

# *Emerging Issues in Water and Infectious Disease*





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# EMERGING ISSUES IN WATER AND INFECTIOUS DISEASE

## FOREWORD

Human development and population growth exert many and diverse pressures on the quality and quantity of water resources and on access to them. Nowhere are the pressures felt so strongly as at the interface of water and human health.

Infectious, water-related diseases are a major cause of morbidity and mortality worldwide. Although a significant proportion of this immense burden of disease is caused by 'classical' water-related pathogens, such as typhoid and cholera, newly-recognized pathogens and new strains of established pathogens are being discovered that present important additional challenges to both the water and public health sectors. Between 1972 and 1999, 35 new agents of disease were discovered and many more have re-emerged after long periods of inactivity, or are expanding into areas where they have not previously been reported. Amongst this group are pathogens that may be transmitted by water.

Understanding why pathogens emerge or re-emerge is fundamental to effective water resource management, drinking-water treatment and delivery, and has become a priority for many national and international organizations. It is also important to be able to gauge the risk from any emerging disease. The perceived severity of risk and significance of an emerging infectious disease may be so far removed from reality that there is potential for inappropriate allocation of resources. This can have repercussions for countries at all stages of development.

Investigating important emerging issues in water and infectious disease and communicating discoveries create unique challenges, which are addressed by an initiative being taken by the World Health Organization (WHO), and collaborators. The initiative seeks to accelerate the identification of actual and perceived issues, to bring together information and knowledge in critical areas, and to disseminate information to policy makers and practitioners in a timely fashion.

We are pleased to issue this publication to broaden awareness of emerging issues in water and infectious disease and to guide readers to sources of information that deal with these issues in greater depth.

*Access to safe water is a fundamental human need and, therefore, a basic human right. Contaminated water jeopardizes both the physical and social health of all people. It is an affront to human dignity.*

**Kofi Annan, United Nations Secretary-General**



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# EVOLUTION OF INFECTIOUS DISEASE

*Nothing in the world of living things is permanently fixed.*

Hans Zinsser. *Rats, Lice and History* (1935)

Pathogenic (disease-causing) micro-organisms have repeatedly altered the course of human history. From the earliest examples of art, literature and scientific writing, the devastating consequences for the populations gripped by diseases of different kinds and severity have been documented in great detail. For example, the influenza pandemic between 1918 and 1920 resulted in an estimated 70 million deaths worldwide. Even today, the overall burden of infectious disease remains high. In 2001, infectious diseases accounted for an estimated 26% of deaths worldwide (Kindhauser, 2003).

In the context of scientific and medical history, microbiology emerged relatively recently as a specialist discipline. Although micro-organisms had been observed in the 17th century and some workers had speculated about the germ theory of infectious disease before the 19th century, the science of microbiology did not become established until after 1850. The skills and perseverance of the early pioneers, combined with advances in analytical tools and techniques, added rapidly to the growing catalogue of pathogens. By 2001, a total of 1415 species of infectious organisms known to be pathogenic to humans had been recorded. Whilst many of these organisms are associated with diseases that have been known for many years, a small but significant percentage are associated with emerging diseases, such as Acquired Immunodeficiency Syndrome (AIDS), Ebola and most recently Severe Acute Respiratory Syndrome (SARS). Indeed, the transmission of the coronavirus responsible for SARS through 'faecal droplets' has re-focused attention on this recognized route of transmission of some viruses.

*I discovered, in a tiny drop of water, incredibly many very little animalcules, and these of diverse sorts and sizes. They moved with bendings, as an eel always swims with its head in front, and never tail first, yet these animalcules swam as well backwards as forwards, though their motion was very slow.*

Antony van Leeuwenhoek (1632–1723)



## **Respiratory Transmission of Faecally Excreted Viruses\***

The transmission of the coronavirus responsible for Severe Acute Respiratory Syndrome (SARS) through 'faecal droplets' has re-focused attention on this recognized route of transmission of some viruses. This document reviews what is known about viruses transmitted by this route and the adequacy of control measures, including building design and management, and plumbing practices.

\* This publication is expected in 2004

Water-related infectious diseases, such as cholera, have also influenced social and political development. Since 1817 at least seven cholera pandemics have been recorded and most have provided specific examples of issues of pathogen emergence, or have significantly influenced public health reforms and the development of microbiology.

Investigating the history of many diseases demonstrates clearly that the evolution of both humans and pathogens is interlinked: human migration has disseminated infectious disease or brought people into contact with new

pathogens; global environmental change has expanded the range of known pathogens or created the conditions for indigenous micro-organisms to emerge as significant human pathogens; modern techniques in animal husbandry, as well as some of the more traditional methods of livestock farming, create a risk from new zoonotic diseases (an infectious disease which normally circulates in an animal host but that can be contracted by humans).

#### Selected cholera pandemics since 1817 and principal outcomes

Dates	Principal outcomes
1817–1823	Possible emergence of a more virulent strain of <i>Vibrio cholerae</i> ( <i>V. cholerae</i> ). Global trade with the Indian sub-continent carried the cholera vibrio around the world.
1829–1851	Waterborne transmission of <i>V. cholerae</i> established.
1852–1859	First isolation of cholera bacterium. Fear of cholera stimulated international co-operation in health.
1881–1896	Conclusive demonstration that cholera was caused by a bacterium.
1961–	Emergence of <i>V. cholerae</i> O1, biotype El Tor.
1992–	Emergence of <i>V. cholerae</i> O139.

