} per g faeces and norovirus up to 10^{11}/g. This could result in concentrations of 10^3-10^5 virus particles/L water. -Time spent exposed to water differs according to the type of recreational activity. Time spent swimming is typically reported as minutes/month with US EPA recreational guidelines making use of 2 key studies reported in the US EPA Exposure Factors Handbook (US EPA, 2011)[xxiii].

Many dose-response models have been used for Norovirus which were based on fitting distributions to human feeding challenge data. Studies reporting on human feeding challenges demonstrated that infection rates were >50%, with doses of less than 5000 Norovirus genome copies (Van Abel et al., 2017). The feeding studies were not able to consider the sensitive subpopulations that might be at higher risk of infection. Van Abel et al. (2017) report on how 25 different QMRA studies for Norovirus using published Norovirus dose-response models illustrated that different models predicted very different risks, especially at low doses. This highlights the importance of choosing the model most suitable for the purpose it is being used for. The hyper-geometric dose response model predicted higher risks than the Beta-Poisson model. According to CDC Global Burden Report data (CDC. 2015) [xxiv], the current evidence is that disease burden of norovirus is second only to rotavirus as a cause of severe acute gastroenteritis and diarrhoea-associated mortality worldwide. However considerable uncertainty remains with limited disease burden data. Based on calculations using the US CDC data – a DALY of 0.00256 is calculated and illustrated in Table 4-3.

Table 4-3: DALY calculations for Rotavirus and Norovirus

Severity of symptoms	Weight of symptom	Numbers - % Rotavirus	Numbers - % Norovirus	Duration (years)	Rotavirus (Source WHO, 2017)	Norovirus (Calculated using CDC data)
Mild diarrhoea	0.1	97.5%	97.7%	7/365	0.0019	0.00056
Severe diarrhoea	0.23	2.5%	2.26%	7/365	0.0001	0.0001
Death	1.0	0.015% #	0.0034% #	70 (56 for SA*)	0.0105	0.0019
Total DALY					**0.0125**	**0.00256**

the largest difference between rotavirus and norovirus outcomes is the lower death rate for norovirus resulting in a lower DALY for Norovirus
*used in Norovirus calculation
Data for calculating Norovirus DALY made use of CDC Global Burden Report (CDC, 2015) [xxv]

If DALY = YLL (years of life lost) + YLD (years lived with a disability or illness) the following calculation presented as an example in the WHO (2017) drinking water quality guidelines, infection with rotavirus (in developed countries) causes:

- mild diarrhoea (severity rating of 0.1) lasting 7 days in 97.5% of cases;
- severe diarrhoea (severity rating of 0.23) lasting 7 days in 2.5% of cases;
- rare deaths of very young children in 0.015% of cases.

The Rotavirus DALY per case is calculated as follows:

$$\begin{aligned} \text{DALY} &= (0.1 \times 7/365 \times 0.975) + (0.23 \times 7/365 \times 0.025) + (1 \times 70 \times 0.00015) \\ &= 0.0019 + 0.0001 + 0.0105 \\ &= 0.0125 \end{aligned}$$

Similarly, a DALY for Norovirus can be calculated making use of data from the US (Hall et al., 2013)[xxvi] as 0.00256 shown in Table 4-3 as a comparison to Rotavirus. The largest difference between rotavirus and norovirus disease outcomes is the lower death rate for norovirus in young children which results in a lower DALY for Norovirus. The concentration of *E. coli* in water used for recreational purposes, resulting in a specified risk of infection or illness, can be calculated using the DALY for Norovirus shown in Table 4-4. A target DALY agreed to be acceptable or tolerable, and depending on the anticipated number of events per annum, an *E. coli* concentration can be calculated dependent on the anticipated ingestion volume. An example of this is shown in Table 4-6. This illustrates how the DSS Tool provides a risk of illness based on *E. coli* counts, dependent on type of recreational activity. Depending on the numbers of *E. coli* present in the water, the type of recreational activity, and the duration of that activity, the likelihood that more than 3-5% of individuals will develop gastro-intestinal (GI) illness is calculated. For example, if the geometric mean of 100 mL of water accidentally ingested, contains 42 *E. coli*, the risk of exceeding 3.6% illness rate falls within the “tolerable” range, with a 50% likelihood that 3.6% of individuals would get ill (Table 4-6). *E. coli* counts >500 would result in a 100% risk that more than the 3.6% of individuals would become ill.

Table 4-4: Probabilities of infection and illness, and DALYs associated with either single or multiple exposures to water assuming different *E. coli* concentrations and volumes ingested based on type of recreational activities

E coli /100 mL in water	Volume (mL) ingested based on activity	*E. coli* dose ingested	Predicted P infection	Number of events /years	P infection long-term	P illness long-term	DALY (Disability Adjusted Life Years)
10	50	5	3.44E-05	30	1.03E-03	4.33E-04	1.00E-06
100	50	50	3.44E-04	30	1.03E-02	4.31E-03	9.97E-06
150	50	75	5.16E-04	30	1.54E-02	6.45E-03	1.49E-05
200	50	100	6.88E-04	30	2.04E-02	8.58E-03	1.98E-05
250	50	125	8.59E-04	30	2.55E-02	1.07E-02	2.47E-05
300	50	150	1.03E-03	30	3.05E-02	1.28E-02	2.96E-05
500	50	250	1.72E-03	30	5.03E-02	2.11E-02	4.89E-05

Table 4-5: Norovirus and *E. coli* concentrations based on DALY dose and probability of infection/illness targets assuming 30 events per annum

Calculation of organism’s equivalent to 10 $^{-4}$ DALYs pppy	
Probability of *infection* per 1 organism	0.69
***Illness* rate per infection**	0.7
Probability of *illness* per 1 organism	0.483
Disease Burden per case	0.0026
Number of swimming events assumed per year	30
Target Norovirus dose for 10^{-4} DALY target	**0.0027**
Target E coli dose (ingested volume dependent	**270**

Where Target dose for specific DALY

$$= \frac{(Target\ DALY)}{Prob\ illness\ 1\ org\ \times DB \times events\ per\ year}$$

= number of organisms permitted per volume ingested

Table 4-6: *E. coli* numbers and likelihood of exceeding 3.6% illness rates

Risk of more than 3.6% of people developing illness from microbial contamination		
Probability of exceeding 3.6% GI illness rate due to recreational activity	Fitness-for-use Class	*E coli* counts/100 mL)
0-5%	Ideal	<4
>5-10%	Acceptable	5-15
>10-50%	Tolerable	>15-42
>50-100%	Unacceptable	>42->500

Additional approaches using QMRA to determine the probability of infection or illness and subsequent DALYs (described earlier in the Technical Report) as a result of exposure to a reference pathogen such as Norovirus can be used to manage water quality. The DSS provides the opportunity for water quality managers to assess this by using the *E. coli* data input and the activities sheet. Health risks are presented as either probabilities of infection or probabilities of illness in addition to allowing multiple exposures to be considered. The default mode set is 30 events a year which is representative of an average exposure every fortnight. An example is presented in Table 4-7 where based on the activities chosen and the *E. coli* data, a probability of infection or illness from Norovirus is presented as well as DALYs associated with the exposure. Depending on the purpose of either the water use or management, either a single event probability of illness may be assessed or a long-term assessment of historical data.

Table 4-7: QMRA for Norovirus infection and illness probabilities

QMRA for Norovirus Probability of infection, illness and DALY's	
Daily ingestion (ml/day) (from Activities Tab)	60
Geometric mean *E coli* data (counts/100ml) (User data from *E coli* Tab)	114.9
Number of days exposure per year (User entry)	30
Probability of long term infection	0.0141
Probability of long term illness	0.0059
Norovirus DALY	1.37E-05
Target DALY	1.00E-04

4.3 QUANTITATIVE MICROBIAL RISK ASSESSMENT METHODOLGY

4.3.1 QMRA Using Reference Pathogens

A full description of the types of waterborne pathogens and background information is described in WHO DWQGL, 2017 page 126-128, in the South African Irrigation WQGLs and Health Canada (2012) recreational guidelines pages 52-72. Because it is not feasible to test water for all potential waterborne pathogens, including bacteria, viruses, protozoa and helminths a more practical approach is needed which identifies reference pathogens to represent groups of pathogens. Variations in characteristics, behaviours and susceptibilities of each group must be taken into account to represent different pathogenicity and survival characteristics. As presented in both the latest South African Water Quality Guidelines for Irrigation (being developed) and the WHO WQGs for agriculture (WHO, 2006)[xxvii] the risk of norovirus infection per person per year is determined in the DSS by comparing the count of *E. coli* per 100 mL to a published dose-response function (Mara and Bos, 2010). The quantification of virus concentrations in source water is seldom done, however historical sets of faecal indicator data are available. An exploration of how the faecal indicator data can be used to inform and support the quantification of virus concentration in surface waters is therefore needed (Petterson et al., 2016). In the case of recreational guidelines, the current revised guidelines present target water quality levels which represent the risk of infection, expressed as the risk of exceeding a 3.6% illness rate, based on the *E. coli* intake. Depending on the type of pathogen of interest, different surrogate organisms can be used in assessing probabilities of infection for organisms other than viruses, although the risk of virus infection is much higher than for bacteria and parasites.

4.3.2 Probability of Infection Models

The process of QMRA is derived from the chemical risk assessment paradigm that encompasses the 4 steps of risk assessment, namely: hazard identification and characterisation; exposure assessment; dose-response assessment and lastly risk characterisation (WHO, 2016, 2017a, 2017b, US-EPA, 2016).

Table 4-8: Probability of Infection Models

Daily risk (Probability) of infection	
Beta-Poisson Model (WHO, 2001) $Pi = 1 - [1 + \frac{dose}{\beta}]^{-\alpha}$ and $N_{50} = \beta * [2^{1/\alpha} - 1]$ therefore $P_i = 1 - [1 + \frac{d}{N_{50}}](2^{1/\alpha} - 1)^{-\alpha}$	*Exponential Model (Haas, 1996)* $P_i = 1 - e^{-rN}$
P_i = probability (risk) of infection ***d*** = dose or exposure (number of organisms ingested based on consumption of water (*l*) per day) **β** = parameter characterised by dose-response relationship **α** = parameter characterised by dose-response relationship ***N_{50}*** = median infectious dose	

4.3.2.1 The Probability of infection based on multiple exposures

Multiple or long-term exposures result in a probability of infection calculated based on the number of exposures (events) expected to occur over a year (WHO, 2006).

$P\ multiple = 1 - (1 - P\ inf)^n$,
where n is the number of times exposure occurs. For example, monthly exposure, n = 12; exposure every 12 days, n= 30 and for weekly exposure, n= 52.

This method of calculating annual risk of infection assumes a constant infection probability (or constant daily dose) and is not a true reflection of annual risk as it assumes that water quality and other exposure assumptions remain constant. Additional methods of calculating annual risk are available that more realistically represent this, taking into account the variability of daily dose (and therefore daily risk of infection). The alternate annual risk formula is calculated as the product of independent daily infection probabilities and allows for variation in daily risk of infection (Benke and Hamilton, 2008). Adjustments to this formula have been proposed by other researchers to account for variations (Karavarsamis and Hamilton, 2010). The numerous dose estimates in the calculations can be either direct measurements or generated through simulation of an exposure model.

As it is not practical to have daily samples analysed and simulation tools are not always accessible for conducting a risk-based assessment, uncertainty and variability are ignored in this calculation of annual risk (Karavarsamis and Hamilton, 2010), but are acknowledged. The formulae above provide results which reflect probability of **infection** – which involves the multiplication of microorganisms such as bacteria, viruses, and parasites. An infection may cause no symptoms and be subclinical, or it may cause symptoms and be clinically apparent. The different outcomes resulting from exposure to microbial pathogens is illustrated in the following diagram. Various models exist for the dose-response relationship for infection and the dose-response relationship for illness when infected depicted in the next figure (Figure 4-6).

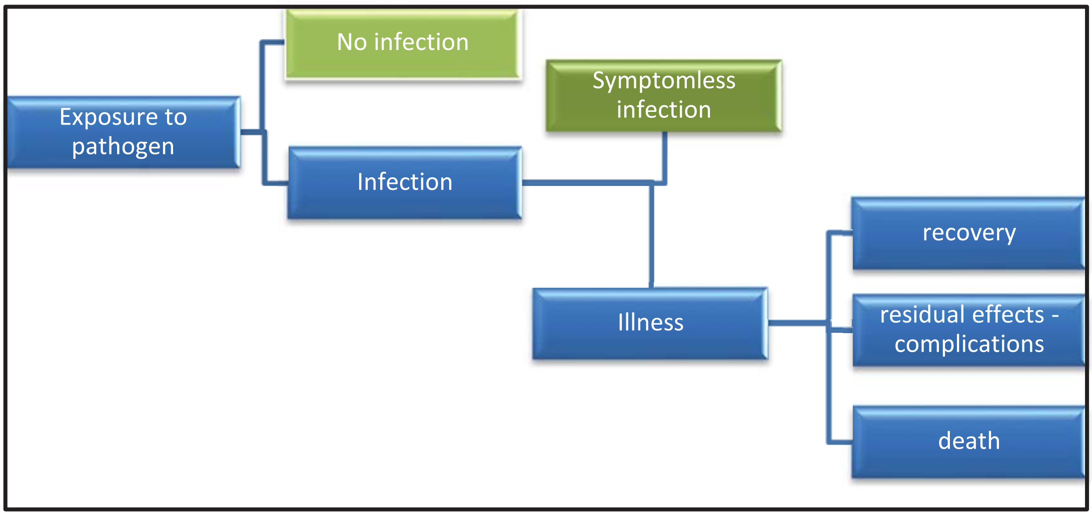


Figure 4-6: Disease progression model. Adapted from: Pruss & Havelaar (2003)

Depending on the type of pathogen of interest, different surrogate organisms can be used in assessing probabilities of infection for organisms other than viruses, although the risk of virus infection is much higher than for bacteria and parasites. Viruses can persist for long periods in water and have low infective doses. Rotaviruses, enteroviruses and noroviruses have been identified as potential reference pathogens in QMRA. Rotaviruses and Noroviruses are the most important cause of gastrointestinal infection in children and can have severe consequences, including hospitalization and death, with fatality rates being more frequent in low-income regions. Typically, viruses are excreted in very large numbers by infected patients, and waters contaminated by human waste could contain high concentrations. QMRA can be used to characterise risks associated with a particular pathogen to calculate a concentration of a specific pathogen that would correspond to a pre-specified level of risk, or to evaluate the relative ranking of pathogen/exposure combinations.

The figure below (Figure 4-7) illustrates the process as described by Sunger and Haas (2006) that can be used to calculate risk of illnesses per 1000 users per day at a site and the total risk of illnesses per day. Many studies have been undertaken in which dose-response models have been fitted to experimental data. The reference pathogens used as examples in the Drinking Water Quality Guidelines (WHO, 2017a) are *Campylobacter*, rotavirus and *Cryptosporidium*. The introduction of a rotavirus vaccine which is changing the incidence and severity of disease outcomes from this pathogen has complicated the use of it as a reference pathogen (Gibney et al., 2014). Norovirus, which fulfils the requirement of a reference pathogen, is therefore a suitable alternative to use as a reference pathogen. Norovirus causes about 18% of acute diarrhoeal disease globally with similar proportions in high- and low-income settings (Lopman et al., 2015) and is a common cause of waterborne outbreaks (Guzman-Herrador et al., 2015; Moreira et al., 2016.

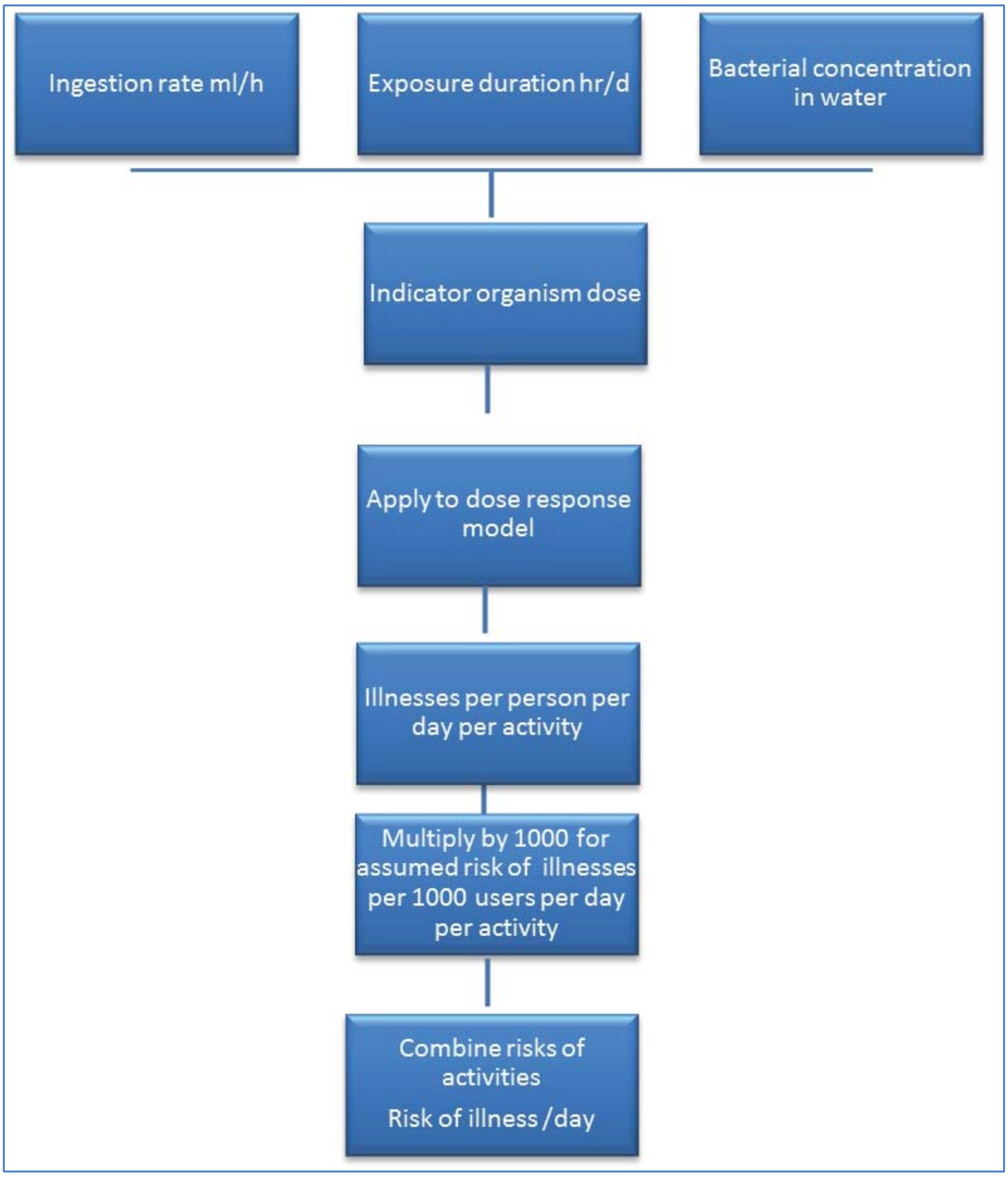


Figure 4-7: Flow chart calculating total risk of illnesses per day and illnesses per 1000 users per day at each site. (Source Sunger and Haas, 2006)

The most common pathogens used as reference pathogens in QMRAs for managing water quality include:

- *Campylobacter*
- *E. coli*
- Enteroviruses
- Adenovirus
- Rotavirus
- Norovirus
- *Giardia lamblia*
- *Cryptosporidium*

Concentrations of pathogens equivalent to a health outcome target of 10^{-6} DALY per person per year are typically less than 1 organism per 10^4-10^5 litres. Therefore, it is more feasible and cost-effective to monitor for indicator organisms such as *E. coli*. Because QMRA is a sensitive tool that can estimate the probability of infection that could not be measured through epidemiological studies it complements epidemiological studies. QMRA predicts infection or illness rates based on the densities of a specific pathogen and predicted or measured ingestion rates of water associated with different activities.

In the agricultural water quality guidelines for irrigation, *E. coli* levels are calculated based on protection from Norovirus infection as this will also protect against bacterial and parasite infections. Norovirus is recognized as one of the most common agents of viral diarrhoea. Although the risk of infection by norovirus would usually be modelled based on measured or modelled norovirus particles, here the risk of norovirus infection per person per year is determined using *E. coli* counts per 100 mL. This is used to estimate a norovirus concentration to predict the probability of illness established using Norovirus dose-response parameters (Teunis et al., 2008).

4.3.2.2 Low-dose approximation formulae

WHO (2017a and b) suggest using low-dose approximations of the QMRA formulae. In this document, the traditional dose dependent beta Poisson model adopted by WHO (2017) was also adopted (Shown in Table 4-9), with outcomes of the two models reported to be similar.

Table 4-9: Reference pathogen formulae and data to calculate DALYs (Source FAO /WHO, 2003; WHO, 2017b)

Reference pathogen	Campylobacter	Norovirus	Cryptosporidium
Dose-response parameters	α = 0.145 β = 7.58 Approximate beta Poisson	α = 0.0044 β = 0.002 Hypergeometric	r = 0.2 exponential
Low-dose extrapolation formula	$Pinf = \frac{\alpha}{\beta} \times dose$	$Pinf = \frac{\alpha}{(\alpha + \beta)} \times dose$	$Pinf = r \times dose$
Probability of infection from a single organism	0.019	0.69	0.2
Probability of illness if infected	0.3	0.7	0.7

4.4 ALGAE AND CYANOBACTERIA IN FRESH WATER

4.4.1 Background

Globally, exposure to algae and cyanobacteria and/ or their associated toxins are considered less of a health concern than that of pathogenic microorganism exposure (NHMRC, 2008). The collective term “algae” refers to a wide range of pigmented, oxygen-producing, photosynthetic organisms usually present in surface waters (Textbox 1). Almost all aquatic vegetation without true roots, stems and leaves are regarded as algae. Algae range from microscopically small unicellular forms, the size of bacteria, to larger filamentous forms (e.g. filamentous algae) which may be metres in length (DWAF, 1996). To proliferate, algae require light, carbon dioxide, water, nutrients such as nitrate and phosphate, as well as trace elements. Through the assimilation of nitrogen species (ammonia and nitrate) as well as the release of oxygen to the aquatic environment as a result of photosynthesis, algae play an important role in natural purification of surface water. In addition, algae often form the basis for aquatic food webs (DWAF, 1996). Excess algae or undesirable algal types can become a nuisance and negatively impact recreational uses of a water body. Algae such as filamentous algae that grow on surfaces such as rock may become detached and form floating masses.

Textbox 1: Classification of algae

The classification of algae is extremely complex. However, for the purposes of this guideline, the following classes are important:

- **Cyanophyta**: These are more commonly known as the blue-green algae but are sometimes referred to as cyanobacteria. These typically dominate in highly nutrient enriched waters.
- **Chlorophyta:** These are commonly referred to as green algae and are common summer residents of less enriched water bodies.
- **Euglenophyta**: These are flagellate unicellular algae, typical of organically-enriched water
- **Cryptophyta:** These are also flagellate unicellular algae.
- **Bacillophyta**: This group is commonly referred to as the diatoms, and are unicellular algae surrounded by a silica frustule (coating). This group often dominates winter algal populations.

These masses could entangle swimmers or boats and may obscure the view of recreational users. Dense algal growth, as well as dry and decaying algal masses are not only visually displeasing, but can cause unpleasant odours (DWAF, 1996). Excess algal growth is usually associated with eutrophication of surface waters resulting from anthropogenic activities (e.g. increased nutrients associated with untreated or inadequately treated sewage water, agricultural runoff, or runoff from industry, urban environments or informal settlements (WHO, 2003). Although many freshwater algae species proliferate rather extensively in eutrophic waters, dense scums (referred to as algal blooms) are usually associated with cyanobacteria. As a result, the toxins that freshwater algae may contain are unlikely to accumulate to concentrations which could negatively impact human health or livestock (WHO, 2003). This section will therefore focus mainly on cyanobacteria and their potential health impacts for recreational users.

4.4.2 Cyanobacteria

Cyanobacteria, also referred to as blue-green algae (due to the blue-green and green pigment they contain), are similar to algae in size, can photosynthesise and share characteristics of both algae and bacteria. Chorus and Bartram (1999) described how some species form colonies, while others can appear as irregular groupings or straight, coiled or branched filamentous chains. Cyanobacteria are capable of controlling their buoyancy by means of their gas-like bubbles called vacuoles, moving up and down in the water column towards where light or nutrients are more abundant (Falconer, 2005). Compared to other algae and phytoplankton, cyanobacteria have a greater affinity for nitrogen and phosphorous and lower light intensity requirements which further allow them to outcompete other organisms under limiting conditions (Mankiewicz et al., 2003). Excess buoyancy can allow for surface bloom / scum formation which can be blown towards the shore to accumulate (Chorus and Bartram, 1999; WHO, 2003). Chorus et al. (2000) reported that the density of cyanobacterial blooms can increase by a factor of more than a 1000 or even more in a very short timeframe.

4.4.3 Cyanobacterial toxins

Cyanobacteria are best known for the many genera and more than 46 species (Sivonen and Jones, 1999) capable of producing a range of extremely potent biological toxins (Table 4-10). Cyanobacterial toxins are produced in a random and unpredictable fashion, and pose a public health concern in terms of acute and chronic health risks to both animals and humans. These toxins include a variety of neuro-, hepato- and lipopolysaccharide and are most commonly associated with the cyanobacterial genera *Anabaena, Aphanizomenon, Cylindrospermopsis, Microcystis, Nodularia, Nostoc and Oscillatoria (Planktothrix*) (Harding and Paxton, 2001; Falconer, 2005; WHO, 2003). Table 4-10, adopted from Carmichael (2001) provides a summary of all the names and organisms producing cyanotoxins. In South Africa, the most common bloom forming toxic freshwater species are *Microcystis spp* and *Anabaena spp*, although a number of other species may also produce toxins on occasion (DWAF, 1996).

Table 4-10: Cyanobacterial Toxins, their Acute Toxicity, target organs and health effects (Adapted from Sivonen and Jones, 1999, Chorus et al., 2000 and US EPA, 2014)

Cyanotoxins	LD50 (ip, mouse) of pure toxin	Taxa known to produce the toxin(s)	Mechanism of toxicity	Primary Target Organ	Health effects
Protein-phosphatase-blockers Block protein (cyclic peptides with ADDA[1]) phosphatases	45->1000 µg/kg		Blocks protein phosphatases by covalent binding and cause haemorrhaging of the liver; cumulative damage may occur	Liver	Abdominal pain Vomiting and diarrhoea Liver inflammation and haemorrhage Acute pneumonia Acute dermatitis Kidney damage Potential tumour growth promotion
Microcystins in general (~60 known congeners)		*Microcystis, Planktothrix/ Oscillatoria, Nostoc*			
Microcystin-LR	60(25-125) µg/kg	*Anabaena, Anabaenopsis*			
Microcystin-YR	70 µg/kg	*Hapalosiphon*			
Microcystin-RR	300-600 µg/kg				
Nodularin	30-50 µg/kg	*Nodularia spumigena*			
Cytotoxin	2100 µg/kg	Cylindrospermopsis raciborskii	Blocks protein synthesis; substantial cumulative toxicity	Liver	
Cylindrospermopsin (alkaloid)	200 µg/kg/5-6 d				

Neurotoxins				Nervous System	
Anatoxin-a [4](alkaloid)	250 µg/kg	Anabaena, Oscillatoria, Aphanizomenon, Cylindrospermum	Blocks postsynaptic depolarization	Nerve synapse	Tingling, burning, numbness, drowsiness, incoherent speech, salivation, respiratory paralysis leading to death
Anatoxin-a(s) (unique organophosphate)	40 µg/kg	Known only from 2 species of Anabaena	Blocks acetyl-cholinesterase	Nerve synapse	
Saxitoxins (carbamate alkaloids)	10-30 µg/kg	Aphanizomenon, Anabaena, Lyngbya, Cylindrospermopsis raciborskii	Blocks sodium channels	Nerve axons	

1 - ADDA: 2S,3S,8S,9S-3-amino-9-methoxy-2,6,8-trimethyl-10-phenyldeca-4,6-dienoic acid.
2 - Source: Harmful Algal Research and Response National Environmental Science Strategy (HARRNESS)
3 - Not all species of the listed genera produce toxin; in addition, listed genera are not equally as important in producing cyanotoxins.
4 - The anatoxin-a group does not include the organophosphate toxin anatoxin-a(S) as it is a separate group. In the US, the most common member is thought to be anatoxin-a, and thus this toxin is listed specifically.

4.4.4 Interactions

The concentration of nutrients, specifically nitrogen and phosphorus in the water, are directly linked to the amount of algae in surface waters (DWAF, 1996). Physical conditions such as turbidity and the associated light availability as well as pH may influence the growth of algae. DWAF (1996) stated that the photosynthetic uptake and release of CO_2 may result in pH fluctuations, impacting growth of algae. Excess algal growth and the resultant collapse of algal populations may cause oxygen depletion which has been linked to fish kills and the death of other aquatic organisms. Filamentous algae attached to rocks and surfaces can also serve as a habitat for the waterborne vectors from schistosomiasis (bilharzia). Chorus and Bartram (1999) reported that maximum cyanobacteria growth rates occurred at temperatures above 25°C and therefore typically occur in late summer months. While the conditions associated with the development of cyanobacterial blooms have been reported by various studies (Chorus and Bartram, 1999; Harding and Paxton, 2001, Falconer, 2005), the factors responsible for the dominance of toxin producing strains are not well understood. Release of the cyanotoxins occurs during die-off of the cells or when they are stressed or damaged. It is suggested that most of the toxicity last as long as the bloom, but that some toxicity may persist for a short period after the boom has disappeared (Chorus and Bartram, 1999; Falconer 2005).

4.4.5 Monitoring and analysis

Visual inspection alone cannot confirm the presence of toxins within a bloom and samples have to be tested by a laboratory (Health Canada, 2012). Measurement of the algal biomass in the first edition South Africa guidelines included either the chlorophyll-*a* concentration in water, or the algal cell or colony counts (DWAF, 1996). While it known that the percentage of chlorophyll-*a* varies during the lifecycle of a species and also between species, chlorophyll-*a* is the preferred indicator for algal biomass estimates as it is present in all algae (apart from the so-called colourless algae) and make up 1-2% of the dry weight of organic material in all planktonic algae. Concentrations are expressed as Fg/l chlorophyll *a*. Chlorophyll *a* concentration vary from less than one µg/ℓ in clear waters, to over 50 µg/ℓ in severe nuisance conditions. In extreme cases concentrations in excess of 1 000 µg/ℓ have been recorded. The amount of algae in water can also be enumerated by means of cell or colony counts. Cell counts may range from less than 50 cells/l in very clear waters, to many thousands of cells/mL in the case of algal blooms. The algal cell or colony count provides an accurate measure of the amount of algae as well as an indication of the species of algae present in recreational waters, but is more labour intensive (DWAF, 1991). Advances in analytical chemistry and commercially available sensitive immunoassays and enzyme assays, has enabled large scale monitoring programmes and testing for cyanotoxins in water. Table 4-11 shows the different methods available for detecting cyanobacterial toxins (Loftin et al., 2010 cited in US EPA, 2014). It allowed for successful isolation and structural identification of the three neurotoxins *anatoxin-a*, *anatoxin-a(s)* and *saxitoxins*, a cytotoxin known as *cylindrospermopsin* , as well as a group that inhibit protein phosphatases known as microcystins (or nodularins found in brackish water) (WHO, 2003). Phosphatase inhibition is generally cytotoxic but microcystins are mainly hepatotoxic making use of the bile acid carrier to pass through cell membranes (WHO, 2003).

Table 4-11: Methods Available for Cyanotoxin Detection*

Freshwater Cyanotoxins			
Methods	**Anatoxins**	**Cylindrospermopsins**	**Microcystins**
Biological Assays			
Mouse	Yes	Yes	Yes
Protein Phosphatase Inhibition Assays (PPIA)	No	No	Yes
Neurochemical	Yes	No	No
Enzyme-Linked Immunosorbent Assays (ELISA)	No	Yes	Yes
Chromatographic Methods ***Gas Chromatography***			
Gas Chromatography with Flame Ionization Detection (GC/FID)	Yes	No	No
Gas Chromatography with Mass Spectrometry (GC/MS)	Yes	No	No
Liquid Chromatography			
Liquid Chromatography / Ultraviolet-Visible Detection (LC/UV or LC/PDA)	Yes	Yes	Yes
Liquid Chromatography/Fluorescence (LC/FL)	Yes	No	No
Liquid Chromatography Combined with Mass Spectrometry			
Liquid Chromatography Ion Trap Mass Spectrometry (LC/IT MS)	Yes	Yes	Yes
Liquid Chromatography Time-of-Flight Mass Spectrometry (LC/TOF MS)	Yes	Yes	Yes
Liquid Chromatography Single Quadrupole Mass Spectrometry (LC/MS)	Yes	Yes	Yes
Liquid Chromatography Triple Quadrupole Mass Spectrometry (LC/MS/MS)	Yes	Yes	Yes

*Loftin et al., 2010 - Adopted from US EPA, 2014.

4.4.6 Data Interpretation

As a result of fluctuations in algae and seasonal chlorophyll concentrations, annual mean values would more accurately represent the water quality for recreational use (DWAF, 1996). Chorus et al. (2000) reported that an average of 60% of all cyanobacterial blooms tested positive for cyanotoxins. It is therefore important to treat any cyanobacterial bloom as potentially toxic. The WHO (2003) cautions that the toxicity of a single bloom may change in time and space and that thinly dispersed cells do not necessary imply an environmental or human health hazard, while surface scums and mass developments pose a risk. Regular longer-term monitoring of the distribution of algal cell counts and or chlorophyll concentrations can provide an indication of the potential problems that may be experienced. Similarly, the species present can also provide an indication of the problems likely to be experienced (e.g. cyanobacteria or other non-toxic species) (DWAF, 1996). Prolonged or persistent algal blooms and continued intensive recreational activities pose a greater risk of acute exposure to cyanotoxins (Funari and Testai, 2008).

4.4.7 Cyanobacterial blooms in the South African environment

According to Ndlela et al. (2016) South Africa has some of the most documented information on cyanobacterial blooms over the past decade compared to the rest of Africa. Reporting of cyanobacterial blooms across the country was initiated by an outbreak of illness or animal death within an area. Oberholster and Ashton (2008) reported that cyanobacterial blooms are amongst the main issues that threaten water quality in South Africa. They found that cyanobacterial blooms have occurred in nearly all the known water sources in South Africa. Toxic blooms containing M*icrocystis aeruginosa* and *Anabaena spp*. are predominantly reported with some *Oscillatoria spp*. also dominant in certain reports. Janse van Vuuren and Kriel (2008) found increased cell numbers reported for *Cylindrospermopsis raciborskii* particularly in the Northern part of South Africa since early 2000. A summary of all the earlier findings and possible outbreaks associated with cyanobacteria in South Africa was reported by Harding and Paxton (2001). Oberholster et al. (2005) summarised the toxic bloom outbreaks and findings up to the year 2000 for South Africa.

More recent reports of cyanobacterial blooms have been found for Lake Krugersdrift. These blooms occurred in the summer months in 2004 and coincided with fish kills (Oberholster et al., 2009a). Oberholster et al. (2009b) found microcystin levels reaching as high as 43 mg/L in some sites in 2005-2006. In 2007, the Nhlangezwane Dam, a water source for wildlife in the Kruger National Park, had microcystin concentrations exceeding 20,000 mg/L which resulted in death of wildlife (Oberholster et al., 2009c). Cyanobacterial blooms have also been reported beyond the last decade in Hartbeespoort Dam in 2002 (Oberholster et al., 2004). This dam has since been plagued with toxic blooms as a result of nutrient loadings from sewage effluent in the upper catchment. While *Microcystis aeruginosa* was previously reported to dominate in toxic algal blooms, Ballot et al. (2014) indicates the diversity and abundance of the blooms in Hartbeespoort may have been underestimated, with 96% of the microbial biomass comprising cyanobacteria, with *Nostoc spp*. and *Oscillatoria spp.* forming part of the diversity among other species. Oberholster et al. (2009c) and Nchabeleng et al. (2014) reported *Microcystis* blooms in Loskop Dam. Blooms in this dam have been associated with wildlife killings, potentially posing a threat to eco-tourism industry in South Africa. Although typically known to occur in the warmer months, Oberholster and Botha (2007) reported a winter bloom of Microcystis in Lake Midmar (Pietermaritzburg, KwaZulu-Natal). Of greater concern, are the recent reports of Anabaena bloom prevalence during winter months and containing microcystin L-R in Theewaterskloof Dam near Cape Town (Oberholster et al., 2015). Mathews and Bernard (2015) recently published their findings on a 10-year time series for 50 water bodies in South Africa making use of satellite remote sensing. They found that the majority (62%) of the 50 water bodies were hypertrophic. In addition, they found that 26 of the 50 water bodies contained cyanobacterial blooms posing possible health risks from surface scums.

Textbox 2: **Records of human 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.

1991: Australia: Two teenage girls suffered gastroenteritis and myalgia after swimming in the Darling River at Wilcannia during a cyanobacterial bloom containing Anabaena (Williamson and Corbett, 1993).

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

Textbox 3: Records of human 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).

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).

4.4.8 Evidence of cyanobacteria toxicity

4.4.8.1 Aesthetics:

The aesthetic appeal of recreational waters may be affected by all forms of excess algal growth. Dense growth of free-floating algae or dry and decaying algal masses are visually unappealing and can cause unpleasant odours.

4.4.8.2 Human Health:

Animal deaths (e.g. cattle, sheep, horses, pigs, dogs, fish, rodents, amphibians, waterfowl, bats, zebras and rhinoceroses) as a result of algal contaminated water consumption has been recorded globally (Codd et al., 1989; DWAF, 1996). Renal dialysis (Carmichael, 1996) as well as drinking water (Teixera et al., 1993) has been implicated in human fatalities associated with cyanobacterial toxins (WHO, 2003). Human death as a direct result of cyanotoxin exposure via recreational exposure have not been recorded, but illness has been linked to recreational use of water containing *Microcystis* and *Anabaena* blooms in many parts of the world (Canada, 2012). Three routes of exposure have been identified as important for human health risk associated with recreational use of water with cyanobacterial toxins (NHMRC, 2008):

- Direct contact of the ears, eyes, mouth and throat as well as the areas covered by a bathing suit or wet suit.
- Ingestion as a result of accidental swallowing of water
- Aspiration of cells (inhalation of water)

Dense growth of free-floating algae may cause human health impact as it may obscure a swimmer's visibility and prevent them from identifying underwater hazards or create the danger of entanglement or obstruct boats. Toxins released from cyanobacterial blooms may be toxic if accidentally ingested and may cause skin irritation on contact. Experimental evidence suggests that the toxicity of the algal toxins seems to increase when absorbed via the nasal route. People skiing in water with cyanobacterial blooms, may therefore be exposed resulting in an increased health risk associated with the inhalation of contaminated aerosols (Fitzgeorge et al., 1994; DWAF, 1996; Chorus and Bartram, 1999). Direct epidemiological evidence of human health effects due to recreational exposure to cyanobacterial toxins are limited and mostly anecdotal. The case reports that do exist usually have information gaps as they do not report on the algal species or the concentration of cells or toxins. Additional information is from animal studies or accidental animal poisonings. The WHO (2003) noted that the low number of report cases might be due to a lack of knowledge about cyanobacteria toxicity and or patients or doctors failing to link symptoms with this cause.

Symptoms of cyanotoxin exposure reported by a Canadian study (Dillenberg and Dehnel (1959) cited in Canada, 2002) include headache, fever, stomach cramps, diarrhoea, vomiting, pain in muscles and joints, as well as weakness. In addition to these symptoms, Ressom et al. (1994) reported dermal irritation, sore red eyes, sore throat and allergic responses (Stewart et al., 2006). Anecdotal evidence exist which suggests a link between eutrophic recreational waters and hay-fever-like (allergic) reactions (NHMRC, 2008; Canada, 2012). While these allergic reactions are not strictly linked to cyanobacteria exposures, elevated cell densities as a result of mass development and which are usually caused by cyanobacteria, is needed for allergic reactions (NHMRC, 2008). In the UK, Turner et al. (1990) reported a dry cough and blistering around the mouth of ten military recruits. They also found a possible link between pneumonia and *Microcystis aeruginosa* in two of the recruits after canoeing in a reservoir containing these toxins.

For the development of guidelines for recreational exposure in Australia, Pilotto et al. (2004) investigated whether humans experienced skin irritation effects from cyanobacterial cell suspensions. They found an adverse health hazard associated with exposure, but irritation was mild and self-limiting. An epidemiological study by Pilotto et al. (1997) investigated human health effects after recreational exposure to cyanobacteria in Australia. An important finding was the correlation between symptoms and duration of contact (>60 minutes) as well as with cyanobacterial concentration. In a prospective cohort of 1331 individuals in Australia, Stewart et al. (2006) found that respiratory symptoms were 2.08 times more likely in individuals exposed to high levels of cyanobacteria (>12 mm^2/mL) as opposed to those exposed to low levels (<2.4 mm^2/mL).

4.4.9 International evidence and guideline development

Internationally, guidelines for cyanobacterial toxins, mostly based on microcystin levels have been developed over the last number of years. The guidelines tend to focus on microcystins as the neurotoxins are not as widespread nor as hazardous due to their lack of chronic toxicity. *Cylindrospermopsin* which is very toxic, does not form surface water scums and was therefore deemed more of a drinking water problem (Chorus et al., 2010). Based on an animal study Falconer (1994) presented a provisional safety level for microcystin in drinking water based on a calculated Acceptable Daily Intake (ADI) of 1µg/L for short term exposures of up to 14 days (which is equivalent to 10ug/L for recreational activity). This is similar to approximately 5000 cells of Microcystin/mL of water. While questioning the feasibility to determine “safe” levels for cyanobacteria in recreational water, Ressom et al. (1994) suggested a first threshold level of 20 000 cells/mL of water.