## EMERGING WATERBORNE PATHOGENS

### WHAT ARE EMERGING PATHOGENS?

*Long before the advent of modern medical care, industrialized countries decreased their levels of water-related disease through good water management. Yet, even in these countries, outbreaks of waterborne disease continue to occur, sometimes with lethal consequences. In developing countries, water-related disease blights the lives of the poor.*

Gro Harlem Brundtland, WHO Director-General, (2001)

Emerging pathogens are those that have appeared in a human population for the first time, or have occurred previously but are increasing in incidence or expanding into areas where they have not previously been reported, usually over the last 20 years (WHO, 1997). Re-emerging pathogens are those whose incidence is increasing as a result of long-term changes in their underlying epidemiology (Woolhouse, 2002). By these criteria, 175 species of infectious agent from 96 different genera are classified as emerging pathogens. Of this group, 75% are zoonotic species.

Improved methods of surveillance, epidemiological studies and the continuous development of more advanced methods of diagnosis have allowed us to detect new pathogenic species of micro-organism or to associate a known micro-organism with a new or atypical set of disease symptoms. Furthermore, the agents of several diseases that were thought to have been controlled are re-emerging as a result of adaptive changes in the pathogen, changes to the immunological status of the

In 2001, a review of the scientific literature identified 1415 species of infectious organisms known to be pathogenic to humans, including 217 viruses and prions, 538 bacteria and rickettsiae, 307 fungi, 66 protozoa and 287 helminths. Of these, 61% were zoonotic and 12% were associated with diseases considered to be emerging (Taylor, Latham & Woolhouse, 2001).

host, or environmental, demographic and socio-economic changes. Each of these pathogens represents a public health problem.

Developments in our understanding of the relationships between water and human health have been characterized by the periodic recognition of previously unknown pathogens or of the water-related significance of recognized pathogens. Several studies have confirmed that water-related diseases not only remain a leading cause of morbidity and mortality worldwide, but that the spectrum of disease is expanding and the incidence of many water-related microbial diseases is increasing. Since 1970, several species of micro-organism from human and animal faeces and from environmental sources, including water, have been confirmed as pathogens. Examples include *Cryptosporidium*, *Legionella*, *Escherichia coli* O157 (*E. coli* O157), rotavirus, hepatitis E virus and norovirus (formerly Norwalk virus). Furthermore, the importance of water in the transmission of recognized pathogens is being continually assessed as new tools become available through advances in science, technology and epidemiology. *Helicobacter pylori* (*H. pylori*) is an example of a recently emerged pathogen that may be transmitted through water.

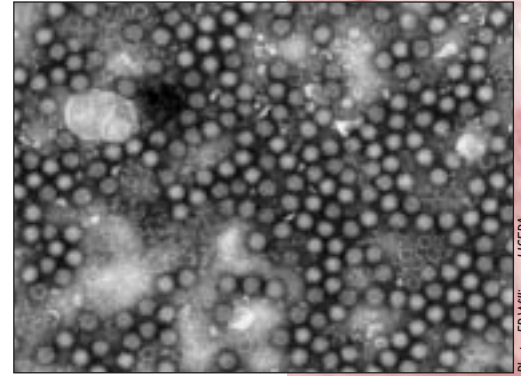


Photo: FP Williams, USEPA

Rotavirus

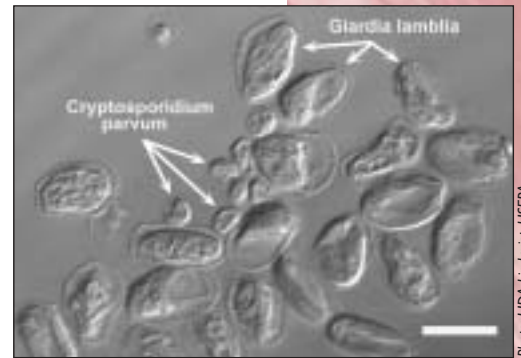
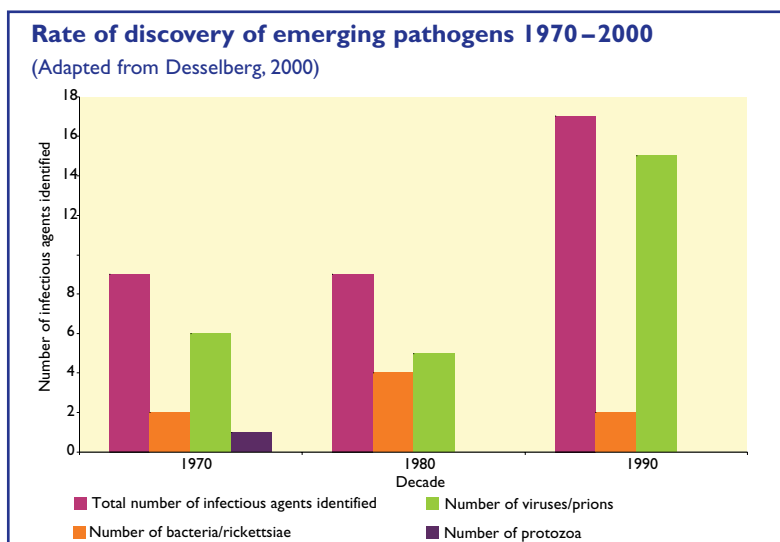


Photo: HDA Lindquist, USEPA

*Cryptosporidium* and *Giardia*

There is a strong link between *H. pylori* infection and gastric cancer in many countries, but there are large intercountry variations in incidence of gastric cancer and *H. pylori* seroprevalence seen among many Asian countries. For example, the prevalence of *H. pylori* infection is high in India and Bangladesh, but low gastric cancer rates have been reported. Factors that may influence the etiology of gastric cancer include the genetic diversity of the infecting *H. pylori* strains and differences in the host genetic background in various ethnic groups. These factors, in addition to environmental factors, such as personal hygiene and dietary habits, reflect the multifactorial etiology of gastric cancer (Miwa, Sakaki & Sugiyama, 2002). A number of studies have demonstrated that *H. pylori* survives in water although isolation of *H. pylori* from water systems has been shown to be difficult.