Carmichael (2001) reported that the WHO (1998) and Chorus and Bartram (1999) made the first attempt to establish guidelines for acceptable cyanotoxins levels in water supplies and to assess the risk of toxic cyanobacteria in recreation or drinking water supplies. By then countries like Australia, Brazil, Canada, Great Britain and Germany were trying to establish no adverse or maximum acceptable levels for microcystins in drinking water. At present, many countries have developed guidelines or action levels for recreational water use. Table 4-12 provides a summary of the lowest guideline level/action values which have been summarised by the USEPA (2016). This table has been adapted to also include the recently updated USEPA (2016) recommendations. Further details regarding the guideline development approach for each country or organisation have been referenced and should be used for additional supporting information.

Table 4-12: International Microcystin Guideline levels

Jurisdiction	Lowest Recreational Water Guideline/Action Level[a]	Reference
Australia[b]	microcystins (total):< 10 µg/L or *Microcystis aeruginosa* (total): < 500 to < 5,000 cells/mL or cyanobacteria (total): < 0.4 to < 4 mm^3/L (where a known toxin producer is dominant in the total biovolume)	Australian Government National Health and Medical Research Council (2008)
Canada	microcystins (total): ≤ 20 µg/L (expressed as microcystin-LR) or cyanobacteria (total): ≤ 100,000 cells/mL	Health Canada (2012)
Cuba	cyanobacteria: < 1 of the species known as potentially toxic or phytoplankton cells: < 20,000 – to < 100,000 cells/mL,	German Federal Environment Agency (2012)c

Jurisdiction	Lowest Recreational Water Guideline/Action Level[a]	Reference
	> 50 percent of cells cyanobacteria	
Czech Republic	cells: >20,000 cells/mL	German Federal Environment Agency (2012)c
Denmark	chlorophyll *a*: <50 µg/L, dominated by cyanobacteria or visible surface scum	German Federal Environment Agency (2012)c
European Union	Appropriate monitoring must be implemented if there is a risk of proliferation of algae. Member state authorities responsible must take management measures and provide information immediately if a proliferation of cyanobacteria (or blue algae) occurs.	European Parliament and the Council of the European Union (2006)
Finland	algae (includes cyanobacteria): detected	German Federal Environment Agency (2012)c
France[b]	microcystins: < 25 µg/L or cyanobacteria: <20,000 to < 100,000 cells/mL (±20 percent)	German Federal Environment Agency (2012)c
Germany	Secchi Disk reading > 1 m AND (microcystins: ≤ 10 µg/L or chlorophyll *a* (with dominance by cyanobacteria): ≤ 40 µg/L or biovolume: ≤1 mm³/L)	German Federal Environment Agency (2012)c
Hungary	microcystins: ≤4 to < 10 µg/L or cell count: ≤20,000 to < 50,000 cells/mL or chlorophyll a (with dominance by cyanobacteria): < 10 to < 25 µg/L	German Federal Environment Agency (2012)c
Italy[b]	microcystins: < 25 µg/L or cyanobacterial cell count (combined with identification of genus and, if possible, species): < 20,000 cells/mL	German Federal Environment Agency (2012)c
Netherlands	chlorophyll a: <12.5 to ≤ 75 µg/Lor biovolume (cyanobacterial cell count): <2.5 to ≤ 15 mm³/L	German Federal Environment Agency (2012)c
New Zealand[b]	microcystins (total): ≤ 12 µg/L or cyanobacteria (benthic): 20-50 percent coverage of potentially toxigenic cyanobacteria attached to substrate or cyanobacteria (total):< 0.5 to < 1.8 mm³/L (biovolume equivalent of potentially toxic cyanobacteria) or cyanobacteria (total): < 0.5 to < 10 mm³/L (biovolume equivalent of the combined total of all cyanobacteria)	Wood et al. (2008)

Jurisdiction	Lowest Recreational Water Guideline/Action Level[a]	Reference
Poland	visible blooms	German Federal Environment Agency (2012)c
Scotland[b]	chlorophyll a: ≤10 µg/L with dominance of cyanobacteria or cyanobacteria: ≤20,000 cells/mL	Scottish Government Health and Social Care Directorates Blue-Green Algae Working Group (2012)
Spain	cyanobacteria proliferation potential (Low)	German Federal Environment Agency (2012)c
Turkey	microcystin-LR: <25 µg/L equivalents or cells: <20,000 to 100,000 cells/mL	German Federal Environment Agency (2012)c
USA [d]	Microcystin 4 µg/L Cylindrospermopsin 8 µg/L	US EPA 2016
World Health Organization (WHO)	cyanobacteria: 20,000 cells/mL or chlorophyll a: 10 µg/L (approximately 2-4 µg microcystin/L, assuming cyanobacteria dominance)	Chorus and Bartram (1999); WHO (2003b)

a More details are provided in Appendix A.

b The lowest guideline values for each quantitative parameter (i.e. cyanobacterial cell density, biovolume, cyanotoxin concentration) are not associated with the same action level. For example, for Australia, the lowest cyanobacterial cell density and biovolume criteria trigger the green level surveillance mode, and the lowest cyanotoxin concentration triggered the red level action mode.

c Following the VIII[th] International Conference on Toxic Cyanobacteria, the German Federal Environmental Agency compiled and published in 2012 regulatory approaches to the assessment and management of cyanotoxin risks based on contributions by member countries.

d More details for each state found in US EPA, 2016.

Note: Additional info regarding this text in table to be found in the Appendix from USEPA (2016)

Recent research presented by Farrer et al. (2015) describes how the Oregon Health Authority in the USA developed tentative guideline values for four of the most common cyanotoxins found in the local water resources for 3 specific water users, namely, drinking water, human recreational exposure and dog recreational exposure. A tolerable daily intake (TDI) was calculated by applying uncertainty factors (UF) to a benchmark dose[3]. Once TDIs were established, exposure factors were applied to calculate guideline values applicable for the specific use, such as recreational use. The exposure factors considered were body weight (BW), oral intake rate (IR) and relative source contribution or proportion from exposure to water (P).

A Guideline Value is then calculated using the following equation:

$$GV = \frac{TDI \times BW \times P}{IR}$$

Two different critical studies were used by different organisations to develop TDIs or RfDs for microcystin-LR. The WHO used a study conducted by Fawell, *et al.,* 1999, resulting in a recommended *TDI of 0.04 µg/kg-day*. The second critical study was published by Heinze et al. and is very similar to the provisional acute value of 0.05 µg/kg-day, proposed by US EPA

[3] The benchmark dose was based on toxicity data the WHO used from mouse studies carried out by Fawell et al., 1999. The study identified a no-observed-adverse-effect-level of NOAEL of 40 µg/kg-day. WHO divided this NOAEL by a total uncertainty factor of 1000 to develop a TDI of 0.04 µg/kg-day.

For recreational water use a bodyweight (BW) of 20 kg was chosen to represent children 4 to 6 years old and a P value of 1, assuming 100% of an individual's cyanotoxin intake would be through water swallowed incidentally through recreational water use. Based on microcystin, with a TDI value of 0.05 µg/kg/d, a guideline value of 10 µg/ℓ was calculated for recreational water. If a lower TDI, equal to 0.04 ug/kg/d is used, the guideline value would be 8 ug/ℓ which is very close to 10 ug ℓ.

In the DSS of the Revised Recreational Water Quality Guidelines additional health effects / endpoints were used to calculate risks. More specifically, the RfD or TDI was used to calculate the ideal level where no adverse health effects would be expected as well as the concentrations where no adverse effects were seen in animal studies (the NOAEL) and the LOAEL where the lowest effects can be expected. (Table 4-13). These levels are 3 orders of magnitude higher and demonstrate that a concentration of double the ideal concentration will still be highly protective. Adverse effects would only be expected at 1000 times the ideal level of cyanotoxins.

Table 4-13: Health effects evidence used to develop guideline for cyanotoxin

Type & Severity of Adverse Health Effect	Concentration in water (ug/L) based on a child weighing 20 kg, ingesting 100 mL		
Irritant	1 000	10 mg/L	
Death – LD50*	20 000	10 mg/kg	=(10 g*1000(ug)*70 kg)*(50 mL/1000 mL)
LOAEL liver effects	10 000	50 ug/kg caused liver effects in animals	
NOAEL in mice	8 000	Based on 40 ug/kg NOAEL →(40 ug)(*20 kg)/(100/1000 L)	
Rec Guideline for children-50 mL	8	TDI of 0.04 ug/kg/d for a 20 kg child ingesting 100 mL	
	10	0.05 ug/kg	RfD
$\frac{(\frac{40ug}{kg}\times 20kg\times 1)}{0.1l}=$			

*Lethal dose in 50% of test animals = 50 mg/kg

Table 4-13 illustrates how data can be used for Tier II and Tier III assessments to be more site- and activity specific making use of similar data and equations. The WHO (2003) guidelines for safe practice for managing cyanobacterial exposure from recreational waters (Textbox 3) shows the WHO makes use of a variety of evidence including epidemiological studies, animal studies and human case histories but uses the number of cyanobacterial cells or chlorophyll concentrations to manage for health impacts of cyanotoxins. The WHO (2003) classified health effects from cyanobacteria into two classes: 1) mainly irritative symptoms caused by unknown cyanobacterial substances, and 2) potentially more severe hazard of exposure to high concentrations of known cyanotoxins, particularly microcystins. Based on this, they concluded that a single guideline value was not sufficient. Instead, they developed a series of three guideline values based on increased severity and probability of health effects. The WHO recreational guidelines were originally expressed as total cell concentrations (number of blue-green algal cells per volume) and extrapolated to the range of microcystin concentrations, assuming all cells are *Microcystis*.
There is low probability of adverse health effects: 2-4 µg/ℓ of microcystin to protect against irritative and allergenic effects. Recreational contact with microcystin at or below this concentration is unlikely to pose a health risk to an average person. However, individual sensitivities to allergens vary greatly making it difficult to determine 'safe' concentrations. A moderate probability of adverse health effects is expected at: 20 µg/ℓ of microcystin-LR based on protection against hepatotoxic effects due to accidental ingestion. It is based on the tolerable daily intake for an adult (60 kg) accidentally ingesting 100 mL of water while swimming.

Risk increases for children (due to lower body weight and greater likelihood of accidental ingestion) and to individuals with compromised liver function. A high probability of adverse health effects: Scums can represent thousand-fold concentrations of microcystin. Accidental ingestion of small volumes could cause serious harm. Immediate action to avoid contact with visible scums is advised.

Textbox 4: WHO Guideline for safe practice in managing recreational waters (WHO, 2003)

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).

4.4.10 Risk Management and Management Options

Risk management must take the current uncertainties of risk assessment into account. Currently, the information available on adverse health effects from various groups of eukaryotic algae and dinoflagellates in freshwater suggests that risk management should focus on health risks due to toxic cyanobacteria, while collection of case studies and information on health effects of algae in general should be intensified. Cyanobacteria are increasingly being included in bathing water monitoring programs, and in some cases so are their toxins. It is unclear whether all important cyanotoxins have been identified, and the health outcomes observed after recreational exposure – particularly irritation of the skin and mucous membranes – may be due to substances other than the toxins listed in Table 4-12. For this reason, monitoring of cyanobacterial cell density may be more relevant than monitoring selected cyanobacterial toxins. Further, approaches including the capacity of a water body to sustain major cyanobacterial populations have a greater predictive power. Several countries have derived guidelines regarding cyanobacteria and/ or their toxins in drinking and/or recreational waters. Short-term measures encompass warning of the public, closing of bathing sites, and cancelling water sports activities such as competitions. Medium- to long-term measures are identification of the sources of nutrient (usually phosphate) enrichment and significant reduction of nutrient input in order to effectively reduce proliferation not only of cyanobacteria, but of algae as well. Metabolites of algae have scarcely been studied for their effects on human health; however, allergic reactions have been reported to Chlorophyta (McElhenny et al., 1962; Mittal et al., 1979), and dermal irritation after exposure to a species of Raphidophyta, *Gonyosstomum semen,* led to closure of numerous bathing sites in Sweden (Cronberg et al., 1988).

Usually water used for recreational purposes is not treated for algal growth. Nuisance filamentous algal species can be removed by mechanical harvesting. In the past, copper sulphate and other algaecides have been used to control the growth of algae in open waters. Treatment with algaecides causes the cells to lyse which causes them to release the hazardous toxins to the water (DWAF, 1996). The toxins can then be mixed into the water column where they are rapidly diluted and probably degraded. This can reduce the risk of recreational contact with the toxins but makes them more difficult to remove if the water is to be treated for drinking purposes. Treatment of recreational waters with copper sulphate is not a recommended approach internationally. Instead the WHO (2003) and others (References) recommend a catchment approach to managing water sources and recreational sites. The WHO suggests short- and long-term measures to manage cyanobacteria in recreational water (Textbox 5).

The aim of measures to minimize risks due to toxic algae is not to close bathing sites, but rather the restoration of bathing water quality with transparencies of >2 m (Secchi disc reading) and absence of cyanobacterial blooms by measures that address the primary causes of the problem. In most water bodies this can be achieved by keeping total phosphorus concentrations below 0.01 mg/L P. Cyanobacterial densities rarely reach hazardous levels even in water bodies containing 0.02-0.03 mg/L total P.

Textbox 5: Table of surveillance for toxic cyanobacteria and phosphorous monitoring of WHO (2003)

1. *Monitor total phosphorus* at least twice a year, in subtropical and temperate climates at total overturn (e.g., in spring) and in summer during the main bathing season. If total phosphorus concentrations (not only soluble phosphorus or "*ortho*-phosphate") are below 0.01–0.02 mg/L P, mass developments of cyanobacteria are unlikely and high turbidities may have other causes. Use a method of sample digestion such as that of ISO/FDIS 6878 (ISO, 1988). At higher concentrations of total phosphorus, phytoplankton should be checked for mass developments of cyanobacteria (see steps 2 and 3).
2. *Monitor mass developments of phytoplankton (algae and cyanobacteria)* at fortnightly intervals. Perform visual inspection following scheme given in Table 5. For quantitative assessment, use chlorophyll-a concentration (ISO 10260; ISO, 1992) as a simple measure for algal (including cyanobacterial) density. If concentrations of chlorophyll-a remain below 0.01 mg/L hazardous densities of cyanobacteria are unlikely.

   At higher concentrations, microscopic investigations for dominance of cyanobacteria are required (see step 3).

   Inspect as much as possible of the catchment area for signs of sewage outlets, excessive fertilization close to the shoreline, erosion, or other potential sources of phosphate input.
3. *Monitor dominance of potentially toxic cyanobacteria:* If microscopic investigations show dominance of cyanobacteria and chlorophyll-a concentrations above 0.01 mg/L, immediate measures, such as posting warning signs or checking bathing beaches regularly for scum formation, must be taken, and long-term measures for restoration of bathing water quality should be planned.

   Monitoring of toxin concentrations is optional, but not necessary, unless health effects are reported.

It is recommended to include measurements of transparency (Secchi disk readings) in steps 2 and 3, because transparency data greatly enhance understanding of the system. Values of <2 m frequently indicate cyanobacterial or algal mass developments. Methods for steps 1–3 are given in Chorus and Bartram (1999).

4.4.11 Decision support and guideline development for South Africa

Globally, cyanobacterial blooms and their associated cyanotoxins are a public health concern and have been linked to adverse health impacts through recreational exposure (DWAF, 1996; Harding and Paxton, 2001; Chorus and Bartram, 1999; WHO, 2003; NHMRC, 2008; Canada, 2012).
Tier 1 of the guidelines is similar to the current South African Water Quality Guidelines for Recreational Use (Volume 2), 1996.

4.4.11.1 Tier I Guideline levels based on SA 1996 Guidelines:

The South African Recreational Water Quality Guidelines (1996) made provision for different levels of contact as well as for aesthetic or human health impacts associated with algae in water.

<u>Free floating algae and aesthetics (full and non-contact combined)</u>
Aesthetics: For free-floating algae, a mean annual concentration of less than 15 µg/ℓ chlorophyll-a, was set as the target water quality range at which no aesthetic impacts would be expected for full contact recreation,

and severe nuisance conditions would be encountered for <12% of the year, with no health effects. Nuisance conditions with likely occurrence of algal scums[4] were expected at mean annual concentrations between 15-30 µg/ℓ chlorophyll-a. At this concentration, the water is also likely to turn green with limited light penetration. Algal growth could impede the swimmer's visibility, obscure underwater hazards or create a danger of entanglement. Attached filamentous algae mats should therefore be absent from areas intended for contact recreation. At the higher range of the spectrum between 20 and 30 µg/ℓ chlorophyll-a, severe nuisance conditions due to algal blooms may occur together with oxygen depletion and possible fish kills. Additionally, unappealing mats of drying and rotting algae may cause severe odour problems. Mean annual chlorophyll-a concentrations exceeding 30 µg/ℓ is associated with aesthetically unacceptable surface algal scums present most of the time causing severe nuisance conditions for full contact recreation activities. At this concentration, rotting algae may cause severe odour problems and the composition or health of fish (depending on the species) may also be affected.

Blue-green algae (Cyanobacteria) and human health: A target water quality range was set between < 6 units[5] of blue green algae where no blue-green algal bloom or health effects are expected to occur. At sites with more than 6 blue-green algae units, significant numbers of blue-green algae are present and scum formation is likely. Recreational users should be vigilant and avoid contact with scums as human health effects are likely to occur as a result of accidental ingestion. Skin irritations are likely to occur as a result of contact with the scums. Notices warning users to avoid algal scums should be posted.

4.4.11.2 Tier II Guideline levels for South Africa

This tier allows altering exposure durations and activities to allow a site and activity specific assessment. Water quality managers can then apply this information to set ideal as well as tolerable, and unacceptable limits.

4.4.11.3 Tier III Guideline levels for South Africa

Tier III assessments allow for changing volumes of ingestion assumed to be associated with specific activities if more specific data and information are available to the water quality manager. These guidelines should not be suggested by the authors however enough evidence and supporting information has been provided for water quality managers to make a decision. Important to note is that site specific information (long term monitoring and observation data) is required together with a motivation to make changes to any of the assumptions used in the original dose and exposure calculations. For example, if empirical evidence suggests that 250 mL instead of 50 mL is what children are exposed to, then changes to this level could be made in the decision support tool and the risk can be calculated. Similarly, evidence might exist for South African specific data on weights of children at age and this could also then be used to make the data more country and site specific. If a site is continuously plagued by cyanobacterial blooms but have been found to only in 20% of the time contain toxic blooms, calculations could also be adjusted.

[4] An algal scum is described as “any visible accumulation of algae on the shoreline or the surface of the water”.
[5] This refers to the number of blue-green units (colonies and filaments) counted in a two-minute scan of 0.5 mL of water at x200 magnification.

4.5 SCHISTOSOMIASIS / BILHARZIA

4.5.1 Background

Schistosomiasis, better known as Bilharzia is a systemic helminth infection of humans and animals caused by the *Schistosoma* blood fluke (Magaisa et al., 2015) (Figure 4-8). It is the second most important tropical disease after malaria, in terms of public health impact (Fenwick et al., 2002). An estimated 4 million South Africans are infected with schistosomiasis (Mbabazi et al., 2011), with school aged children usually having the highest prevalence and intensity of infection (Saathof et al., 2004). The worms have a complex life cycle. The larval stages develop in freshwater snails (*Bulinus* sp., *Biomphalaria* sp. and *Oncomelania* sp., the last one being amphibic) which are the essential intermediate hosts for the larval development of trematode parasites of the genus *Schistosoma*.