Similarly, water-related vector-borne pathogens have been (re-) emerging over the past 20 years. To a large extent this has been caused by the emergence and spread of drug-resistant parasites (for example, the *Plasmodium* species causing malaria)

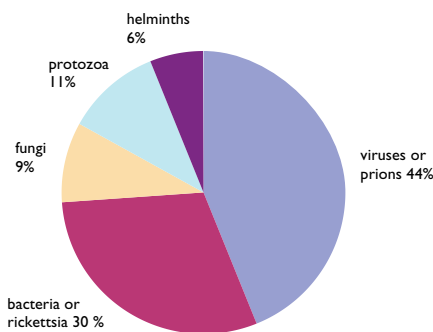


### Major etiological agents of infectious diseases identified since 1972

Year	Agent	Disease
1972	Small round structured viruses	Diarrhoea
1973	Rotaviruses	Infantile diarrhoea
1975	Astroviruses	Diarrhoea
1975	Parvovirus B19	Aplastic crisis in chronic haemolytic anaemia
1976	<i>Cryptosporidium parvum</i>	Acute enterocolitis
1977	Ebola virus	Ebola haemorrhagic fever
1977	<i>Legionella pneumophila</i>	Legionnaires' disease
1977	Hantaan virus	Haemorrhagic fever with renal syndrome
1977	<i>Campylobacter spp.</i>	Diarrhoea
1980	Human T-cell lymphotropic virus-1 (HTLV-1)	Adult T-cell leukaemia/ HTLV-1 associated myelopathy
1982	HTLV-2	Hairy T-cell leukaemia
1982	<i>Borrelia burgdorferi</i>	Lyme disease
1983	HIV-1, HIV-2	Acquired immunodeficiency syndrome
1983	<i>Escherichia coli</i> O157:H7	Haemorrhagic colitis; haemolytic uremic syndrome
1983	<i>Helicobacter pylori</i>	Gastritis, gastric ulcers, increased risk of gastric cancer
1988	Human herpesvirus-6	Exanthema subitum
1989	<i>Ehrlichia spp.</i>	Human ehrlichiosis
1989	Hepatitis C virus	Parenterally transmitted non-A, non-B hepatitis
1990	Human herpesvirus-7	Exanthema subitum
1990	Hepatitis E virus	Enterically transmitted non-A, non-B hepatitis
1991	Hepatitis F virus	Severe non-A, non-B hepatitis
1992	<i>Vibrio cholerae</i> O139:H7	New strain associated with epidemic cholera
1992	<i>Bartonella henselae</i>	CAT-scratch disease, bacillary angiomatosis
1993	Sin nombre virus	Hantavirus pulmonary syndrome
1993	Hepatitis G virus	Non A-C hepatitis
1994	Sabia virus	Brazilian haemorrhagic fever
1994	Human herpesvirus-8	Kaposi's sarcoma
1995	Hendravirus	Castleman's disease
1996	Prion (BSE)	Meningitis, encephalitis
1997	Influenza A virus	New variant Creutzfeldt-Jakob disease
1997	Transfusion-transmitted virus	
1997	Enterovirus 71	Epidemic encephalitis
1998	Nipah virus	Meningitis, encephalitis
1999	Influenza A virus	Influenza (Hong Kong)
1999	West Nile-like virus	Encephalitis (New York)

(Desselberg, 2000)

### Distribution of emerging pathogens by group



The distribution of emerging pathogens according to the main group of micro-organisms to which they belong. The figure shows that nearly half of all emerging pathogens are viruses or prions (adapted from Taylor, Latham & Woolhouse, 2001).

An outbreak of arboviral encephalitis was first recognized in New York City in 1999. The cause of the outbreak was confirmed as a West Nile-like virus. Before and concurrent with this outbreak, local health officials observed increased fatalities among New York City birds, especially crows. Tissue specimens from these birds with pathologic evidence of encephalitis were reported as positive for West Nile-like virus sequence by genomic analysis, implying these as the vectors. Four human deaths occurred among elderly persons. One case-patient with onset in late August reported a history of travel to Africa completed in June 1999. Vector control measures were initiated to control the host-seeking adult *Culex pipiens* mosquito population (MMWR, 1999).

and of insecticide-resistant vectors. Changing environments linked to such trends as intensified water resources development and urbanization, and the accompanying demographic changes, have created conditions where vector-borne diseases can gain new strongholds. International travel has contributed to the spread of pathogens to areas where the vector was already present but so far innocuous (for example, West Nile virus in North America).



## WHY DO PATHOGENS EMERGE?

There are many reasons why human pathogens emerge or re-emerge after a long period of inactivity, but most have a common theme and may be grouped under a few general headings: new environments, new technologies, scientific advances, and changes in human behaviour and vulnerability.

Some factors associated with emerging issues in water and infectious disease, for example, agricultural and wastewater management practices, may be anticipated and subsequently controlled by implementing appropriate resource protection and management strategies. Others, such as demographic, behavioural changes and socio-economic factors, also may be anticipated, but the outcomes are unpredictable and appropriate control measures difficult to implement.