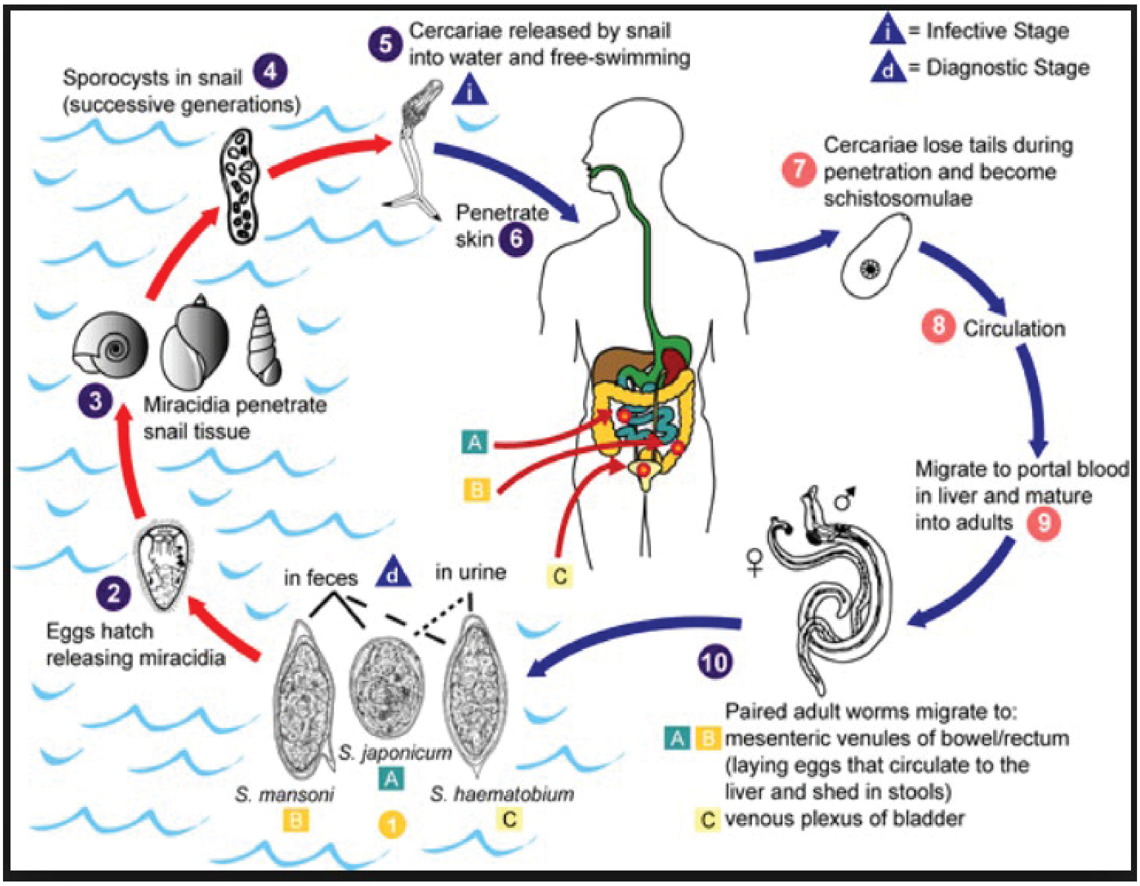


Figure 4-8: Life cycle of Schistosomiasis (Source: CDC, 2012)

4.5.2 Occurrence

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. The adult worms live in mammals. The adult worms lay eggs in the veins of several organs. These eggs are passed out in the excreta of infected persons or animals and hatch in water where the miracidia (lifecycle stage that infects the intermediate host) infect certain species of aquatic snails. The snails later discharge cercariae (lifecycle stage that infects the final mammalian host), which infect man and animals. Thus, an intermediate host is required and infection cannot pass directly from man to man or from snail to snail. Although water is not essential for all lifecycle stages, the absence of a suitable aquatic environment supporting intermediate host snails would make it impossible for the parasite to survive. Two forms of bilharzia occur in South Africa:

- bladder and urinary bilharzia of humans, characterised by blood in the urine, caused by the parasite *Schistosoma haematobium*, the larval stages of which develop in the aquatic snail *Bulinus africanus*;
- intestinal bilharzia in humans, characterised by diarrhoea with blood and mucus, caused by the parasite *Schistosoma mansoni*, the larval stages of which develop in the aquatic snail *Biomphalaria pfeifferi*. *Schistosoma mattheei*, the larval stages of which develop in the aquatic snail *Bulinus africanus*, causes intestinal bilharzia of sheep and goats and very rarely infects humans, and so rarely occurs in South Africa.

Only very rarely have cases of Schistosoma which infect animals (i.e. *S. mattheei, S. bovis* and others) been reported in humans. Bilharzia is a health risk only in the northern and eastern parts of South Africa represented in Figure 4-9 below.

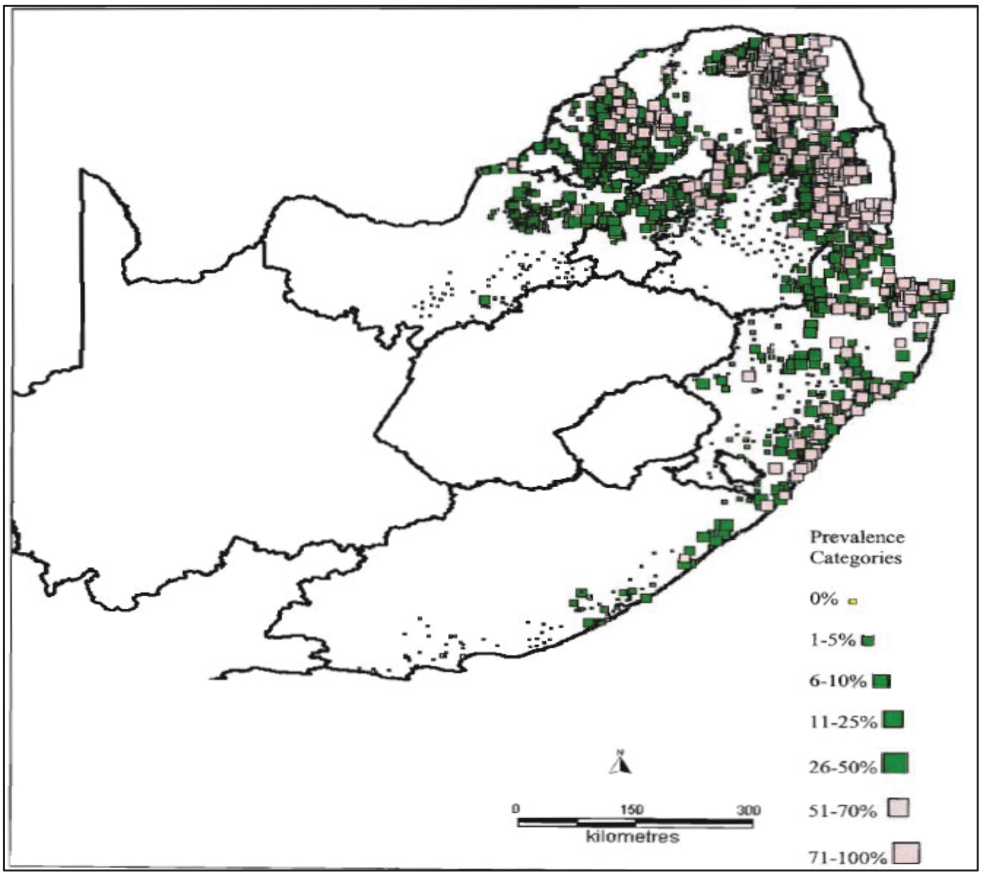


Figure 4-9: Map of Bilharzia hotspots in South Africa

The major constituents determining the survival and transmission of bilharzia parasites is the existence of a suitable environment for the snail host. This includes the availability of suitable reed beds along the shorelines of water bodies.

4.5.3 Measurement

Due to difficulties associated with the recovery of bilharzia parasites from large water bodies, routine monitoring of bilharzia parasites is not practical. However, routine monitoring of recreational water bodies for the presence of host snails can provide sufficient information to implement control measures.

4.5.4 Data Interpretation

Bilharzia or schistosomiasis is very rarely included in guidelines because of the impracticality of monitoring the lifecycle stages of the bilharzia parasite in water. For this reason, no numeric criteria for risk assessments are given and only control measures for the intermediate host snail are recommended.

4.5.5 Effects

The presence of bilharzia parasites in water bodies poses a health risk to recreational water users due to infection by *schistosome cercariae* entering the body through the skin during contact with contaminated water. Contact may occur during activities such as swimming, bathing, angling or paddling in water infested with snails which are shedding *cercariae*. 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. Infected humans suffer from a slowly developing chronic, debilitating and potentially lethal tropical disease. Typical symptoms include fever, anaemia and tissue damage (WHO, 2003). According to Kjetland et al. (2012), in the *S. haematobium* endemic areas, 33-75% of females have genital schistosomiasis. Female genital schistosomiasis involves schistosome eggs and or worms in the female genital organs. Large numbers of eggs penetrating the wall of the urinary tract may become sequestered in the bladder, cervix, vagina and fallopian tubes, resulting in chronic inflammation. Symptoms may include pelvic pain, postcoital bleeding, inter-menstrual bleeding, genital itch and abnormal vaginal discharge, easily mistaken for sexually transmitted diseases. Some females with this disease may experience increased frequency of urination and stress incontinence, fertility problems and abortions. Female genital schistosomiases have bene linked to increased susceptibility to HIV infection. In addition, women co-infected with HIV and *S. haematobium* infection may transmit HIV to their partners more easily (Johnson and Lewis, 2008). While complete cure is possible using the drug praziquantel (WHO, 2003), the generic treatment against schistosomiasis is not available in South Africa. The treatment option available is a schedule 4 drug requiring a prescription and treatment is very expensive (Magaisa et al., 2015).

Austrobilharzia and *Trichobilharzia* (Levesque et al., 2002; CDC, 2004a) are schistosome parasites of ducks and aquatic rodents, 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 (Manitoba Water Stewardship, 2007). 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).

4.5.6 Management options

No snails capable of acting as the intermediate host of the bilharzia parasite should be present in waters used for full or intermediate contact recreation (DWAF, 1996). Skin contact (swimming or wading) should be avoided in fresh water in areas 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 (WHO, 2003). A management strategy that combines 1) actions to control the extent of the water quality hazard and 2) steps to limit exposure during periods or in areas perceived to be of increased risk is recommended to reduce the risk of human exposure in recreational waters. Warning signs that clearly notify the public of the risk of exposure should be posted at recreational water areas where cases of swimmer's itch have been reported. Additionally, a swimming advisory may be issued at the discretion of the responsible authority. Further details on the posting of information at recreational water areas can be found in Part I (Management of Recreational Waters) (Health Canada, 2012).

4.5.7 Evidence and International Guideline Development

The schistosomes responsible for swimmer's itch are encountered in fresh waters and at coastal beaches throughout Canada and the northern United States (Health Canada, 2012). Reports of incidents appear to be increasing in the United States and Canada, possibly reflecting increasing use of recreational water bodies. Much of the information on swimmer's itch infection has come from case reports of human illness. For most recreational waters in Canada, the risk of contracting swimmer's itch through recreational activity is considered to be quite low. However, many cases go unreported, as the symptoms are typically benign and thus users may not seek out medical attention.

An outbreak investigation on cercarial dermatitis on the Lac Beauport recreational lake in the Quebec City region of Canada in 1999 by Levesque et al. (2002) found that 63 episodes reported were consistent with cercarial dermatitis and that the symptoms affected mainly children under 10 years of age. Swimming in the shallow water along the shoreline was associated with 69% of the cases. To prevent this for the next season, residents were asked to not feed the waterfowl, and snail populations were reduced by removing organic wastes found within the main snail habitat. Another study by Leighton et al. (2004) looked at case reports and the biological factors contributing to two outbreaks of dermatitis at Crescent Beach near Surrey, B.C. Thirty-six cases of dermatitis were reported in the summer of 2001, and 44 more cases were reported in the summer of 2002. The clinical presentation was consistent with schistosome dermatitis or swimmer's itch, caused by *Austrobilharzia variglandis*, carried by the introduced host snail, *Ilyanassa obsoleta*. Both the snail host and the schistosome species had been known to be present at this location for several years. Factors attributed to the sudden outbreak included increased beach use by recreational users, seasonal environmental factors (temperature, weather), the age of the snail population and the size of the host population (Health Canada, 2012).

A prospective epidemiological study to assess the incidence and severity of swimmer's itch among recreational water users at Douglas Lake, Michigan, in July 2000 was conducted by Verbrugge et al. (2004). A total of 301 subjects were included in the analysis and exposure data was collected on 1300 water exposure days. In total 89 episodes of swimmer's itch were recorded (corresponding to an incidence of 6.8% per water exposure day). A total of 52 people (17.3%) experienced swimmer's itch, with 58% of these having only one episode, 25% having two episodes and 17% having three or more episodes. Shallow water use was significantly associated with swimmer's itch. Risk was also shown to increase with the number of days of exposure reported.

CHAPTER 5: AESTHETIC ASPECTS

5.1 COLOUR, CLARITY AND TURBIDITY

5.1.1 Background

Water clarity provides a visual indication of the condition of water and refers to the depth to which sunlight can penetrate. It is affected by a number of physical, chemical and biological factors that are connected to the natural geology and human use of the surrounding catchment (USEPA, 2016). Iron deposits for example may impart a reddish colour to water while natural tannins (e.g. from fynbos, decaying plant material) in water may give it a tea-like appearance. Other factors affecting the clarity of water and the penetration of light included suspended microscopic algae and animals, detergents, foams, suspended mineral particles, etc. (WHO, 2003; NHMRC, 2008). The WHO (2003) describes two measures of colour: true and apparent. The true colour of natural water refers to the colour of filtered water where turbidity has been removed. Natural minerals give true colour to water (e.g. calcium carbonate in limestone causes a green colour). Apparent colour is an aesthetic quality and results from interplay of light on suspended particles, coloured particulates or reflection from the sky or bottom. Changes from the normal situation is used as indication of possible problems (WHO, 2003).

The lack of clarity is therefore frequently associated with turbidity. Some waters are naturally turbid. However, waters that receive excessive inputs of nutrients (such as fertilizer runoff) and sediments (for example, from construction runoff) are generally less clear and more turbid (US EPA, 2016). Possible health risks are associated with turbid water due to micro-organisms which may be associated with suspended particulate matter. Clarity, expressed as Secchi disk visibility / depth (Z_{SD}), may vary from as much as 20 m in very transparent waters, to as little as 0.002 m in very turbid waters. Clays, organic particles from decomposing plant and animal matter, fibrous particles and suspended soils and sediments constitute most of the particulate matter that contributes to high turbidity and low clarity. Further, sewage and other wastes may contribute significantly to reduced water clarity. Water clarity expressed as Secchi disk visibility is related to turbidity (see Measurement). Recreational waters in many dams in the interior of the country, particularly in the Orange Free State, have high turbidity in summer, for example as much as 2 000 NTU (Secchi disk visibility ca., 0.0025 m), with lower turbidity occurring in winter, for example 100 NTU (Secchi disk visibility ca., 0.05 m). The fine clay particles usually responsible for turbidity can remain in suspension for very long periods, unless a flocculent is added to the water (DWAF, 1996).

Ideally, recreational water should have high clarity (low turbidity and low colour). Water should be clear enough for recreational users to estimate the depth. Recreational sites should also be clear enough to identify subsurface hazards (e.g. rocks, broken glass) or submerged objects or people (other swimmers / divers) (WHO, 2003). Clarity is important from a physical safety perspective as well as being aesthetically pleasing (National Academy of Sciences, 1973).

Figure 5-1: Fynbos tannins in water on Table Mountain (Photo credit: Janna Schreiner)

5.1.2 Interactions

Lack of clarity is associated with water turbidity and with the possible presence of microbiological pollution.

5.1.3 Measurement

Clarity is measured as the Secchi disk visibility in metres. A standard Secchi disk, 0.25 m, with alternating black and white quadrants, is lowered into the water and the depth at which it just disappears, or reappears on raising, is measured. Water clarity as measured by the Secchi disk, is related to turbidity as follows:

Secchi depth (m) = 5.07/Turbidity (NTU).

The above relationship only applies to intermediate turbidity levels and not to very high or low turbidity. It is also affected by the nature of the suspended matter and is only applicable to typical clay particles. Some water bodies may be too shallow for an accurate description. For instance, if the water body is less than 2 m deep it is impossible to have a reading greater than 2 m. See Textbox 6.

Textbox 6: Clarity measurement

a) Is this water clear, or murky, or

55 NTU and opaque at 515 NTU

Sechi discs allows for personal perception and judgement.

b) At 5 NTU, water still appears clear. It is cloudy at

In most situations, a total suspended solids concentration below 20 mg/L appears clear, while levels over 40 mg/L may begin to appear cloudy (MDEQ, nd). In comparison, a turbidity reading below 5 NTU appears clear, while a reading of 55 NTU will start to look cloudy and a reading over 500 NTU will appear completely opaque (Perlman, 2014).

5.1.4 Data Interpretation

A fair amount of judgement is required in the interpretation of the criteria given. Discretion and good judgement for each individual case should be used to compare with the criteria. A change from the normal situation is used internationally as an indication to investigate or a possible problem.

5.1.5 Effects

Lack of clarity (presence of turbidity and/or colour) poses a danger for swimmers since potentially hazardous objects and evidence of shallow waters may be obscured. Diving accidents could happen which could leave people injured for life. Mennen (1981) found that diving injuries in South Africa often occur in water bodies known to the diver. In South Africa diving is responsible for 2.3% of all spinal injuries (Blanksby et al., 1997). In turbid waters, micro-organisms associated with particulate matter may pose a health risk. If water has a low turbidity, the occurrence of infectious microorganisms may be reduced, but cannot be excluded solely on the basis of clarity (DWAF, 1996).

5.1.6 International evidence and guideline development

Lee et al. (2015) in a recent study updated the Law of Contrast Reduction, a key concept in visibility theory, and this work developed and validated a new theoretical model to interpret Secchi disk depth. The new model is expected to significantly improve the capacity to monitor water transparency via satellite remote sensing globally. An ethnohydrology study by West et al. (2016) on optical water quality and human perceptions, suggested that human evaluation of water quality is guided by culturally constructed criteria and did not depend on expertise, experience or demographics. Visible attributes used in human judgement was directly related to measured physical and chemical water quality parameters.

Vesterinen et al., 2010 used hurdle models to analyse the association between water clarity in home municipality in Europe with national recreation inventory data for boating, swimming, and fishing. No impact was found on boating but an increase in clarity increased the frequency of close-to home use for swimming and fishing. In contrast to this, (Ziv et al., 2016) found water quality to be a poor predictor of recreational hotspots in England. Achieving the Water Framework Directive quality at recreational sites had no or in some cases negative correlation with recreational use, in particular fishing and swimming. In future cultural services and input from social scientists and the public will need to define metrics and targets to form a transdisciplinary framework for Europe. Water clarity is subjective measurement as it is determined by human observation (Wetzel, 2001). Since lack of clarity or turbidity can reduce visibility of reactional users in seeing underwater hazards (Osmond et al., 1995), it is important to determine guidelines for recreational water use to ensure safety of recreational users.

A 1992 study by Smith and Davies-Colley in New Zealand that consensus on suitability for bathing changed from “marginally suitable” above 1.1 m to “suitable” above 1.6 m black disk visibility. In terms of colour, yellow-hued water was not regarded aesthetically acceptable, while green-yellow waters were marginally acceptable and green-blue was suitable. The WHO (2003) does not provide a numerical guideline value for clarity or turbidity specifically for recreational use of water. Australia followed this approach and only specifies that the recreational water should be aesthetically acceptable to its users and that it should not have any objectionable odours, tastes, colour, etc. They further note that customer /public complains will be used as indication of the suitability of recreational sites. The Canadian guidelines for recreational water use (2012) stipulate a Secchi disk visibility of at least 1.2 m to allow users to see subsurface hazards and estimate depth and a turbidity of 50 NTU to satisfy most recreational uses. For people learning to swim they suggest that the bottom should be visible in case of drownings or people in distress. Diving in recreational areas depends on the height of the diving platform. The Canadian Recreational Guidelines further states that the colour of water should not negatively impact aesthetic enjoyment of recreational sites or impede visibility in swimming areas. For full body as well as incidental contact recreation, the USEPA suggests 50 NTU in streams and 25 NTU in lakes.

5.1.7 Management options

Management of recreational sites will therefore rely heavily on catchment management plans and long-term monitoring programs to provide background data over a number of years to detect any change. A hazard ranking system (similar to that used internationally) could compliment recreational use and safety at such sites.

5.1.8 Decision support and guideline development for South Africa

5.1.8.1 Tier I Guideline levels based on SA 1996 Guidelines:

The South African Water Quality Guidelines for Recreational Water Use (1996) will be applied for the Tier I guideline level. A Secchi disk visibility of more than 3 m would remain the ideal situation where no human health impacts are expected to occur and sites are suitable for all recreational activities. Clarity levels between 1.5 m and 3 m are deemed acceptable. At this level most users will still find recreational site aesthetically pleasing and water suitable for swimming. Risk of disease transmission is very low but cannot be excluded based on clarity alone. Clarity levels between 1 m and 1.5 m is the minimum depth of visibility suitable for swimming. No effects on aesthetic acceptability for recreation expected at this level and the risk for disease transmission remain low. Visibility of less than 1 m is not suitable for swimming and some problems with aesthetic quality and enjoyment of the water might be noted. Swimming can still be allowed at this level if subsurface hazardous objects are removed and signs indicating the water depth are clearly posted (e.g. to warn against risk of diving, etc.). There might be a slight increase in disease transmission associated with particulate matter at this level but does not depend on clarity alone.

Note:
Conversion of clarity to turbidity data for the above criteria gives a range of 1.84-5.07 NTU for Secchi disc depths of 2.75-1.2 m respectively. This range for turbidity measures is far below the range commonly found in South African water bodies and is also at the lower limit of sensitivity for turbidity measurements. The turbidity of the water should not increase by more than 5 NTU above natural background turbidity when that turbidity is less than 50 NTU.

5.2 FLOATING MATTER AND REFUSE

5.2.1 Background

The aesthetic appreciation and psychological enjoyment of recreational water is adversely impacted by the presence of floating and shoreline litter and other floating matter of human and natural origin (DWAF, 1996). If associated with flying or biting insects such accumulations may also be a nuisance. Submerged refuse can be a danger to recreational water users. Human activities frequently result in the presence of floating matter and refuse in the aquatic environment. A large variety of litter has been found at recreational sites (NHMRC, 2008), including:

- drift wood, debris, including wooden crates;
- cardboard cartons and newspaper;
- steel drums;
- plastic containers and foam products;
- rubber goods, such as vehicle tyres;
- bottles and bottle tops, cans;
- dead animals or animal bones;
- human hair;
- discarded clothing;
- hypodermic syringes, needles and other medical wastes;
- cigarette butts and packets, matchsticks;
- fish netting, fishing line and rope ends.

Solid refuse will persist for a long time and accumulate if not removed. Most plastics and rubbers disintegrate and biodegrade very slowly if at all; some types of cans (modern aluminium beverage cans) corrode very slowly, while glass persists. Natural processes can also contribute to this phenomenon. Floating algae and aquatic plants, although not strictly identifiable as floating refuse, can also be considered undesirable. Dead vegetation (terrestrial or aquatic) in an advanced state of decomposition in water, releases fatty and oily by-products which produce an oily sheen on the water and often results in objectionable odours.