### Potential drivers of the emergence and re-emergence of pathogens in water

#### New environments:

- Climate shifts/deforestation
- Water resources development projects (dams and irrigation)
- Water-cooled air conditioning plants
- Changing industrial and agricultural practices (eg intensive livestock rearing)
- Piped water systems and their inadequate design and operation
- An increasing number of humanitarian emergencies

#### Changes in human behaviour and vulnerability:

- Human circulation and the accessibility and rapidity of transport worldwide
- Demographic changes
- Increasing size of high risk populations
- Deliberate and accidental release of pathogens to water
- An increasing number of humanitarian emergencies

#### New technologies:

- Water resources development projects (dams and irrigation)
- Water-cooled air conditioning plants
- Changing industrial and agricultural practices
- Waterborne sewage and sewage treatment alternatives

#### Scientific advances:

- Inappropriate, excessive use of antibiotics, anti-parasitic drugs and public health insecticides
- Changing industrial and agricultural practices
- Improved methods of detection and analysis
- Inappropriate use of new generation insecticides

## NEW ENVIRONMENTS

The interplay between the host and the pathogen is a complex one, each driven by the need to secure the success of the species. Adaptations by one partner to exploit new environments will often stimulate the other to modify its characteristics to take advantage of the change. As a consequence of this cycle of interaction created by changing environments, new strains of pathogen will evolve. Over time, these strains may emerge as new species with characteristic disease symptoms.

There is a large portfolio of case studies demonstrating how dams and irrigation schemes have led to the spread of malaria, schistosomiasis, filariasis and Japanese encephalitis. Furthermore, climate change is expanding the range of mosquito species responsible for the transmission of the malarial parasite and the dengue virus. The widespread use of water-based cooling towers for industrial air-conditioning was the catalyst for the first major outbreaks of Legionnaires'

In Sri Lanka, the introduction of Japanese encephalitis in rehabilitated rice irrigation schemes under the accelerated Mahaweli Development Project shows the intricacies of environmental change. With intensified irrigation, the population of *Culex* mosquitoes increased rapidly. Yet, the critical factor was a programme to promote pig rearing as a secondary source of income for local communities. Pigs serve as amplifying hosts for the virus and the combination of intensified irrigation and pigs led to serious outbreaks of Japanese encephalitis in the region.

Disease. Thus, new environments can favour the proliferation of pathogens or their vectors and bring about contact with a previously-unexposed population.

Dams are one of the most visible examples of human engineering being used to create a new environment. The Aswan High Dam in Egypt, for example, created a lake, Lake Nassar, 480 km long by up to 16 km wide from the River Nile: a body of flowing water, replaced by a larger body of relatively static water.

Although the Aswan Dam has brought commercial benefits to Egypt, it has also been a factor in the redistribution of the two species of snail, *Bulinus truncatus* and *Biomphalaria alexandrina*, which are the intermediate hosts in the transmission of schistosomiasis. The redistribution of the snails has been used to explain the decreasing prevalence of urinary schistosomiasis and the increasing prevalence of schistosomal nephritis in the region. More recently, the construction of the Diama Dam at the mouth of the Senegal River (1988) led to the single largest outbreak of intestinal schistosomiasis ever recorded in Africa, south of the Sahara.

The *Legionella* bacterium provides another example of the significance of new environments to emerging pathogens. In 1976 a large outbreak of pneumonia was reported amongst delegates at an American Legion Convention in Philadelphia, USA. The etiological agent, *Legionella pneumophila*, was identified



### Toxic Cyanobacteria in Water

Edited by I. Chorus and J. Bartram.

Eutrophication has been recognized as a growing concern since the 1950's. Recently, cyanobacterial toxins became widely recognized as a human health problem arising as a consequence of eutrophication. Cyanotoxins may cause waterborne disease when ingested, and contact through recreational exposure.

Health problems attributable to the presence of such toxins have been reported in a number of countries, including Australia, Brazil, China, England, South Africa and the USA.

This book describes the present state of knowledge regarding the impact of cyanobacteria on health through the use of water. It is an invaluable source of information for environmental health officers and professionals in the field of water supply, freshwater ecology, public health and health education, as well as for student groups and consumer groups.

### Gastro-enteritis epidemic in the area of the Itaparica Dam, Bahia, Brazil

A severe gastro-enteritis epidemic in the Paulo Afonso region of Bahia State in Brazil followed the flooding of the newly constructed Itaparica Dam reservoir in 1988. Some 2000 gastro-enteritis cases, 88 of which resulted in death, were reported over a 42-day period.

Clinical data and water sample tests were reviewed, blood and faecal specimens from patients were subjected to bacteriological, virological and toxicological testing and drinking-water samples were examined for micro-organisms and heavy metals. The results demonstrated that the source of the outbreak was water impounded by the dam and pointed to toxin produced by cyanobacteria present in the water as the responsible agent. No other infectious agent or toxin was identified, and cases occurred in patients who had been drinking only boiled water. The cases were restricted to areas supplied with drinking water from the dam.

Cyanobacteria of the *Anabaena* and *Microcystis* genera were present in untreated water at 1104 to 9755 units per ml.