5.2.2 Measurement

No numerical value can be determined for litter at recreational sites. The presence, amount and type of floating matter and refuse is determined qualitatively and no empirical methods of measurement exist. A sanitary survey can determine the extent of the aesthetic impact and inform management if further steps are needed to improve the situation.

5.2.3 Data Interpretation

Only qualitative criteria are given and interpretation thereof should involve discretion and good judgement. Long term monitoring should inform management of problem sites and sanitary surveys will assist with management of negatively impacted sites.

5.2.4 The Effects of Floating Matter and Refuse

The presence of floating matter and refuse affects the aesthetic appeal of all forms of recreational water use. Submerged refuse such as broken glass bottles may pose a safety risk and decomposing refuse may provide a suitable habitat for vectors of disease. Water should be free of floating or submerged debris which may injure, entangle or obstruct water users. Shorelines should be free of litter. Recreational water should also be free of wastewater or other discharges and substances which could cause an adverse visual impact or affect aquatic life forms. This includes oil, scum, foam and substances which can settle out to form objectionable deposits. Oil and petrochemicals should not be present in concentrations which form a visible film on, or discolouration of, the water surface, which can be detected.

5.2.5 International Evidence and Guideline Development

Internationally, aesthetic quality of recreational sites is viewed similarly. The aesthetic enjoyment of recreational sites is important and should be managed. Recreational sites should be free from objectionable floating matter, debris and litter. Besides the aesthetic impacts, submerged objects or litter such as broken glass could injure recreational users. Physical injury and aesthetic impacts at recreational sites could also have economic impacts.

5.2.6 Management options

Aesthetic aspects are important in terms of maximizing the benefit of recreational water use. Philipp (1993) listed the following questions frequently raised for consideration by local managers:

- *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?*

NHMRC (2008) suggest the use of litter counts as a proxy indicator for the likelihood of gastrointestinal effects associated with swimming. Findings from University of Surrey (1987) suggested self-reporting of gastrointestinal effects in swimmers associated with public perception of different items affecting the aesthetic appearance of recreational water. Testing the validity and reliability of such litter counts as measures of health protection is therefore needed (Phillip et al., 1997).

5.2.7 Decision support and guideline development for South Africa

No numerical guideline can be determined. Recreational sites should be managed to be aesthetically pleasing for the enjoyment of all recreational activities.

5.3 OIL, GREASE, AND DETERGENTS

5.3.1 Background

*Oil and grease are defined as: "*any material recovered as a substance soluble in the solvent" (APHA *et a*l., 2005). Oil and grease form a complex mixture of substances which may be of mineral, animal, vegetable or synthetic origin and may be of natural origin (e.g. decomposition of vegetative materials) or result from human activities (e.g. industrial waste discharge, motorboat and jet ski's engine exhaust emissions, discharge of fuel tank contents of boats). Since these mixtures can differ vastly in terms of their physical, chemical and toxicological properties, it is difficult to establish guidelines or criteria for oil and grease (WHO, 2003; Canada, 2012).

5.3.2 International Evidence and Guideline Development

Environment Canada (1981) reported that even very small quantities of oily substances make water aesthetically unattractive. While some oils can form films on the water surface, some of the oil-derivatives (e.g. xylene, ethylbenzene) are volatile and can result in odours or tastes even though they are of low toxicity. Tar may also present a problem on the shore and will require mechanical removal from the sand (WHO, 2003). Boat launches can also be important sources of oil and grease contamination for recreational waters (Canada, 2012). In addition, foaming resulting from detergents may also give rise to aesthetic problems. Foam from detergents could be confused with the by-products from algal growth (WHO, 2003). In some countries (e.g. Canada), it has been reasoned that no numerical value can be determined for oils, grease and detergents. The Canadian Guidelines for recreational water use (2012) further state that oil, grease or petrochemicals should not be present in concentrations that:

- can be detected as a visible film, sheen or discoloration on the surface;
- can be detected by odour; or
- can form deposits on shorelines and bottom sediments that are detectable by sight or odour (International Joint Commission, 1987).

Recreational exposure to oily substances through ingestion, skin absorption or inhalation of vapours is regarded to be of low toxicity. Oils and grease from natural origin (e.g. animal and vegetative origin) are considered non-toxic to recreational users. Train (1979) cited in the Canadian Guidelines for Recreational water use (2012) reported that oil-polluted water is not likely to be a significant source of exposure to humans as petroleum products are organoleptically objectionable at levels far lower than the chronic human toxicity levels.

5.3.3 Management Options

Catchment management plans should specify the necessary long-term monitoring and specify the requirements and frequency for sanitary inspections. Decisions will be based on site specific investigations.

5.3.4 Decision Support and Guideline development for South Africa

No guideline value can be determined for oil, grease and detergents in recreational water. Sanitary surveys and site inspections will inform decision making.

5.4 ODOUR

5.4.1 Background

When mixtures of light and small molecules come into contact with the human sensory system it stimulates an anatomical response known as odour (Brattoli et al., 2011). Frechen in 1994 described odour perception to start as a physiological reception followed by a psychological interpretation, with the end-result being a mental impression of the odour. Odours arise from the sensory nature of smell. Olfaction is one of the oldest senses which, since the time of evolution, has been used for seeking food, recognizing danger or communication. It is also a protection mechanism as sense of smell allows people to detect potential illnesses or infections by registering or identifying the odour as pleasant or unpleasant (Brittoli et al., 2011). People differ in their sensitivity to physiological reception of odours. This sensitivity declines with age (Bliss et al., 1996; Cain et al., 1995; Fortier et al., 1991; Griep et al., 1995, 1997; Patterson et al., 1993). Similarly, sensitivity is worse in people who smoke or have poor health or dental state (Fortier et al., 1991; Griep et al., 1995, 1997). No statistically significant differences were found for odour sensitivity between males and females (Bliss et al., 1996; Cain et al., 1995; Fortier et al., 1991; Griep et al., 1995). Prior exposure can also affect sensitivity to an odour. While continuous exposure to an odour can cause a loss in sensitivity to the odour (known as adaptation or olfactory fatigue) (Dravnieks and Jarke, 1980), Laska and Hudson (1991) found that repeated (not continuous) exposure to an odour can increase case sensitivity.

Gostelow et al. (2001) reported that psychological interpretation of odours leads to judgements about how strong an odour is, whether it is pleasant or unpleasant, and also an impression of what the odour may be associated with. Usually an unpleasant odour is associated with unpleasant things. Unpleasant odours are perceived as a warning signal to avoid their source. The odours emanating from a sewage treatment works for example are generally associated with biological decay of organic material. Although the odours themselves may not be toxic, their association with decaying material indicates something that is best avoided as the decaying material itself can represent a health risk. In a recent study Kaeppler and Mueller (2013) tried to decode the psychological dimensions of human odour by reviewing perception-based classification studies. The mutual effects of odour characteristics are summarised in Figure 5-2.

Recreational water users can be deterred by unpleasant or bad smells. Generally, offensive odours occur as a result of biological or industrial processes. Objectionable smells can arise from sewage effluent, decaying organic matter such as vegetation, dead animals or fish. Discharged diesel oil, petrol or other industrial effluents containing substances such as phenolic compounds and other volatile organic pollutants, and/or microbial action that releases hydrogen sulphide could also result in unpleasant odours affecting aesthetic appreciation of recreational sites (DWAF, 1996; WHO, 2003; NHMRC, 2008).

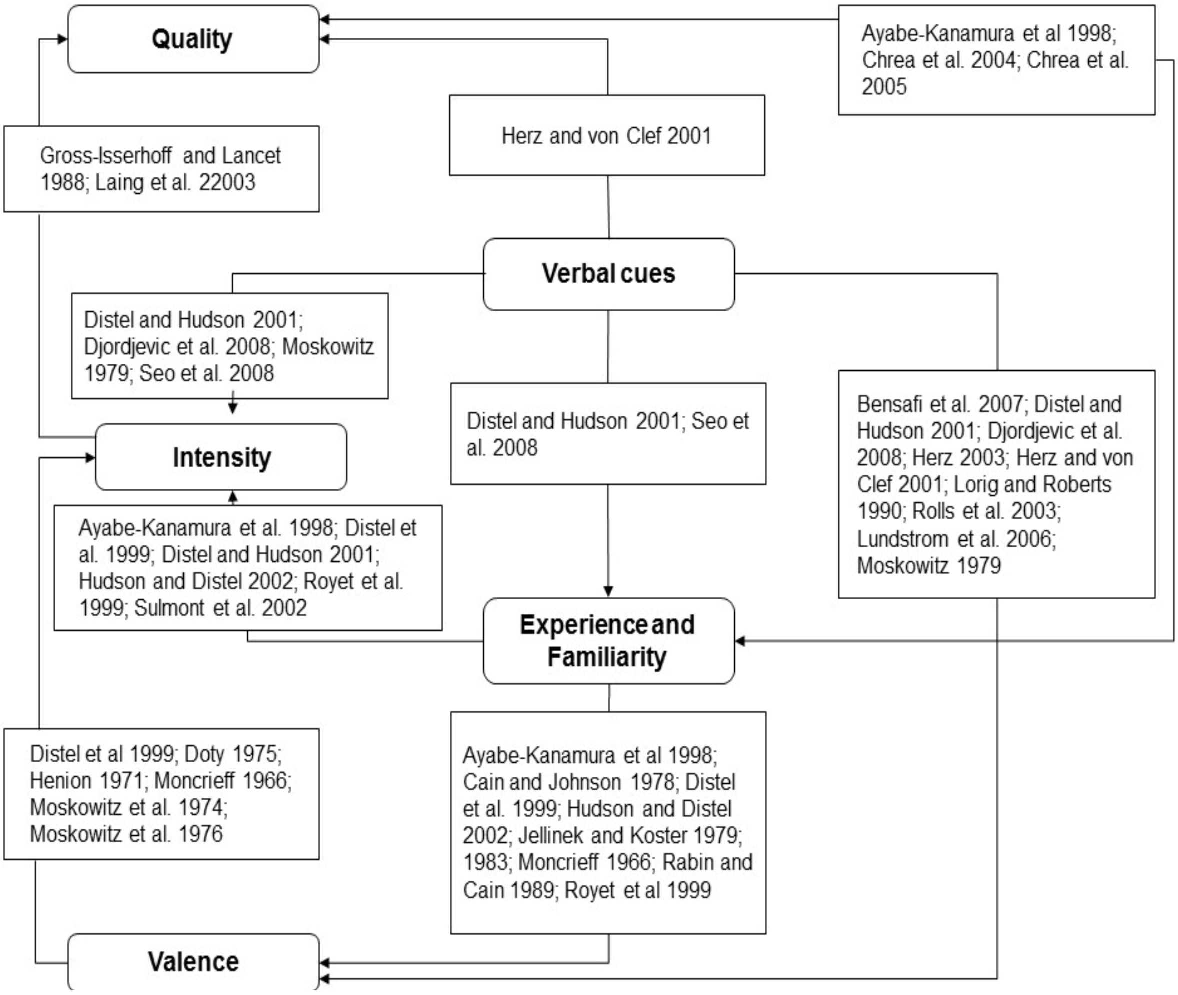


Figure 5-2: Research on mutual effects of odour characteristics. Arrows indicate the direction of relations assessed.

Odours of natural origin tend to be described as earthy, musty or sour, on one hand, or fishy, grassy or cucumber-like, on the other. Industrially derived odours tend to smell like iodine, petroleum, medicine, varnish or creosote, for example. Some of the odours of natural origin may be indirectly due to human activities; for example, the dumping of raw sewage into the aquatic environment enhances biological growth and consequently odours. Although the actual cause of an unpleasant odour can be identified occasionally, in most cases the specific agent is unknown. The nature of the pollution manifested by an odour problem will differ from water source to water source. Changes in conditions such as wind, runoff, temperature, storm conditions and flow rate also influence the processes that lead to odour production. Odour problems are therefore best dealt with on a case-by-case basis (Canada, 1995).

5.4.2 Interactions

Odour can be linked to a wide range of factors and can indicate varied instances of pollution or imbalances in natural ecosystems. These include the presence of excess algae or aquatic plants, excess nutrients, low dissolved oxygen, extremes of pH or temperature, discharges of sewage or other wastes, chemical discharges and refuse (DWAF, 1996). Dissolved oxygen (DO) levels of the water body is important as it can help to prevent the formation of undesirable amounts of odorous hydrogen sulphide (WHO, 2003; NHMRC, 2008). Canada (1995) highlighted some of the interactions causing odour (in drinking water) which may to some degree also be applicable to recreational waters.

5.4.2.1 Physical Characteristics

The physical characteristics temperature and pH plays an important role in odour formation in water. The vapour pressure and therefore the odour intensity of any odour causing substance are directly related to the water temperature. Standard Methods (APHA, 1976) suggests that any threshold odour number (TON; see section on *Measurement*) should be reported at 60°C for TON measurements, except in cases where very volatile substances are rapidly lost from solution at this temperature, in which case 40°C is recommended. Odour-causing substances that are the products of specific chemical processes, such as the chlorophenols, will also be produced at faster rates at higher water temperatures. Similarly, pH of the water can be related to odour formation under circumstances in which it controls the equilibrium distribution between the neutral and ionic forms of a substance that gives rise to an odour in its neutral form. For example, the chlorinous odour of hypochlorous acid would be expected to be more pronounced at low pH levels, where it is favoured over the odourless hypochlorite ion (Canada, 1995).

5.4.2.2 Microbiological Characteristics

The presence of coliform organism and related pathogens had no direct relationship with odour in drinking water. Odour in drinking water is attributable to the presence of a wide range of so-called nuisance organisms in water. During a taste and odour survey the United States and Canada (1976) at least 50 of these were identified. Canada (1995) reported that the very intense odours of substances produced by actinomycetes (and by at least some algae) can be a major source of odour contamination in public water supplies.

5.4.2.3 Chemical Characteristics

Some chemical parameters that are of concern because of their toxicity, may also cause odour problems (e.g. cyanide). The threshold odour concentration for hydrogen cyanide in water has been reported to be 0.001 mg/L. Thus, a limit for cyanide in drinking water based on odour considerations would be one-half the current objective limit, 0.002 mg/L, and one two hundredth the recommended maximum acceptable concentration, 0.2 mg/L. This is an example in which the sense of smell is more sensitive than the best available analytical instrumentation. Sigworth (1965) cited in Canada (1995) reported threshold odour concentrations of common pesticides. These generally fall in the range of thousandths to a few tenths of a milligram per litre. Besides chlordane, the odours of most pesticides are too weak to allow their detection at or below their maximum acceptable concentrations. Very low phenol concentrations are known for the production of intense taste and odour in water. The threshold odour concentrations of the most odorous chlorination products of phenol are approximately one five hundredth of that of phenol (Butchel et al., 1959 cited in Canada, 1995). Therefore, in order to guarantee freedom from chlorophenolic odours and flavours, it is necessary to maintain phenol at or below one five-hundredth of its threshold odour concentration of approximately 1 mg/L. With special phenol levels much higher than 0.002 mg/L can be tolerated (Canada, 1995).

5.4.3 Measurement

Odour in recreational water is usually assessed qualitatively. A quantitative measurement of odour is generally not necessary, as is the case with water used for domestic purposes. Odour in water is usually measured in terms of its threshold odour number (TON), the number of times a sample must be diluted with an equal volume of odour free water to become just detectable by 50% of a panel of judges under very carefully controlled test conditions (APHA, 1976). Undiluted samples of water that have no detectable odour should be reported as "odourless." A TON of One (1) therefore indicates that the water sample has a detectable odour. As exceptionally small concentrations of some substances in water can cause very intense odours that result in very large TON values. An alternative measurement known as the odour intensity index (OII), has been employed on occasion. The OII represents the number of times the volume of a sample must be doubled with odour-free water before it is just detectable by 50% of a panel of judges (Canada, 1995).

5.4.4 Data Interpretation

The criteria for water odour are qualitative and should be interpreted with good judgement and discretion. Generally, pathogens and toxic substances that pose chronic health threats are odourless.

5.4.5 Treatment Options

Recreational water bodies are usually not treated directly for odours and the quality of the inflow and receiving water should be monitored and regulated to avoid odour-associated problems. (DWAF, 1996).

5.4.6 Effects

The effects of undesirable or bad odours can be acute (e.g. due to a sudden occurrence or accident) or chronic (e.g. if the conditions producing them lasts for a long period of time). Bad odours can be eliminated or ameliorated by locating and identifying the source and implementing measures to treat the offending condition or chemical substances responsible for emitting the odour. Sanitary surveys should therefore include investigations for possible or existing sources of odour, and attempts should always be made to identify the source of an odour problem. In general, however, pathogens and toxic substances that pose chronic health threats are odourless.

5.4.7 Evidence and International Guideline Development

Several hundred odour-causing compounds have been reported in water. Odour thresholds or the associated concentration of the different pollutants in recreational waters have not been determined. The US EPA recommends a TON of 3 as their secondary maximum contaminant level (SMCL) for drinking water contaminants that have an undesirable effect on aesthetics, cosmetics (i.e. no harmful effects on the body) equipment or treatment efficacy (Watson et al., 2008). Young et al. (1996) reported odour threshold concentrations for 59 potential drinking water contaminants, including pesticides, phenol, chlorinated phenolic compounds and anisoles, geosmin, 2-methyl-isoborneol and aluminium sulphate. Table 21 summarises the lowest concentration at which an odour was detected together with the geometric mean odour threshold concentration for these contaminants. Figure 5-3 and Tables 5-1 and 5-2 summarise the odour descriptions most frequently used.

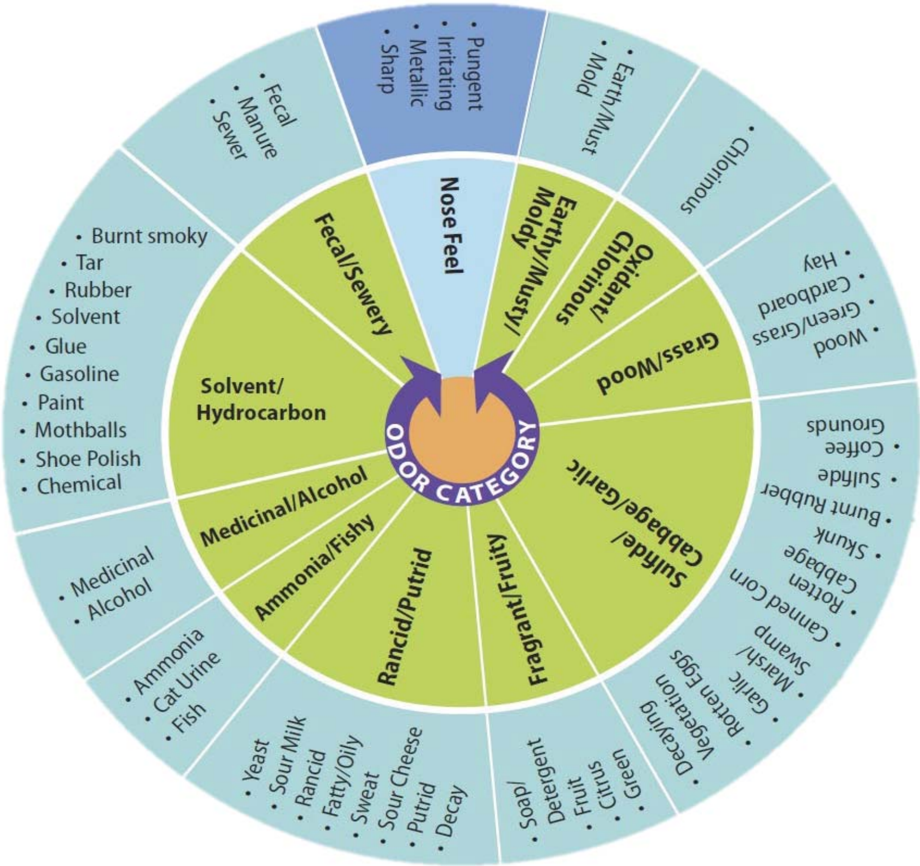


Figure 5-3: Odour Wheel (Source: Su-et et al., 2004)

Table 5-1: Odour Threshold concentrations

Chemical	Geometric mean odour threshold concentration (ug/L)	Lowest concentration at which an odour was detected (ug/L)
Pesticides		
Atrazine	N.D.	9200
Bromoxynil	N.D	> 11000
Carbaryl	280	37
Chlorfenvinphos	340	240
Chlormeqnat dichloride	N.D.	> 8700
Chlortoluron	N.D.	> 9000
Dalapon-NA	N.D.	> 11000
Diazinon	170	40
Dichlobenil	200	40
Dichlorprop	N.D.	> 9100
Diquat dibromide	N.D.	> 8900
Diuron	N.D.	> 8000
Isoproturon	N.D.	> 8000
Linuron	N.D.	> 9700
Maleic hydrazide	N.D.	> 9900
MCPA	-	460
MCPB	N.D.	> 10000

Mecoprop	N.D.	> 8100
Paraquat dichloride	N.D.	> 8600
Pirimicarb	N.D.	> 1100
Propyzamide	3000	700
Phenolic and anisole compounds		
4-Chloroanisole	20	< 2.0
4-Chloro-2-methylphenol	200	62
4-Chloro-3-met hylphenol	5.0	2.5
2-Chloro-4-methylphenol	0.30	0.15
2-Chlorophenol	0.36	0.088
4-Chlorophenol	20	10
2,4-Dichloroanisole	0.5	0.21
2,4-Dichlorophenol	29	5.4
2,6-Dichlorophenol	22	5.9
Pentachlorophenol	23	9.3
Phenol	31	9.5
2,4,6-Trichloroanisole	0.0009	0.00008
2,4,5-Trichlorophenol	350	63
2,4,6-Trichlorophenol	-	380
Naturally occurring organic compounds		
Geosmin	0.0038	0.0013
2-Isobutyl-3-methoxypyrazine	0.001	<0.00005
2-Isoprupyl-3-methoxypyrazine	0.0002	<0.00003
2-Methyl-isoborneol	0.015	0.0063
Other organic compounds		
Benzene	-	190
Chlorobenzene	-	190
Chloroform	30 000	7500
2-Chlorotoluene	-	980
3-Chlorotoluene	500	150
4-Chlorotoluene	150	60
1,2-Dichlorobenzene	-	200
1,3-Dichlorobenzene	170	77
1,4-Dichlorobenzene	18	4.5
Ethylbenzene	550	150
HHCB	5	1.4
Isopropylbenzene	70	10
4-Isopropyltoluene	400	25
Methyl tert-butyl ether	34	15
Naphthalene	6	2.5
Styrene	65	37
Toluene	-	960
1,1, l-Trichloroethane	20 000	3200

Table 5-2: Odour descriptors most frequently used

Chemical	**Odour descriptor**
Pesticides	
Atrazine	Plastic, polythene, weak bleach
Carbaryl	Disinfectant, glue, hospital, plasters
Chlorphenvinphos	Insecticide, fertiliser, antiseptic
Diazinon	Earthy, musty, potato, cabbage water
Dichlobenil	Plastic, cardboard
MCPA	Antiseptic
Maleic hydrazide	-
Isoproturon	-
Propyzamide	Dusty, sooty, cardboard
Phenolic and anisole compounds	
4-Chloroanisole	Musty, medicinal, perfume, musky, wet paper
4-Chloro-2-methylphenol	Chemical,TCP, medicinal, acetone
4-Chloro-3-methylphenol	Musty, stale, wet paper, woody, damp
2-Chloro-4-methylphenol	Antiseptic, TCP, plasters
Chlorophenol	Musty, sweet, floral, chemical, TCP
2,4-Dichloroanisole	Musty, stale, chemical, roses
2,4-Dichlorophenol	Musty, antiseptic, medicinal, TCP
2,6-Dichlorophenol	Musty, antiseptic, medicinal, TCP, metallic
Phenol	Wet paper, wet newspaper, cardboard
2,4,6-Trichloroanisole	Dusty, musty, earthy, rotten vegetable
Naturally occurring organic compounds	
Geosmin	Musty, earthy, stagnant, grassy, beetroot, mould
2-Isobutyl-3-methoxypyrazine	Woody, stale, musty, coal-dust, ash
2-Isopropyl-3-met hoxypyrazine	Sooty, dusty, cabbage, wet paper
2-Methylisoborneol	Musty, earthy, brazil nuts, peaty
Other organic' compound~	
Benzene	TCP, musty, phenolic
Chlorobenzene	Medicinal, chemical, musty
Chloroform	Chemical, antiseptic, acetone, estery
2-Chlorotoluene	Nail varnish
3-Chlorotoluene	Disinfectant, TCP, antiseptic
4-Chlorotoluene	Marzipan, almond
1,2-Diehlorobenzene	Grassy, vegetable water
1,3-Dichlorobenzene	Medicinal, disinfectant, musty
1,4-Dichlorobenzene	Almond, sweet, marzipan, antiseptic
Etbylbenzene	Musty, plastic, resin, oily, chemical, styrene, stale
HHCB	Perfume, floral, soapy, musk, sweet
Isopropylbenzene	Windolene, polish, paint, pear drops
4-Isopropyltoluene	Rubber gloves, paraffin, sweet, TCP
Methyl tert-butyl ether	Estery, vanilla, sweet
Naphthalene	Mothballs,
Styrene	Rubber, paint, sulphurous
Toluene	Paint, chemical, weak petrol
I,I,I-Trichloroethane	Dusty, sooty, polish
Inorganic compounds	
Aluminium sulphate	-

5.4.8 Management options

Odours associated with recreational water detract from aesthetic appreciation of water bodies and are perceived by potential users to indicate the presence of pollutants as demonstrated in case studies conducted at Hartbeespoort Dam (Pretoria) and Zandvlei (Cape Town). Complaints concerning the odour of a water body are often useful in evaluating suitability for recreational use (DWAF, 1996). Odour thresholds and their association with concentrations of different pollutants in the recreational water environment have not been determined (WHO, 2003; NHMRC, 2008).

5.5 NOISE

5.5.1 Background

The tranquillity of the recreational user can be disturbed by noise resulting from the following sources: traffic on nearby roads, trade hawkers, beach buggies, motorbikes, portable radios and hi-fi equipment, motorboats and jet-skis. Some people may enjoy noisy activities. WHO (1980) cited in WHO (2003) suggested that authorities could zone areas for different activities but that people need to be mindful of the need for mutual respect.

CHAPTER 6: PHYSICAL ASPECTS

6.1 pH

6.1.1 Background

The pH of a substance is measured on a scale of 0 to 14, with 0 being the most acidic and 14 being the most alkaline. The pH of pure water is 7 and therefore neutral. The pH of water has a direct impact on the recreational users at very low or very high values. Figure 6-1 shows the pH of substances and the pH range best tolerated by aquatic animals and humans. The pH of natural waters is a measure of the acid-base equilibrium of various dissolved compounds and is a result of the carbon dioxide-bicarbonate-carbonate equilibrium which involves various constituent equilibria, all of which are affected by temperature. Conditions which favour production of hydrogen ions result in a lowering of pH, referred to as an acidification process. Alternatively, conditions which favour neutralisation of hydrogen ions result in an increase in pH, referred to as an alkalinisation process. It should be noted that the pH of water does not indicate the ability to neutralise additions of acids or bases without appreciable change. This characteristic, termed buffering capacity, is controlled by the amounts of acidity and alkalinity present. The pH of a water does not have direct health consequences except at extremes. Rather, the effects of pH arise as a result of the solubilisation of toxic heavy metals and the protonation or deprotonation of other ions.

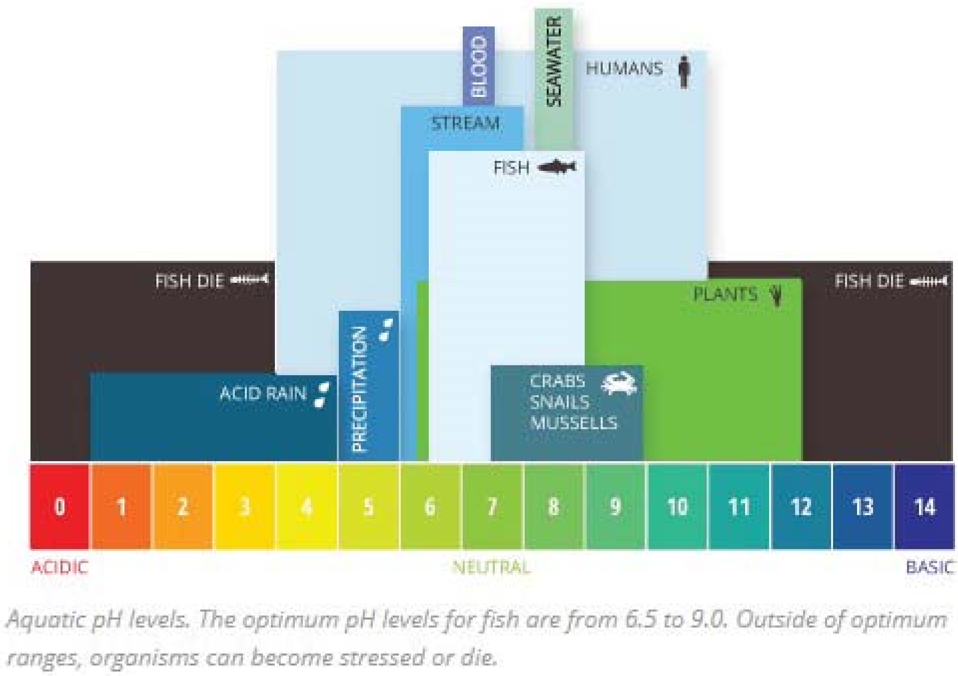


Figure 6-1: pH levels and effects

There are many factors that can affect pH in water, both natural and man-made. Most natural changes occur due to interactions with surrounding rock (particularly carbonate forms) and other materials. The geology and geochemistry of the rocks and soils of a catchment area affect the pH and alkalinity of the aquatic system. The pH of most raw waters lies in the range of 6.5-9.5. Biological and anthropogenic activities such as nutrient cycling and industrial effluent discharge respectively, can give rise to pH fluctuations. Acid mine drainage, in particular, can have a marked effect on the pH. Further, acid-forming substances released into the atmosphere such as oxides of sulphur and nitrogen, may ultimately alter the acid-base equilibria in natural waters and result in a reduced acid-neutralising capacity and hence a lower pH (DWAF, 1996; EPA, 2012).

6.1.2 Interactions

The pH of natural waters is influenced by various factors and processes, including temperature, discharge of effluents, algal growth, acid mine drainage, acidic precipitation, runoff, microbial activity and decay processes. The alkalinity of water also plays an important role in daily pH levels. During photosynthesis, algae and plants use hydrogen, thereby increasing water pH levels. Similarly, lower pH levels will result from decomposition and respiration. Small localized pH fluctuations are often quickly modified and not easily detected, as most water bodies are able to buffer these changes due to their alkalinity (WSDE, 1991). 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 (WHO, 2003).

6.1.3 Measurement

Water pH is usually measured electrometrically using a pH meter. The pH meter should be calibrated against standard buffer solutions of known pH, prior to measurement of a sample. Fresh samples should be used to determine pH. The temperature at which measurements are made should always be reported, since pH measurement is influenced by temperature. Errors may be caused by the presence of sodium at pH values higher than 10. The pH should be interpreted in relation to the full analysis of the water sample and its use. Mean or single-sample maximal values may be used depending on the application.

6.1.4 Treatment Options

Recreational water bodies are not treated for pH. The water quality should be monitored and regulated to avoid excessively high or low pH.

6.1.5 Effects

The norm used in the guideline for pH is human health. Water pH values outside a fairly narrow range of circum-neutral pH cause irritation of eyes, skin, ears and mucous membranes of the nose, mouth and throat of swimmers and other contact recreational water users. When the water is on the acid range of the pH scale, (lower than 7.0), you might feel the difference in the water as you swim. This low pH can cause skin irritation and make your eyes burn. The lachrymal fluid (tears) of the eye has a normal pH of close to 7.4, which is maintained within a narrow range by physiological buffering agents. A pH change of as little as 0.1 in the lachrymal fluid can cause irritation, and greater change can cause severe discomfort and pain. Ideally, water used for contact recreation should be as close to pH 7.4 as possible. Discomfort of the eyes and other susceptible parts of the body is not permanent and usually disappears rapidly if contact is discontinued. The WHO (2003) mentions the 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 meq/litre; Red Chalk Lake:

pH ~6.5, acid neutralizing capacity 70 meq/litre) to cause eye irritation in rabbits and human volunteers. No adverse effects were noted.

High pH appears to be more linked to skin, 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 (WHO, 2003). A high-water pH may cause hair fibres to swell and by cleaving the cystine bridges between the adjacent polypeptide chains of the hair protein, may adversely affect hair condition. The impact however depends on the buffering capacity of the water (WHO, 2003).

6.1.6 Mitigation

Eye irritation can be alleviated using over the counter or prescription eye-drops. In most cases taking a shower in clean water is sufficient to alleviate the irritation to other body parts.

6.1.7 Evidence and international guideline development

Potts (1991) reports that "as the pH of buffered solutions applied to the human eye is decreased from 7.4, the onset of discomfort begins at about pH 4.5. Between pH 4.5 and 3.5, one creates punctate breaks in the corneal epithelium that are stainable with fluorescein but heal in a few hours' time." Thus, to avoid the potential for ocular irritant effects and reversible damage it is recommended that water with a pH below 4.5 not be used. Dermal irritation is the production of reversible damage of the skin, whereas dermal corrosion is the production of irreversible damage of the skin. Dermal effects are associated with pH extremes like < 2 and > 11.5, especially when buffering capacity is known, although the correlation is not perfect. Generally, such agents are expected to produce significant effects on the skin. While humans have a higher tolerance for pH levels (drinkable levels range from 4-11 with minimal gastrointestinal irritation), there are still concerns. Skin and eye irritations are linked to water pH values greater than 11 and below 4. A pH value below 2.5 will cause irreversible damage to skin and organ linings. Lower pH levels increase the risk of mobilized toxic metals that can be absorbed, even by humans, and levels above 8.0 cannot be effectively disinfected with chlorine, causing other indirect risks (WHO, 2003). In addition, pH levels outside of 6.5-9.5 can damage and corrode pipes and other systems, further increasing heavy metal toxicity.

6.1.8 Management options

Management at a catchment level is required and long-term monitoring will provide an indication of spikes in pH or seasonal impacts. Similarly, anthropogenic impacts form industrial effluent or chemical spills will be picked up and can then be managed on a case by case basis.

6.1.9 Decision support and South African Guideline

6.1.9.1 Tier I Guideline levels based on SA 1996 Guidelines:

The target water quality range of pH 6.5-8.5 of the South African Recreational Water Quality Guidelines (1996) is still applicable. International evidence seems to agree in most regards with this. No skin, ear or mucous membrane irritation associated with this pH, although mild eye irritation might occur. At this pH, the water is well within the buffering capacity of the lachrymal fluid of the human eye. At pH <5 and > 9 severe eye irritations will occur and skin, ear and mucous membrane irritation likely. At this pH, an adverse aesthetic taste effect is expected when accidentally swallowed. At water pH between 5and 6.5, swimming is still acceptable. Some eye irritation may occur, but skin, ear and mucous membrane irritation unlikely. Similarly, swimming is still acceptable at pH values between 8.5 and 9.0. Some eye irritation is expected, while skin, ear and mucous membrane irritation may occur. At this range, an adverse aesthetic taste is expected when water is accidentally swallowed.

6.2 NUISANCE PLANTS

6.2.1 Background

In addition to algae, aquatic vascular plants (macrophytes) can affect recreational water uses. It is however difficult to estimate the magnitude of the adverse effects of these organisms in terms of their degree of interference with recreational activities or the potential risks to health posed to recreational water users (Canada, 2012). Plant growth can be extremely dense and may form large, free-floating mats. Exotic plant species such as water hyacinth and excess nutrients from anthropogenic sources (e.g. wastewater discharges or agricultural runoff) can cause increased plant growth. Increased silt loads and changes in shorelines or land uses can also contribute to changes in the aquatic habitat which may promote plant growth (DWAF, 1996).

Nuisance plants can endanger the safety of and impinge on the physical comfort of recreational water users. Excessive plant growth can obstruct the view of swimmers and obscure underwater hazards. It can even entangle swimmers which might induce panic, especially if encountered unexpectedly (DWAF, 1996). Algal matrices attached to rocks and other substrata (i.e. periphyton) can cause slippery conditions that may lead to unintentional immersions or injuries. Excessive growth of the organisms can also create aesthetic problems for recreational water areas (Canada, 2012). Macrophytes can grow to high densities and make nearshore and shallow regions unsuitable for any purpose (Priyadarshi, 2005). Boating, water-skiing, boardsailing and angling may be restricted or impossible if the growth is very dense. Excessive growth of or objectionable odours from decaying plants may render water aesthetically objectionable to recreational users. Floating or attached plants that become dislodged from the substrate may drift into swimming areas. Dead and decaying aquatic plants are unsightly, cause objectionable odours and provide a breeding ground for a variety of insects and bacteria (Whitman et al., 2003). The green algal species *Cladophora* (Priyadarshi, 2005) have been known to cause aesthetic problems at recreational sites as a result of rotting, stinking masses of these algae. Mats of these *Cladophora* provide a secondary habitat for bacteria that could potentially influence water quality in affected swimming areas (Whitman et al., 2003; Ishii et al., 2006b).

6.2.2 Interactions

Many physical, chemical and biological properties govern aquatic plant growth in water bodies. Increased plant growth can be caused by the presence of excess nutrients. Various nutrient sources, including agricultural practices, domestic sewage and industrial effluent, all increase the amount of phosphorus and nitrogen in aquatic systems. Such an increase in nutrients is known as eutrophication. Impaired water quality as a result of high algal populations and eutrophication can reduce recreational opportunities (Chambers et al., 2001).
Nuisance plants will continue to flourish unless removed or deprived of nutrients. This can lead ultimately to the complete choking up of a river or dam (e.g. water hyacinth in Hartbeespoort dam; Figure 6-2). However, aquatic plants can also be highly beneficial in a catchment area. When not present in large amounts, aquatic plants can enhance the habitat for certain fish species, thereby benefiting angling. Certain species accumulate nutrients, heavy metals and other pollutants and may form the basis for the conservation and development of wetland areas.

Figure 6-2: Water hyacinth choking the Hartbeespoort Dam, North West Province, South Africa (Source: https://kormorant.co.za/30419/family-rescued-after-being-trapped-in-hyacinths/).

6.2.3 Measurement

Evaluation of the nuisance value of aquatic plant growth is essentially qualitative and subjective and no methods of measurement are applicable.

6.2.4 Data Interpretation

Good judgement and discretion are required to interpret the qualitative criteria provided.

6.2.5 Treatment Options

Many aquatic plants and algae also provide an important habitat for fish and other aquatic biota. The removal of plants from water bodies may constitute a major undertaking. Management actions that try to remove these plant organisms from natural waters are discouraged, as removal may be harmful to the aquatic environment and is generally not effective from both a practical (plants quickly repopulate) and economical perspective. Normally plants are removed manually and mechanically since the use of pesticides to combat these organisms is similarly not recommended, as their use may create a health hazard for recreational water users if used incorrectly, and they are also detrimental to the healthy functioning of the aquatic ecosystem (DWAF, 1996; Canada, 2012). In the case of uncontrolled plant proliferation, herbicide control measures by aerial spraying have proved effective in the past. For example, aerial spraying of herbicides being a notable case to remove water hyacinth from the Hartbeespoort Dam (North West Province of South Africa). Limitations to the effective removal of excessive plant growth from water bodies may involve difficulties with mechanical removal, the lowering of dissolved oxygen levels through the use of herbicides and consequently adverse effects on aquatic life. Adequate follow-up operations are always required if herbicides are used. Clean-up procedures to remove masses of plants and algal material that may have washed up on shorelines represents a barrier that can be effective in reducing potential risks to recreational users. In the long term the only sustainable solution would be to identify the major nutrient inputs within a catchment and implement strategies for their control (Canada, 2012).

6.2.6 Effects

Plant growth can pose a physical hazard in recreational water by entangling swimmers, water-skiers and board sailors. In addition, it can be a nuisance to anglers through snagging of tackle. In extreme cases water bodies can become unusable for recreation. The inevitable decay of dead plants can give rise to odours and render the water anaesthetic if excessive amounts are present. A water body choked up with prolific plant growth, for example water hyacinth, is less aesthetically enjoyable than one that is free from such growth) (DWAF, 1996). Such sites may be avoided or used less frequently, resulting in possible economic impacts directly to the recreational facility used for management or indirectly to the area (e.g. restaurants).

Textbox 7: A manual for the identification of aquatic plant species is freely available for download (low resolution) by recreational site owners / users.

August 2004: Annelise Gerber, Carina J Cilliers, Carin van Ginkel, René Glen – link to low resolution book: http://www.dwa.gov.za/iwqs/biomon/aquaplantsa/aquaplantid.aspx

6.2.7 Management options

Excessive numbers of aquatic plants and algae should be absent from areas intended for recreational activities such as swimming. Similarly, recreational activities should not be pursued in areas where these organisms are present in quantities such that the responsible authorities deem that their presence poses a potential health or safety risk to recreational water users. It is recommended that an Environmental Health and Safety Survey be conducted at the start of each swimming season to identify potential safety hazards that may be encountered at a given recreational water area. Subsequently, one barrier to risk may involve the posting of signs warning users of potential visibility or entanglement risks that may be posed by these organisms (Canada, 2012). Further information on the posting of warning signs can be found in Part I (Management of Recreational Waters).

6.2.8 Evidence and international guideline development

No international guideline or numerical value can be determined for nuisance plants. The WHO (2003) and NHMRC (2008) does not explicitly mention aquatic plants or vegetation as an issue except where the aesthetic and possible drowning or injury of people are concerned. Canada (2012) have a section on “Aquatic vascular plants and algae” but also do not provide any numerical or guideline value.