Photo: Peter Furu, Danish Billharziasis Laboratory



A single scoop of snails along the dam wall of a heavily snail infested reservoir (Lougourougoumbo, Mali).

later, and only after an exhaustive microbiological investigation. The disease became known as Legionnaires' Disease. *Legionella* bacteria are now known to be a normal part of the aquatic microflora. The design of domestic hot and cold water systems, specialist leisure pools and water-cooled air-conditioning plants create conditions that suit the growth of *Legionella* bacteria. Many water systems produce fine aerosols at some stage in their use providing a dispersion mechanism that proved to be an effective route of infection. *Legionella* is an example of a natural, environmental bacterium that has exploited a niche within man-made water systems and, by chance, emerged as a significant pathogen.

## NEW TECHNOLOGIES

More often than not, new technologies have a neutral impact on the ecology of pathogens, but some technologies accidentally introduce new routes of exposure between humans and pathogens. This is particularly evident when dealing with technologies that are used in water treatment, storage and distribution.

New water treatment, storage and distribution technologies are being developed to improve and maintain the quality of drinking-water. Many of these technologies will have significant benefits, but unforeseen problems with a few may introduce new risks, such as harmful by-products or pathways of transmission that may lead to the re-emergence of water-related pathogens. Each time a risk is identified, systems are developed to eliminate or reduce the risk that may, in turn, increase or decrease other risks. In the context of new technologies, water distribution systems show how an engineering solution to one problem can create new opportunities for contact between humans and water-related pathogens.

The effectiveness of slow-sand filtration to remove pathogens from drinking-water before it enters the distribution system was demonstrated spectacularly during the outbreak of cholera in Germany in 1892. Hamburg suffered a very high mortality amongst its population, whilst neighbouring

Altona, which abstracted water from the same source as Hamburg but used treatment by slow-sand filtration, escaped the worst ravages of the cholera. Slow-sand filters occupy large areas of land and so rapid-sand filtration was introduced as an alternative technology. Yet, in order to maintain their efficiency, rapid-sand filters must be cleaned regularly by 'backwashing'. Producers can reduce costs by recycling the backwash water. *Cryptosporidium* oocysts are concentrated on the filters during normal operation. Recycling backwash water to the raw water flow can return large numbers of oocysts to the treatment plant at a time when the plant is potentially vulnerable to breakthrough. This practice has led to outbreaks of disease.

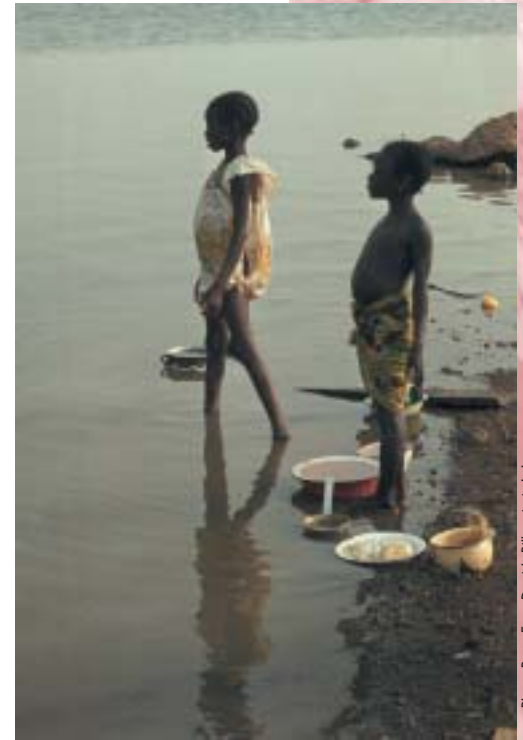


Photo: Peter Furu, Danish Bilharziasis Laboratory

Domestic water contact in a schistosomiasis infested area of the man-made Lake Selingue in Mali (Faraba Village).

The use of technology to treat water is not a modern innovation. Greek and Sanskrit texts dating back 6000 years contain guidance on the use of charcoal filters, boiling, straining and exposure to sunlight to improve the aesthetic quality of drinking-water. Over 4000 years ago, the Egyptians used coagulants to reduce the turbidity of water. With the development of large conurbations throughout the Roman Empire (from 200BC), intricate drinking-water distribution and waterborne sanitation systems were introduced in order to protect the quality of supplies. These piped water systems offered great benefits to the population being served; however, the potential for disseminating pathogens was greatly increased if the source protection and rudimentary treatment systems were breached. Piped distribution without adequate treatment can spread contamination to large populations.



### Sanitation, Sewage and Emerging Health Issues\*

Water safety management relies largely on identifying hazards and ensuring that adequate control measures are available. The proper management of excreta through

the use of appropriate sanitation acts as the primary barrier to prevent the spread of pathogens in the environment. However, faecal contamination of water resources remains a major cause of concern worldwide.

Identification of new hazards occurs relatively frequently, both for microbial pathogens and chemical agents. In some cases controls orientated towards other hazards prove adequate; in other cases control strategies require review. This book provides an authoritative review and discussion of these issues.



### Waterborne Zoonoses\*

The majority of recognized emerging and re-emerging human pathogens are zoonotic. Whether these newly widespread pathogens are within the current envelope of control of waste and source water

management, drinking-water treatment technology and transmission will determine whether these organisms will become newly significant drinking-water risk factors. Identification of those high-risk candidates and their characteristics will allow any necessary adjustments to be made in the drinking-water management cycle in the hopes of avoiding their potential impact upon human health.

Addressing the significant percentage of emerging pathogens which are zoonotic species, this book attempts to analyse the wealth of information from diverse areas to gain insights into the nature of possibly as-yet unrecognized and yet-to-emerge waterborne pathogens that may arise from zoonotic sources. It is oriented towards identifying those hazards that may stress existing control strategies.

Chlorine is the most widely-used drinking-water disinfectant. It was first used for treating water by John Snow (1845) as he intervened to control the outbreak of cholera in London, but it was not until 1897 that it was used to disinfect a potable water distribution main. The use of chlorine disinfection has made an immense contribution to the safety of drinking-water supplies, yet, recently, the limitations of chlorine and some disadvantages linked to its use have been widely publicised:

- Although chlorine is effective against most vegetative bacteria and viruses when used at the normal concentration for treatment, it will not inactivate *Cryptosporidium* oocysts. Furthermore, chlorine has a very limited effect upon pathogens growing in biofilms. So while its use reduces overall risks, it changes the relative impact of different pathogens.
- Traces of chemical by-products of chlorine disinfection have raised public concern about potential long-term but small risks from chemically treated water. Inappropriate decisions made about the risks from chemical contamination versus the need to maintain microbiological safety to protect consumers from imminent high microbial risks have been implicated in the re-emergence of pathogens.

Despite the treatment of source water and the use of chlorine disinfectant, contamination of piped water supply continues to occur, without necessarily causing large easy-to-recognize outbreaks, through leaks, or at other vulnerable parts of the system, and during maintenance work. Once in the system, bacteria, fungi and protozoa can attach to the inner surfaces of the pipes and some may grow to produce biofilms. Some biofilms have been shown to contain one or more species of emerging pathogen, including *Mycobacterium avium* complex (MAC).

Recent analysis of the pathogens regarded as emerging has shown that they are not a random subset of all pathogens, but that they share certain characteristics. Zoonotic pathogens, for example, are almost twice as likely to be regarded as emerging or re-emerging than non-zoonotic pathogens. This observation has implications for intensive livestock farming, which frequently can result in the discharge of pathogens into water from concentrated animal wastes and animal-feeding operations. Several species of emerging water-related pathogen have



In recent years there has been increasing concern to reduce the pollutants within urban stormwater discharges, particularly combined sewer overflows (CSOs). Gibson *et al.* (1998) found *Cryptosporidium* oocysts and *Giardia* cysts were commonly observed at higher levels in discharge from CSO end-of-pipe samples taken during wet weather conditions compared to concentrations in samples taken from an urban dry stream in dry weather. This preliminary study suggests that CSOs may significantly contribute to the load of *Cryptosporidium* and *Giardia* in ambient waters and source waters used for recreational use and potable water.

Photo: Milwaukee Metropolitan Sewerage District



been recognized from these sources, including *Cryptosporidium*, *E. coli* O157 and *Campylobacter*. This example shows how a substantial enhancement of a long-term practice can impact watercourses in ways that are not anticipated.



#### Pathogenic Mycobacteria in Water\*

Previously unrecognized or under-appreciated pathogens continue to be recognized to be associated with the waterborne route and as being of public health significance. *Mycobacterium avium* complex has been a leading cause of death amongst HIV positive populations. Recently, incidence of two of the three diseases associated with MAC (pulmonary MAC and lymphadenitis) appears to be increasing.

There is also evidence of the role that drinking-water plays in the development of MAC-related illness. This book provides information on the *Mycobacterium avium* complex and other pathogenic mycobacteria in water. The book reviews the organisms, their health significance, procedures for investigation and study in water, and weighs up the evidence that water is a significant route for transmission.

## SCIENTIFIC ADVANCES IN WATER MICROBIOLOGY

### DETECTION AND ENUMERATION OF PATHOGENS

The history of pathogen discovery broadly describes a cycle of events beginning with a disease of unknown etiology, development of analytical techniques, and identification of the etiological agent. Advances in analytical techniques are a fundamental component of the exploration of emerging pathogens. By increasing our capacity to concentrate and detect micro-organisms in water samples, we can recognize new pathogens and associate known micro-organisms with diseases of unknown etiology. However, despite advances in diagnostic technology water-related disease of unknown etiology remains a significant percentage of the total outbreaks of disease. Published statistics from the USA show that between 1991 and 2000, the etiological agent of around 40% of drinking-water associated outbreaks was not identified.

Following the conception of the germ theory of infectious disease, methods for the isolation and identification of micro-organisms developed rapidly. During the first half of the 20th century the power of analytical techniques was enhanced by improved culture media for the selection and enumeration of pathogens, and new techniques for visualization of organisms and their cellular structures. Using these techniques, many water-related bacterial and protozoal pathogens were isolated and characterized. The discovery of techniques for growing mammalian viruses in cell culture further expanded the list of water-related pathogens.

In 1972 and 1973 the use of high-resolution microscopy, antibody techniques and genetic analysis identified two groups of viruses that were the causative agents of diarrhoea: small round structured viruses (caliciviruses) and rotaviruses. Subsequent work has shown these two groups to be amongst the



Rat populations thrive where there is human activity. A substantial proportion of above-ground infestations are linked to defects in sewerage infrastructure, and only the presence of watercourses and ditches is a more frequent source (Battersby, 2002). Brown rats (*Rattus norvegicus*) commonly called the sewer rat have been found infected with a greater range of zoonoses than previously thought. For example in England *Cryptosporidium parvum* has been found in rats on farms at 63% prevalence and *Toxoplasma gondii* at 35% (Webster & MacDonald, 1995). In urban areas 11% of a sample of rats were found infected with *T. gondii*. In Milan (Italy) 36% of a sample of wild rats were found to have liver lesions consistent with *Capillaria hepatica* infection (Ceruti et al, 2001). Wild brown rats have been found infected with *Yersinia enterocolitica* at a prevalence of between 2% in urban rats (Battersby et al, 2002) and 11% in rural rats (Webster & MacDonald, 1995). Some 34% of rural rats were found positive for the antibodies of *Coxiella burnetii* (Q Fever) in England (Webster & MacDonald, 1995).