6.2.9 Decision support and South African Guideline development

Based on discretion and will be handled on a case by case basis. Should be free from objectionable nuisance growth and should not restrict access or specific activities or cause unnecessary risk of harm to humans or equipment. The growth of aquatic vascular plants in water bodies used for full-contact recreation should be limited to ensure that entanglement of swimmers does not occur and that plants do not obscure visibility. Excessive plant growth should not occur in full-contact recreational areas. The presence of floating masses of detached plants which may obstruct water users are aesthetically objectionable and provide a habitat for the growth of nuisance and vector organisms (for example insects, fungi and bacteria) and should be limited as far as possible. Since activities involving intermediate-contact recreation may include occasional full body immersion, the criteria given above should be used and the extent of contact should be taken into account. Where water contact is slight or infrequent, the criteria may be applied less stringently. Plant growth should also be limited to prevent possible entanglement of boats, water skiers and boardsailors. Aquatic plant growth should not detract from the aesthetic aspects of water bodies used for non-contact recreation. Hence, water should not be completely covered, plant growth should not be unsightly or cause unpleasant odours, and there should be no adverse effects on other aquatic organisms.

CHAPTER 7: CHEMICAL ASPECTS

7.1 CHEMICAL IRRITANTS

7.1.1 Background

Chemical compounds that exert toxic or irritant effects can occur in water from natural or anthropogenic sources. These may include point sources (e.g. industrial outfalls, or natural springs) and non-point sources of pollution (e.g. urban runoff, agricultural runoff). Risks associated with specific chemical hazards will depend on the particular area (e.g. if the recreational area is in a fast-flowing upland river, a remote lake or drinking water reservoir, compared to a slow-flowing downstream river, or lowland lake). Mineral-rich strata could contain and leach high concentrations of substances to the surrounding recreational areas. These are likely to contain metals such as iron which may give rise to aesthetic degradation of recreational sites.

At sites where a large number of motorised recreational activities take place such as extensive use of motorboats, Jet Ski's, etc., chemical contamination by gasoline additives may cause concern. The fate of chemical irritants in a water body is dependent on the specific identities and properties of the chemical irritant. Generally, most chemicals, such as organics, biodegrade and some may become incorporated into aquatic plants or accumulate in sediments, especially in the case of recalcitrant chemicals (DWAF, 1996). In all cases the dilution and dispersion of chemical discharges should be taken into account at all recreational sites (WHO, 2003).

Waters affected by industrial discharge outlets, mine tailing dams and leaching from dumps are likely to be unsafe for contact recreational use. Biocides incorporated into anti-fouling paints and used for the inhibition of growth and attachment of filamentous algae on boats are possible chemical irritants in recreational waters in South Africa (DWAF, 1996). Chemicals present in recreational water may cause acute toxicity when ingested or absorbed through the skin, or can irritate the skin, eyes or mucous membranes. At these concentrations, chemicals can interfere with all forms of recreational water use that involve some level of contact with the water (DWAF, 1996).

In recreational waters, chemical contaminants typically occur at concentrations that are considered less of a concern when compared to risk from microorganisms (NHMRC, 2008). According to the WHO (2003) it is extremely unlikely for anyone to come into contact with any chemicals which could cause ill effects after a single event and even repeated (chronic) exposure is unlikely to result in ill effects. However, it remains important to monitor for chemical contaminants to ensure recreational users' personal safety.

7.1.2 Organic contaminants

There are numerous sources of organic chemicals which could contaminate recreational water sites. These include industrial manufacturing and use as well as domestic use of items such as paints, glues, dyes, cleaning products, pesticides, and insecticides (Health Canada, 2012). In South Africa, of special mention is the organic pollution associated with agricultural runoff as well as urban run-off from areas being sprayed with DDT against malaria. For organic contaminants, ingestion as well as skin contact has been reported important exposure routes for recreational users. It is recommended that the level of contamination from organic chemicals be lower than that of the recommended levels for drinking water purposes (South African Drinking Water Quality Guidelines) in order to not pose a significant threat to human health.

7.1.3 Inorganic contaminants

Exposure to inorganic contaminants during recreational activities are not considered a significant risk. Ingestion would be the primary route of exposure, with some exposure to metals possible through skin absorption. Similar to organic contaminants, it is recommended that inorganic contaminants be less than that suggested by the South African Drinking Water Quality Guidelines. According to the WHO (2003), exceedance of a particular inorganic contaminant does not necessarily suggest that a problem exists. It does however warrant the need to further investigate and do a site-specific evaluation of the contaminant, taking into consideration local circumstances, etc.

7.1.4 Interactions

The action of chemical irritants is governed by factors such as the pH, the dissolved oxygen concentration (DOC) and the presence of other chemicals in the water. The chemical form of metals should be taken into consideration as this may significantly affect their solubility and absorption (WHO, 2003). Many substances may accumulate in the sediments and when disturbed during recreation, gets re-suspended or people could be exposed during close contact with sediment. In general, this is likely to only make a small contribution to the overall exposure (NHMRC, 2008). Site specific information and local circumstances plays an important role in the interpretation of chemical contaminant data at recreational sites.

7.1.5 Data Interpretation

Site specific information and local circumstances plays an important role in the interpretation of chemical contaminant data at recreational sites. Specific recommendations on the general chemical characteristics of recreational waters are limited and even when available, the full range of possible irritants and toxicants cannot practicably be addressed. Chemical irritants, or similar aggregated constituents, appear in guidelines from several sources. The criteria given are based on qualitative recommendations and good judgement is required in the interpretation thereof (DWAF).

7.1.6 Treatment Options

Recreational waters are usually not treated for chemical irritants. The quality of the inflow and receiving water should be monitored and regulated so as to prevent chemical contamination (see management options below).

7.1.7 The Effects of Chemical Irritants

Recreational users may swallow small amounts of water or absorb toxic chemicals through the skin (DWAF, 1996). According to the WHO (2003) there is a great deal of anecdotal evidence with regards to skin rashes and related effects where individuals have come into contact with chemically contaminated water. Enough evidence for critical scientific evaluation is however not available.

7.1.8 International evidence and guideline development

National surveys in Canada have found low concentrations of both organic and inorganic chemicals in recreational waters, and therefore consider the risk of human exposure to chemical contaminants to be low (Canada, 2012). This is in line with the WHO (2003) as well as Australian Guidelines for Recreational water.

The Australian guidelines made use of sources of information within catchments to collect information regarding the use of chemicals and likely impacts on recreational sites. These sources of information are summarised in Table 7-1. The amount of water accidentally swallowed varies according to the type of activity engaged in and the length of exposure. Assuming an average of 100 mL accidental ingestion as a result of recreational contact with water, will allow a simple screening of chemical substances occurring at concentrations ten times higher than the WHO drinking water quality guidelines (possibly warranting further investigation), to be protective of chemical contamination. According to DWAF (1996) ingestion is seldom likely to exceed 100 mL for any individual per recreational event.

Table 7-1: Sources of information (Source: NHMRC, 2008)

Source of chemical	Information sources
Agriculture	· Farmers' associations · State/territory agricultural authorities · Local government authorities · University extension services · State and Territory Environmental Authorities · Natural Resource Management Agencies
Extractive industries	· State/territory resource management agencies · Local government authorities · University geology departments · Specialist research institutes associated with the mining industry · State and Territory Environmental Authorities · Natural Resource Management Agencies
Manufacturing and processing industries	· State/territory environmental protection authorities and industry departments · Local government authorities · Industry associations (e.g. chambers of commerce) · State and Territory Environmental Authorities · Natural Resource Management Agencies
Contamination from former industrial sites	· State/territory environmental protection agencies · Local government authorities · Historical societies · State and Territory Environmental Authorities · Natural Resource Management Agencies
Natural environment	· Australian Geological Survey Organisation · State/territory departments of natural resources · Geology departments of universities · Local government authorities · Mining companies · State and Territory Environmental Authorities · Natural Resource Management Agencies

7.1.9 Management options

A multi-barrier approach is the most effective way to protect recreational users from risk of exposure to chemical contamination in recreational water. This approach makes use of an Environmental Health and Safety Assessment (EHSA). This will help to identify the potential chemical hazards and also help identify barriers which could be implemented to both reduce the risk of chemical contamination and when needed restrict swimmer exposure during high risk periods or in areas of increased risk (Canada, 2012). A catchment management plan outlining the long term monitoring plan for recreational sites should be used by the Department of Water and Sanitation (DWS) to manage water quality, specifically in terms of organic and inorganic chemicals at recreational sites. These plans will reveal site specific problem areas with regards to natural and anthropogenic chemical pollutants. Resource quality objectives set for rivers will provide the site-specific information required when judging fitness of use for recreational activities. Monitoring of recreational sites should be performed and more frequent surveillance might be needed just before recreational season. Where pesticides are used, monitoring should include testing for those chemicals used. Similarly, testing for DDT and its derivative products is required at recreational sites upstream from areas sprayed for malaria control. As sediments often concentrate chemicals, sediments should be included in the monitoring plan. Catchment management plans should aim to protect the catchment from for example unregulated industrial effluent dumping, prevention or reduction strategies to limit nitrogen and phosphorous pollution form agricultural practices by means of different practices, e.g. safe storage and spreading of manure, limited use of fertilisers, etc.

7.2 DECISION SUPPORT AND GUIDELINE DEVELOPMENT FOR SOUTH AFRICA

7.2.1 Tier I Guideline levels based on SA 1996 Guidelines:

The recreational guidelines for chemical contaminants are based on the concentrations defined as ideal or acceptable in the drinking water quality guidelines as these would protect people in terms of lifetime consumption at drinking water volumes. Water used for full contact recreation should be free of chemicals that are irritating to the skin, eyes or mucous membranes (e.g. nose, mouth). If this cannot be achieved, warning notices should be posted at the recreational site. Unless chemicals are coloured or odorous, aesthetic effects need not be considered.

REFERENCES

1. APHA (American Public Health Association). (1976). Standard Methods for the Examination of Water and Waste Water, 14th Edition. American Public Health Association, American Water Works Association, Water Pollution Control Federation. Published by the American Public Health Association, Washington DC, USA. American Water Works Association. Handbook of taste and odour control experiences in the U.S. and Canada. Denver, CO (1976).

2. APHA, AWWA and WEF. (2005). Standard methods for the examination of water and wastewater. 21st edition. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, DC.

3. AUSTRALIAN GUIDELINES 1990. Australian Guidelines for Recreational Use of Water. Prepared by the National Health and Medical Research Council. Australian Government Publishing Services, Canberra, Australia.

4. Ballot, A., Sandvik, M., Rundberget, T., Botha, C.J., and Miles, C.O. (2014). Diversity of cyanobacteria and cyanotoxins in Hartbeespoort Dam, South Africa Marine and Freshwater Research, 2014, 65, 175-189 http://dx.doi.org/10.1071/MF13153

5. Bartram, J., Fewtrell, L., Stenström, T-A. (2001). Harmonised assessment of risk and risk management for water-related infectious disease: an overview. In: Fewtrell L, Bartram J, eds. Water quality – guidelines, standards and health: assessment of risk and risk management for water-related infectious disease. London, IWA Publishing.

6. Basu, P.K., Avaria, M., Cutz, A. and Chipman, M. (1984). Ocular effects of water from acidic lakes: an experimental study. Can. J. Ophthalmol., 19: 134-141.

7. Blanksby, B.A., Wearne, F.K., Elliott, B.C., Biltvich, J.D. (1997). Aetiology and occurrence of diving injuries. A review of diving safety. Sports Medicine, 23(4): 228-246.

8. Bliss, P.J., Schultz, T.J., Senger, T., and Kaye, R.B. (1996). Odour measurement – factors affecting olfactometry panel performance. Water Science and Technology. 34: (3-4), 549-556.

9. Brattoli, M., de Gennaro, G., de Pinto, V., Loiotile, A.D., Lovascio, S., and Penza, M. (2001). Odour Detection Methods: Olfactometry and Chemical Sensors. Sensors 2011, 11, 5290-5322; doi:10.3390/s110505290.

10. Burttschell, R.H., Rosen, A.A., Middleton, F.M. and Ettinger, M.B. Chlorine derivatives of phenol causing taste and odour. J. Am. Water Works Assoc., 51: 205 (1959). cited in Health Canada, 1995

11. Cabelli et al. (1983). A Marine Recreational Water Quality Criterion Consistent with Indicator Concepts and Risk Analysis. Journal (Water Pollution Control Federation), Vol. 55, No. 10. Pp 1306-1314)

12. Cain, W.S., Stevens, J.C., Nickou, C.M., Giles, A., Johnston, I., and Garcia-Medina, M.R. (1995). Life-span development of odour identification, learning and olfactory sensitivity. Perception 24, 1457-1472.

13. CANADIAN GUIDELINES 1992. Update, Canadian Water Quality Guidelines. Chapter 2, Update: Recreational Water Quality and Aesthetics. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environmental Ministers. Canada.

14. Carmichael, W.W., Azevedo, S.M., An, J.S., Molica, R.J.R., Jochimsen, E.M., Lau, S., Rinehart, K.L., Shaw, G.R., Eaglesham, G.K. (2001). Human fatalities from cyanobacteria: chemical and biological evidence for cyanotoxins. Environ Health Perspect. 2001, 109: 663-668.

15. Carmichael, W.W. (2001). Health effects of Toxin-Producing Cyanobacteria: "The CyanoHABs". Hum. Ecol. Risk Assess. 7(5): 1393-1407

16. Carmichael, W.W. (1996). Proceedings of the IV Symposium of the Brazilian Society of Toxinology. 6-11 October. São Paulo, Brazilian Society of Toxinology.

17. CDC (Centre for Disease Control). (2004). Parasites and health: cercarial dermatitis. DPDx Laboratory Identification of Parasites of Public Health Concern. Centres for Disease Control and Prevention, Atlanta, Georgia.

18. CDC (Centre for Disease Control). (2012). Saving Lives, Protecting People. Parasites: Schistosomiasis. https://www.cdc.gov/parasites/schistosomiasis/biology.html

19. Chambers, P.A., Guy, M., Roberts, E.S., Charlton, M.N., Kent, R., Gagnon, C., Grove, G. & Foster, N. (2001). Nutrients and their impact on the Canadian environment. Agriculture and Agri-Food Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada and Natural Resources Canada. 241 pp.

20. Chorus, I. and Bartram, J. (eds.). (1999). Toxic cyanobacteria in water: A guide to public health significance, monitoring and management. E. & F.N. Spon / Chapman & Hall, London, United Kingdom.

21. Chorus, I. and Cavalieri, M. (2000). Cyanobacteria and algae. In Monitoring bathing waters, eds. J. Bartram and G. Rees, pp. 219-271. London: Spon/Chapman & Hall.

22. Chorus, I., Falconer, I.R., Salas, H.J. and Bartram, J. (2000). Health risks caused by freshwater cyanobacteria in recreational waters. J. Toxicol. Environ. Health B, 3: 323-347.

23. Codd, G.A., Bell, S.G.., Brooks, W.P. (1989). Cyanobacterial toxins in water. Water Science and Technology, 21: 1-13. Cronberg et al., 1988).

24. Dillenberg, H.O and Dehnel, M.K. (1960). Toxic water bloom in Saskatchewan 1959. Can. Med. Assoc. J., 83: 1151-1154.

25. Dravnieks, A. and Jarke, F. (1980). Odour threshold measurement by dynamic olfactory: significant operational variables. J. Air Poll. Cont. Assoc. 30, 1284-1289.

26. DWAF (Department of Water Affairs and Forestry). (1996). South African Water Quality Guidelines. 2nd Edition. Volume 2: Recreational Use. Pretoria, South Africa

27. Environment Canada (1981). Analytical methods manual. Ottawa, Ontario, Environment Canada, Inland Waters Directorate, Water Quality Branch.

28. Falconer, I.R., Burch, M.D., Steffensen, D.A., Choice, M., Coverdale, O.R. (1994). Toxicity of the blue-green algae (cyanobacterium) Microcystis aeruginosa in drinking water to growing pigs, as an animal model for human injury and risk assessment. Environmental Toxicology and Water Quality 9: 131-139.

29. Falconer, I.R. (2005). Cyanobacterial Toxins of Drinking Water Supplies: Cylindrospermopsins and Microcystins. CRC Press Boca Raton, FL, pp. 263.

30. Farrer, R.A., Desjardins, C.A., Sakthikumar, S., Gujja, S., Saif, S., Zeng, Q., Chen, Y., Voelz, K., Heitman, J., May, R.C., Fisher, M.C., Cuomo, C.A. (2015). Genome evolution and innovation across the four major lineages of Cryptococcus gattii. mBio 6(5): e00868-15. doi:10.1128/mBio.00868-15.

31. Fenwick, A., Webster, J.P., Blair, L., Fleming, F.M., Zhang, Y., Garba, A. (2002). The schistosomiasis control initiative (SCI): Rationale, development and implementation from 2002-2008. Parasitology. 2002;136(13):1719-1730. http://dx.doi.org/10.1017/S0031182009990400

32. Fewtrell, L., Godfree, A., Jones, F., Kay, D. and Merret, H. (1994). Pathogenic microorganisms in temperate environmental waters. Tresaith, Samara Publishing Limited, 207pp.

33. Fitzgeorge, R.B., Clark, S.A. and Keevil, C.W. (1994). Routes of intoxication. In: Proceedings of the 1st international symposium on detection methods for cyanobacterial (blue-green algal) toxins. G.A. Codd, T.M. Jeffries, C.W. Keevil and E. Potter (eds.). Royal Society of Chemistry, Cambridge, UK. pp. 69-74 (1994).

34. Fondriest Environmental, Inc.(2013). “pH of Water.” Fundamentals of Environmental Measurements. 19 Nov. 2013. Web. < http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/ >.

35. Fondriest Environmental, Inc. (2014). “Turbidity, Total Suspended Solids and Water Clarity.” Fundamentals of Environmental Measurements. 13 Jun. 2014. Web. < http://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/

36. Fondriest Environmental, Inc. (2013). “pH of Water.” Fundamentals of Environmental Measurements. 19 Nov. 2013. Web. < http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/ >. Accessed: 10 January 2017.

37. Fondriest Environmental, Inc. (2014). “Turbidity, Total Suspended Solids and Water Clarity.” Fundamentals of Environmental Measurements. 13 Jun. 2014. Web. < http://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/ >.

38. Fortier, I., Ferraris, J. and Mergler, D. (1991). Measurement precision of an olfactory perception threshold test for use in field studies. Am. J. Ind. Med., 20: 495-504. doi:10.1002/ajim.4700200405

39. Frechen, F.B. (1994). Odour emissions of wastewater treatment plants – recent German experiences. Water Sci. Technol. 30(4), 35-46. in 1994

40. From SKIN CORROSION/IRRITATION DEFINITIONS – ILO (Int Labour Organisation) www.ilo.org/legacy/english/protection/safework/ghs/ghsfinal/ghsc06.pdf

41. Funari, E. and Testai, E. (2008). Human health risk assessment related to cyanotoxins exposure. Crit. Rev. Toxicol. 38:97-125.

42. Gerber, A., Cilliers, C.J., Van Ginkel, C. & Glen, R. (2004). Eas Identification of aquatic Plants. Pretoria: Department of Water Affairs. http://www.dwa.gov.za/iwqs/biomon/aquaplantsa/aquaplantid.aspx

43. Gostelow, P. Parsons, S.A. and Stuetz, R.M. (2001). Odour Measurements for Sewage Treatment. Wat. Res. Vol. 35, No. 3, pp. 579-597, 2001

44. Griep, M.I., Mets, T.F., Collys, K., Vogelaere, P., Laska, M., and Massart, D.L. (1997). Odour perception in relation to age, general health, anthropometry and dental state. Arch. Gerontology Geriatrics 25, 263-275.

45. Griep, M.I., Mets, T.F., Vercruysse, A., Cromphout, I., Ponjaert, I., Toft, J. and Massart, D.L. (1995). Food odour thresholds in relation to age, nutritional and health status. J. Gerontology 50 A, B407-B414.

46. Harding, W.R. and Paxton, B.R. (2001). Cyanobacteria in South Africa: A Review. Water Research Commission Report. WRC TT153/01. Pretoria, South Africa.

47. Hart et al. (1992). Australian Water Quality Guidelines, Draft for Public Comment. Australian and New Zealand Environment and Conservation Council, Australia.

48. Havelaar, A.H., Melse, J.M. (2003). Quantifying public health risks in the WHO guidelines for drinking water quality: a burden of disease approach. Bilthoven, The Netherlands, Rijksinstituut voor Volksgezondheid en Milieu [National Institute for Public Health and the Environment], (RIVM Report 734301022/2003).

49. Health Canada (2012). Guidelines for Canadian Recreational Water Quality, Third Edition. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No H129-15/2012E).

50. Hunter, P.R., Fewtrell, L. (2001). Acceptable risk. In: Fewtrell L, Bartram J, eds. Water quality – guidelines, standards and health: assessment of risk and risk management for water-related infectious disease. London, IWA Publishing.

51. International Joint Commission (1977). New and revised Great Lakes water quality objectives.

52. Ishii, S., Yan, T., Shively, D.A., Byappanahalli, M.N., Whitman, R.L. and Sadowsky, M.J. (2006b). Cladophora (Chlorophyta) spp. harbour human bacterial pathogens in nearshore water of Lake Michigan. Appl. Environ. Microbiol., 72(7): 4545-4553.

53. Janse van Vuuren, S. and Kriel, G.P. (2008). Cylindrospermopsis raciborskii, a toxic invasive cyanobacterium in South African fresh waters, African Journal of Aquatic Science, 33:1, 17-26, DOI: 10.2989/AJAS.2007.33.1.2.386

54. Johnson, P.C., Mathewson, J.J., DuPont, H.L., Greenberg, H.B., Multiple-challenge study of host susceptibility to Norwalk gastroenteritis in US adults. J Infect Dis 1990; 161:18.