Photo: John Wharam and Daffyd S. R. Baker, Kingston upon Hall City Council





### Heterotrophic Plate Count and Drinking-water Safety

Edited by: J.Bartram, J.Cotruvo, M.Exner, C. Fricker and A. Glasmacher. High levels of microbial growth can affect the taste and odour of drinking-water

and may indicate the presence of contamination posing a challenge to public water utilities. This text addresses the 'heterotrophic plate count' test which is widely used in drinking-water assessment: what it detects (and what it does not detect), its direct and indirect health significance and its use in the safety management of drinking-water supplies.



### Evaluation of the H<sub>2</sub>S method for Detection of Faecal Contamination of Drinking-water

In recent years a number of alternative indicators and tests to detect faecal contamination

of drinking-water have been proposed and developed. Some of these are simple, low cost and do not require a microbiology laboratory or bacteriological field-test kit. Prominent among these is the so-called hydrogen sulphide or H<sub>2</sub>S test, which is intended to detect or quantify hydrogen sulphide-producing bacteria, largely associated with faecal contamination.

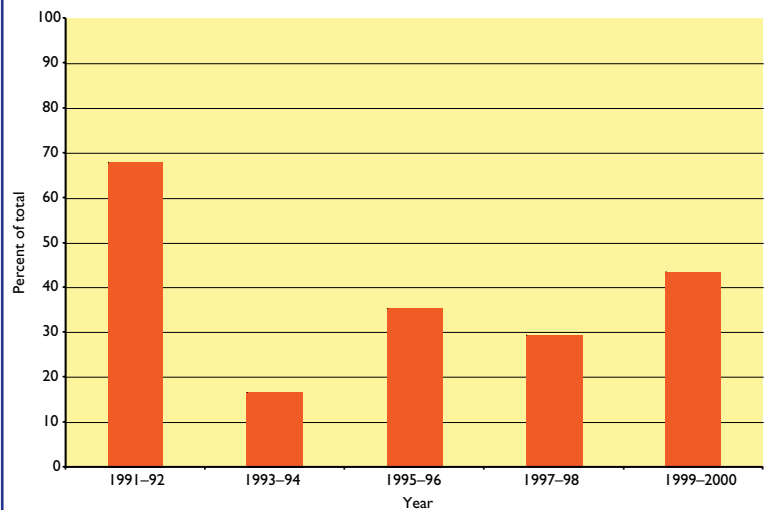
This relatively simple, low cost test has been studied, modified in various ways, tested and used to some extent in many parts of the world as an indicator of faecal contamination of drinking-water.

This book reviews the basis of the hydrogen sulphide test as a measure of faecal contamination of drinking-water and the available scientific and empirical evidence for and against the test as a valid, useful and reliable measure of faecal contamination and drinking-water quality.

major causes of diarrhoea worldwide and a significant cause of mortality amongst children in developing countries.

Possibly the most revolutionary advance in analytical technology during the last 30 years was the discovery of a simple, but effective method of amplifying very specific regions of an organism's genetic material. The technique, called the Polymerase Chain Reaction (PCR), is now widely used in medical, forensic and environmental laboratories. Not only does the method allow investigators to discriminate between micro-organisms from different sources, it can be used to detect extremely small quantities of the nucleic acid: equivalent to a single micro-organism. Detection of nucleic acid by PCR does not necessarily indicate that viable infective organisms are present, but it is an excellent exploratory tool.

### Drinking-water disease outbreaks of unknown etiology in the USA 1990–2000



A significant number of the viruses associated with water-related disease outbreaks cannot be grown in the laboratory using conventional culture techniques. The use of PCR methods for the analysis of pathogens in water has been fundamental to our understanding of the distribution of some of the most important water-related viral pathogens: for example noroviruses, rotaviruses and hepatitis E virus.

Other recently-developed technologies are being assessed for their application in water microbiology. Flow cytometry is a powerful technique using laser light to quantify particles or to recognize structural features of cells. By measuring the scatter and wavelength of light as a particle intercepts the beam, information can be gained that allows the rapid quantification of the organisms. The analytical capability of the technique can be further enhanced by use of fluorescent monoclonal antibodies that are specific for a particular pathogen. Using this, and other fibre optic technologies, we are presented with the potential to detect and quantify water-related pathogens in real time. The implications of these advances to the management of water quality and the protection of public health may be far reaching.

## DEVELOPING EFFECTIVE MONITORING

The recognition of emerging and re-emerging pathogens does not rely solely upon the development of new analytical methods. The reassessment of methods in the context of improved knowledge about the health risks from water-related disease leads to evolving interpretation of findings. This is a feature of many of the publications listed throughout this brochure.

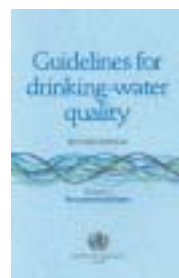
WHO has recognized the limitation of many established methods for monitoring water quality when it comes to predicting the presence of known pathogens. New approaches to health-related monitoring are being introduced that can overcome many of the weaknesses of current methods and provide additional tools for reducing disease risks. Water Safety Plans (WSPs) are an approach to drinking-water safety management that has its roots in the multiple barrier principle of water treatment, and the Hazard Assessment of Critical Control Points (HACCP) approach to the safety of foods. The primary objectives of a WSP in ensuring good drinking-water supply practice are the prevention of contamination of source waters, the reduction or removal of contamination through treatment processes to meet health-based targets, and the prevention of contamination during storage, distribution and handling. WSPs are a central component of the 3rd edition of the WHO *Guidelines for Drinking-water Quality*. This approach to water quality management presents challenges for process monitoring and puts new demands on analysis.