55. Kaeppler, K. and Mueller, F. (2013). Odor classification: A Review of Factors Influencing Perception-Based Odor Arrangements. Che. Senses 38: 138-209

56. Kjetland, E.F., Leutscher, P., Ndhlovu, P. (2012). A review of female genital schistosomiasis. Trends Parasitol. 2012; 28(2):58-65. http://dx.doi.org/10.1016/j.pt.2011.10.008 Leighton et al., 2004.

57. Laska, M. and Hudson, R. (1991). A comparison of the detection thresholds of odour mixtures and their components. Chem. Senses 16. 651-662.

58. Lee, Z.P., Shang, S., Hu, C., Du, K., Weidemann, A., Hou, W., Lin, J., and Lin, G. (2015). Secchi disk depth: A new theory and mechanistic model for underwater visibility. Remote Sensing of Environment 169(2015) 139-149.

59. Levesque, B., Giovenazzo, P., Guerrier, P., Laverdiere, D. and Prud'homme, H. (2002). Investigation of an outbreak of cercarial dermatitis. Epidemiol. Infect., 129: 379-386.

60. Loftin, K., Graham, J., Rosen, B. and Amand, A.S. (2010). Analytical Methods for Cyanotoxin Detection and Impacts on Data Interpretation. A presentation at the 2010 National Water Quality Monitoring Conference, Workshop. Guidelines for Design, Sampling, Analysis and Interpretation for Cyanobacterial Toxin Studies at Denver, CO on April 26, 2010.

61. Magaisa, K., Taylor, M., Kjetland, E.F. and Naidoo, P.J. (2015). A review of the control of schistosomiasis in South Africa. S Afr J Sci. 2015; 111(11/12), Art # 2014-427, 6pg. http://dx.doi.org/10.17159/sajs.2015/20140427.

62. Mance, G., Musselwhite, C. and Brown, V.M. (1984). Proposed environmental quality standards for List II substances in water. Arsenic. Medmenham, Water Research Centre (Technical Report TR 212).

63. Manitoba Water Stewardship (2007). Manitoba's water protection handbook. Manitoba Water Stewardship, Winnipeg, Manitoba. Available at: www.gov.mb.ca/waterstewardship/water_guide/index.html

64. Mankiewicz, J., Tarczynska, M., Walter, Z., and Zalewski, M. (2003). Natural Toxins from Cyanobateria. Acta Biologica Cracoviensia. Series Botanica 45/2:9-20, 2003.

65. Mans, J., Armah, G.E., Steele, A.D., Taylor, M.B. Norovirus Epidemiology in Africa: A Review. Calderaro A, ed. PLoS ONE. 2016;11(4): e0146280. doi: 10.1371/journal.pone.0146280.

66. Matthews, M.W., Bernard, S. Eutrophication and cyanobacteria in South Africa's standing water bodies: A view from space. S Afr J Sci. 2015;111(5/6), Art. #2014-0193, 8 pages. http://dx.doi.org/10.17159/sajs.2015/20140193

67. Mbabazi, P., Andan, O., Fitzgerald, D.W., Chitsulo, L., Engels, D., Downs, J.A. (2011). Examining the relationship between urogenital schistosomiasis and HIV infection. PLoS Negl Trop Dis. 2011; 5(12): e1396. http://dx.doi.org/10.1371/journal.pntd.0001396

68. McElhenny, T.R., Bold, H.C., Malcolm Brown, P. and McGovern J.P. (1962). Algae: A cause of inhalant allergy in children. Ann. Allergy 20:739-743.

69. MDEQ. (n.d.). Total Suspended Solids. In Michigan Department of Environmental Quality. Retrieved from http://www.michigan.gov/documents/deq/wb-npdes-TotalSuspendedSolids_247238_7.pdf

70. Mennen, U. (1981). A survey of spinal injuries from diving. A study of patients in Pretoria and Cape Town. South African Medical Journal 59(22):788-790.

71. Mittal, A., Agarwal, H.K., and Shivpuri, D.N. (1979). Respiratory allergy to algae: Clinical aspects. Ann. Allergy 42:253-256.

72. Morris, R.L., Dougherty, J.D. and Ronald, G.W. Chemical aspects of actinomycetes metabolites as contributors of taste and odour. J. Am. Water Works Assoc., 55: 1380 (1963).

73. Nchabeleng, T., Cheng, P., Oberholster, P.J., Botha, A.M., Smit, W.J., Luus-Powell, W.J. (2014). Microcystin-LR equivalent concentrations in fish tissue during a postbloom Microcystis exposure in Loskop Dam, South Africa. Afr. J. Aquat. Sci. 39 (4).

74. Ndlela, L.L., Oberholster, P.J., Van Wyk, J.H. and Cheng, P.H. (2016). An overview of cyanobacterial bloom occurrences and research in Africa over the last decade. Harmful Algae 60 (2016) 11-26.

75. NHMRC (National Health and Medical Research Council). (2008). Guidelines for Managing Risks in Recreational Water. NHMRC, Australian Government Publishing Service, Canberra.

76. Oberholster, P.J., Ashton, P.J. (2008). State of the nation report: an overview of the current status of water quality and eutrophication in South African rivers and reservoirs. CSIR/NRE/WR/IR/2008/0075/C 1-15.

77. Oberholster, P.J., Botha, A. (2007). Use of PCR based technologies for risk assessment of a winter cyanobacterial bloom in Lake Midmar, South Africa. Afr. J. Biotechnol. 6 (15), 1794-1805.Oberholster et al., 2015).

78. Oberholster, P.J., Botha, A., Myburgh, J.G. (2009a). Linking climate change and progressive eutrophication to incidents of clustered animal mortalities in different geographical regions of South Africa. Afr. J. Biotechnol. 8 (21).

79. Oberholster, P.J., Botha, A., Ashton, P.J. (2009b). The influence of a toxic cyanobacterial bloom and water hydrology on algal populations and macroinvertebrate abundance in the upper littoral zone of Lake Krugersdrift, South Africa. Ecotoxicology 18, 34-46.

80. Oberholster, P.J., Botha, A., Grobbelaar, J.U. (2004). Microcystis aeruginosa: source of toxic microcystins in drinking water. Afr. J. Biotechnol. 3 (3), 159-168.

81. Oberholster, P.J., Myburgh, J.G., Govender, D., Bengis, R., Botha, A. (2009c). Identification of toxigenic Microcystis strains after incidents of wild animal mortalities in the Kruger National Park, South Africa. Ecotoxicol. Environ. Safe 72, 1177-1182.

82. Osmond, D.L., D.E. Line, J.A. Gale, R.W. Gannon, C.B. Knott, K.A. Bartenhagen, M.H. Turner, S.W. Coffey, J. Spooner, J. Wells, J.C. Walker, L.L. Hargrove, M.A. Foster, P.D. Robillard, and D.W. Lehning. (1995). Turbidity. In WATERSHEDSS: Water, Soil and Hydro-Environmental Decision Support System, http://h2osparc.wq.ncsu.edu. Retrieved from http://www.water.ncsu.edu/watershedss/info/turbid.html

83. Patterson, M.Q., Stevens, J.C., Cain, W.S. and Commeto-Muniz, J.E. (1993). Detection thresholds for an olfactory mixture and its three constituent compounds. Chem. Senses 18, 723-734.

84. Perlman, H. (2014). Turbidity. In the USGS Water Science School. Retrieved from http://water.usgs.gov/edu/turbidity.html. March, 2014.

85. Philipp, R. (1993). Community needlestick accident data and trends in environmental quality. Public Health, 107: 363-369.

86. Philipp, R., Pond, K. and Rees, G. (1997). Research and the problems of litter and medical wastes on the UK coastline. British Journal of Clinical Practice 51(3):164-168.

87. Pilotto, L., Hobson, P., Burch, M.D., Ranmuthugala, G., Attewell, R., Weightman, W. (2004). Acute skin irritant effects of cyanobacteria (blue-green algae) in healthy volunteers. Australian and New Zealand Journal of Public Health 28(3): 220-225.

88. Potts, A.M. (1991). Toxic Responses of the Eye, In, Amdur MO, Doull J, Klaassen CD. (eds.) 1991. Casarett and Doull's Toxicology. The Basic Science of Poisons Volume. 4th. New York: Pergamon Press

89. Priyadarshi, N. (2005). Cultural eutrophication. In: Water encyclopaedia 3:114-115 – surface and agricultural water. J.H. Lehr and J. Keeley (eds.). John Wiley and Sons, Hoboken, New Jersey.

90. Pruss et al. and other studies

91. Regli, S. et al. (1991). Modeling the risk from Giardia and viruses in drinking water. Journal of the American Water Works Association, 83:76-84

92. Ressom, R., Soong, F.S., Fitzgerald, J., Turczynowicz, L., El Saadi, O., Roder, D., Maynard, T. and Falconer, I. (1994). Health effects of toxic cyanobacteria (blue-green algae). National Health and Medical Research Council of Australia, Commonwealth Department of Human Services and Health. Australian Government Publishing Service, Canberra, Australia. 108 pp. (1994).

93. Saathoffm E,, Olsen, A., Magnussen, P., Kvalsvig, J.D., Becker, W., Appleton, C.C. (2004). Patterns of Schistosoma haematobium infection, impact of praziquantel treatment and re-infection after treatment in a cohort of schoolchildren from rural KwaZulu-Natal/South Africa. BMC Infect Dis. 2004;4(1):40. http://dx.doi.org/10.1186/1471-2334-4-40Verbrugge et al., 2004.

94. Sigworth, E.A. Identification and removal of herbicides and pesticides. J. Am. Water Works Assoc., 57: 1016 (1965). Cited in Health Canada, 1995.

95. Sivonen, K., and Jones, J. (1999). Cyanobacterial toxins. In: Chorus I, Bartram J [eds.], Toxic cyanobacteria in water: A guide to public health significance, consequences, monitoring and management, 41-111. E&FN SPON, London.

96. Smith, D.G. and Davies-Colley, R.J. (1992). Perception of Water Clarity and Colour in terms of Suitability for Recreational Use. Journal of Environmental Management (1992)36, 225-235.

97. Stahl, W.H. (ed.). Compilation of odour and taste threshold values data. ASTM Data Series Publ. No. DS 48, American Society for Testing and Materials, Philadelphia, PA (1973).

98. Stewart, I., Webb, P.M., Schluter, P.J., Fleming, L.E., Burns, J.W., Gantar, M., Backer, L.C., Shaw, G.R.: Epidemiology of recreational exposure to freshwater cyanobacteria – an international prospective cohort study. BMC Public Health. 2006, 6: 93-10.1186/1471-2458-6-93.

99. Suffet, I.H., Burlingame, G.A., Rosenfeld, P.E. and Bruchet, A. (2004). Wastewater Odour Wheel diagram courtesy of "The Value of an Odour-Quality-Wheel Classification Scheme for Wastewater Treatment Plants," Water Science and Technology, 50 (4), 25-32.

100. Suffet, I.H., Burlingame, G.A., Rosenfeld, P.E. and Bruchet, A. (2004). The Value of an Odour-Quality-Wheel Classification Scheme for Wastewater Treatment Plants. Water Science and Technology, 2004, No. 50 (4) 25-32.

101. W.F. Young, H. Horth, R. Crane, L.T. Ogden and M. Arnott. (1996). Taste and odour threshold concentrations of potential potable water contaminants Wat. Res. Vol. 30, No. 2, pp. 331-340.

102. Teixeira, M.G.L.C., Costa, M.C.N., Carvalho,V.L.P., Pereira, M.S. and Hage, E. (1993). Epidemia de gastroenterite na área da barragem de Itaparica, Bahia. Bol. Sanit. Panam. 114(6): 502-511.

103. Train, R.E. (1979). Quality criteria for water. United States Environmental Protection Agency, Washington, DC; Castle House Publications, Tunbridge Wells, United Kingdom cited in the Canadian Guidelines for Recreational water use (Health Canada, 2012).

104. Turner, P.C., Gammie, A.J., Hollinrake, K. and Codd, G.A. (1990). Pneumonia associated with contact with cyanobacteria. British Medical Journal, 300(6737): 1440-1441.

105. University of Surrey (1987). The public health implications of sewage pollution of bathing water. Guildford, Robens Institute of Industrial and Environmental Health and Safety, 25 pp. cited in WHO< 2003.

106. US EPA (United States Environmental Protection Agency). (2012). Recreational Water Quality Criteria (RWQC). Office of Water 820-F-12-058.

107. US EPA (2012). NEEAR Study

108. US EPA (United States Environmental Protection Agency). (2014). Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems. Office of Water, Mail Code 4304T. EPA-810F11001, September 2014.

109. US EPA (United States Environmental Protection Agency). (2016). Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin. Draft. Office of Water. Mail Code 4304T. EPA 822-P-16-002. December 2016

110. US EPA (United States Environmental Protection Agency). (2016). National Aquatic Resource Surveys. Indicators: Water Clarity. Updated 16 August 2016. Accessed: 6 September 2016. https://www.epa.gov/national-aquatic-resource-surveys/indicators-water-clarity

111. US EPA. (2016). National Aquatic Resource Surveys. Indicators: Water Clarity. Updated 16 August 2016. Accessed: 6 September 2016. https://www.epa.gov/national-aquatic-resource-surveys/indicators-water-clarity

112. Van Gemert, L.J. and Nettenbreijer, A.H. (eds.). Compilation of odour threshold values in air and water. National Institute for Water Supply, Voorburg, and Central Institute for Nutrition and Food Research TNO, Zeist, Netherlands, June (1977).

113. Vesterinen, J., Pouta, E., Huhtala, A. and Neuvonen, M. (2010). Impacts of Changes in Water Quality on Recreation Behavior and Benefits in Finland. Journal of Environmental Management, 91, 984-994. http://dx.doi.org/10.1016/j.jenvman.2009.12.005

114. Vol. II. A Report to the Governments of the United States and Canada. Cited in WHO, 2003.

115. Watson, Susan, B. Ridal, Jeff and Boyer, Gregory L. (2008). Taste and odour and cyanobacterial toxins: impairment, prediction, and management in the Great Lakes. Can. J. Fish. Aquat. Sci. 65: 1779-1796 (2008). doi:10.1139/F08-084

116. West, A.O., Nolan, J.M. and Scott, J.T. (2016). Optical water quality and human perceptions of rivers: an ethnohydrology study. Ecosystem Health and Sustainability 2(8): e01230. Doi:10.1002/ehs2.1230.

117. Wetzel, R.G. (2001). Limnology: Lake and River Ecosystems (3rd ed.). San Diego, CA: Academic Press.

118. Whitman, R.L., Shively, D.A., Pawlik, H., Nevers, M.B. and Byappanahalli, M.N. (2003). Occurrence of Escherichia coli and enterococci in Cladophora (Chlorophyta) in nearshore water and beach sand of Lake Michigan. Appl. Environ. Microbiol., 69: 4714-4719.

119. WHO (1980). Environmental sanitation in European tourist areas. Copenhagen, WHO Regional Office for Europe, 33 pp. (EURO Reports and Studies No. 18).

120. WHO (2006a & b). Guidelines for the safe use of wastewater, excreta and greywater. Vol. 2. Wastewater use in agriculture & Vol. 4. Excreta and greywater use in agriculture. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/publications/gsuweg/en/, accessed June 2017).

121. WHO (2017). Guidelines for drinking-water quality, fourth edition incorporating first addendum. Geneva: World Health Organization.

122. WHO (World Health Organisation). (1998). 2nd ed. Guidelines for Drinking-water Quality, vol. 2. WHO (Addendum to Health criteria and other supporting information).

123. WHO (World Health Organization). (2003). Guidelines for safe recreational water environments. Volume 1, Coastal and fresh waters. Geneva, Switzerland. ISBN 92 4 154580 1

124. WHO (World Health Organization). (2003). Guidelines for safe recreational water environments. Volume 1, Coastal and fresh waters. Geneva, Switzerland. ISBN 92 4 154580 1

125. WHO (2017). Reuse referring to (Lodder WJ, de Roda Husman AM (2005) Presence of noroviruses and other enteric viruses in sewage and surface waters in the Netherlands. Applied and Environmental Microbiology, 71(3):1453-1461.)

126. WSDE (Washington State Department of Ecology). (1991). The model toxics control act cleanup regulation, Chapter 173-340 WAC. Amended February 2001. Olympia, Washington. http://www.ecy.wa.gov/biblio/wac173340.html

127. Young, W.F., Horth, H., Crane, R., Ogden, L T. and Arnott, M. (1996). Taste and odour threshold concentrations of potential potable water contaminants Wat. Res. Vol. 30, No. 2, pp. 331-340.

128. Ziv, G., Mullin, K., Boeur, B., Fincham, W., Taylor, N., Villabos-Jimenes, G., Von Vittorelli, L., Wolf, C, Fritsch, O., Strauch, M., Seppelt, R., Volk, M., and Beckmann, M. (2016). Water Quality Is a Poor Predictor of Recreational Hotspots in England. PLoS ONE 11(11): e0166950. Doi: 10.1371/journal.pone.0166950.

[i] Havelaar AH, Melse JM (2003). Quantifying public health risks in the WHO guidelines for drinking water quality: a burden of disease approach. Bilthoven, The Netherlands, Rijksinstituut voor Volksgezondheid en Milieu [National Institute for Public Health and the Environment], (RIVM Report 734301022/2003).
[ii] Hunter PR, Fewtrell L (2001). Acceptable risk. In: Fewtrell L, Bartram J, eds. Water quality – guidelines, standards and health: assessment of risk and risk management for water-related infectious disease. London, IWA Publishing.
[iii] Regli S et al. (1991). Modeling the risk from Giardia and viruses in drinking water. Journal of the American Water Works Association, 83:76-84
[iv] Pruss et al. and other studies
[v] Cabelli et al., 1983
[vi] Cabelli et al., 1983 A Marine Recreational Water Quality Criterion Consistent with Indicator Concepts and Risk Analysis. Journal (Water Pollution Control Federation), Vol. 55, No. 10. Pp 1306-1314)
[vii] Health Canada, 2012. Guidelines for Canadian Recreational Water Quality, Third Edition. Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. (Catalogue No H129-15/2012E).
[viii] US EPA 2012 NEEAR Study
[ix] Weidenmann
[x] WHO 2017 Reuse referring to (Lodder WJ, de Roda Husman AM (2005) Presence of noroviruses and other enteric viruses in sewage and surface waters in the Netherlands. *Applied and Environmental Microbiology*, 71(3):1453-1461.)
[xi] Mans J, Armah GE, Steele AD, Taylor MB. Norovirus Epidemiology in Africa: A Review. Calderaro A, ed. *PLoS ONE*. 2016;11(4):e0146280. doi:10.1371/journal.pone.0146280.
[xii] Johnson PC, Mathewson JJ, DuPont HL, Greenberg HB. Multiple-challenge study of host susceptibility to Norwalk gastroenteritis in US adults. J Infect Dis 1990; 161:18.
[xiii] Bartram J, Fewtrell L, Stenström T-A (2001). Harmonised assessment of risk and risk management for waterrelated infectious disease: an overview. In: Fewtrell L, Bartram J, eds. Water quality – guidelines, standards and health: assessment of risk and risk management for water-related infectious disease. London, IWA Publishing.
[xiv] WHO (2006a & b). Guidelines for the safe use of wastewater, excreta and greywater. Vol. 2. Wastewater use in agriculture & Vol. 4. Excreta and greywater use in agriculture. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/publications/gsuweg/en/, accessed June 2017).
WHO (2017). Guidelines for drinking-water quality, fourth edition incorporating first addendum. Geneva: World Health Organization.

[xv] Signor & Ashbolt, 2006
[xvi] Smeets et al., 2007
[xvii] Smeets et al., 2007
[xviii] Mara and Bos, 2010
Teunis, 1996;
Haas et al., 1999;
Okhuysen et al., 1999;
Teunis et al., 1999
[xx] Fong, T.-T., Phanikumar, M. S., Xagoraraki, I., & Rose, J. B. (2010). Quantitative Detection of Human Adenoviruses in Wastewater and Combined Sewer Overflows Influencing a Michigan River. *Applied and Environmental Microbiology*, *76*(3), 715-723. http://doi.org/10.1128/AEM.01316-09
[xxi] Eftim et al., 2017. Occurrence of norovirus in raw sewage – A systematic literature review and meta-analysis. Water Research 111, 366-374.
[xxii] Van der Poel, W. and Rzezutka, A. 2017. Hepatitis A. In: J.B. Rose and B. Jiménez-Cisneros, (eds) Global Water Pathogens Project. http://www.waterpathogens.org (J.S Meschke, and R. Girones (eds) Part 3 Viruses)
[xxiii] US EPA Exposure Factors Handbook (US EPA, 2011)
[xxiv] *Emerg Infect Dis*. Published online July 10, 2013.
[xxv] *Emerg Infect Dis*. Published online July 10, 2013.
[xxvi] Hall, A. J., Lopman, B. A., Payne, D. C., Patel, M. M., Gastañaduy, P. A., Vinjé, J....Parashar, U. D. (2013). Norovirus Disease in the United States. *Emerging Infectious Diseases*, *19*(8), 1198-1205. https://dx.doi.org/10.3201/eid1908.130465.
[xxvii] WHO WQGs for agriculture (WHO, 2006)