## CHANGES IN HUMAN BEHAVIOUR AND VULNERABILITY

### IMMUNE STATUS

The immune system provides an efficient line of defence against infection. During the life of an individual, the immune system develops, matures and eventually wanes. At birth the immune system offers little protection against infection, but it develops rapidly in response to stimulants in the environment, infectious disease organisms, and from contact with other people. After a few years the body has acquired an elaborate system of cellular and humoral immunity that can rapidly neutralize an infectious agent as well as set up a barrier against future infection by the same agent. In later life, the efficiency of the immune system begins to wane and the body is once again more susceptible to infection.

Factors apart from age can affect the effectiveness of the immune system: for example, the individual's level of nutrition and fitness, stress, excessive exposure to ultraviolet irradiation, and pregnancy. Some, however, can have a devastating impact on the immune system. The transplantation of organs, such as the heart,



### Guidelines for Drinking-water Quality

The WHO *Guidelines for Drinking-water Quality* are the international reference point for standard setting and drinking-water safety. The Guidelines are supported by

other publications explaining how they were derived and to assist in implementing safe water activities. To keep pace with new developments the *Guidelines for Drinking-water Quality* are under constant rolling revision. Thus the development of the third edition of the *Guidelines for Drinking-water Quality (2004)* includes a substantive revision of approaches to ensuring microbial safety. This takes account of important developments in microbial risk assessment and its linkages to risk management.

Information on updating the Guidelines is available on the Internet [http://www.who.int/water\\_sanitation\\_health/GDWQ/index.html](http://www.who.int/water_sanitation_health/GDWQ/index.html).

liver and kidneys, is followed by the long-term administration of immunosuppressive drugs to prevent rejection of the new organ. Cancer treatment often involves procedures that reduce the effectiveness of the immune system. Infection with the human immunodeficiency virus (HIV), itself a recent emerging pathogen, severely impairs the host's cellular immune system, eventually leading to AIDS.

In combination, the ageing of the world's population, the use of immunosuppressive procedures, and the global spread of HIV/AIDS have

Microsporidia are obligate, intracellular spore-forming protozoa. About 1000 species of microsporidia have been recognized, mainly as parasites of fish and invertebrates. In a susceptible human host, infection by the organism can cause chronic diarrhoea, dehydration and weight loss. Human disease caused by microsporidia was largely unknown before the emergence of HIV, and subsequent recorded cases of the disease, in the main, have been confined to HIV-infected immunocompromised individuals and organ transplant recipients who are being treated with immunosuppressive drugs (Franzen & Müller, 1999). Waterborne outbreaks of microsporidiosis have been recorded and, once again, the cases have been largely limited to immunocompromised individuals (Slifko, Smith & Rose, 2000).

created a large and growing population with impaired immune systems. This group of people is highly susceptible to infection by organisms that may be of little or no threat to immunocompetent individuals, or have a greater risk of mortality from normally-benign infections. Several pathogens have emerged or are re-emerging within the immunocompromised population eg. *Cryptosporidium* and MAC.

## BREAKDOWN IN PUBLIC HEALTH MEASURES

*The fundamental maxim of public health must guide current disease prevention programmes: the health of the individual is best ensured by maintaining and improving the health of the entire community.*  
Satcher (1995)

Human frailty has been the cause of many outbreaks of infectious disease, but the consequences can be particularly devastating when the failure has occurred within established public health protection measures. The 1976 USEPA Interim Primary Drinking Water Regulations recognize this risk in their statement on water sources:

*Production of water that poses no threat to the consumer's health depends on continuous protection. Because of human frailties associated with protection, priority should be given to selection of the purest source. Polluted sources should not be used unless other sources are economically unavailable, and then only when personnel, equipment and operating procedures can be depended on to purify and otherwise continuously protect the drinking-water supply.*

In May 2002 the water supply of Walkerton, Canada became contaminated with a mixture of pathogens including *E.coli* O157:H7 and *Campylobacter jejuni* when runoff in contact with livestock waste entered a well. As a result, over 2300 people became ill and seven people died from infection by these bacteria. The inquiry into the incident was highly critical of many of the local agencies involved in the supply of water and in the protection of public health, and

*Cryptosporidium*, a coccidian protozoan parasite, was only identified as a human pathogen in 1976. It can cause diarrhoeal illness in the immunocompetent but with dire consequences in immunocompromised individuals. The disease is endemic throughout the world. The incidence of infection is also high, illustrated by the finding that in the USA 20% of young adults have evidence of infection by *Cryptosporidium*. This rate was over 90% amongst children under one year old in a Brazilian shanty town (Kosek et al, 2001).

highlighted a breakdown of ordinary public health measures as one cause of the outbreak.

The 1993 outbreak of cryptosporidiosis in Milwaukee, USA, involved up to 400,000 cases of serious illness and 100 deaths, principally among AIDS patients. The cause of the outbreak appeared to be linked to two factors: the location of the water intake to the treatment works and the experimental coagulation system which turned out to be ineffective, resulting in the turbidity limits for some of the filters being exceeded.

The Milwaukee and Walkerton incidents have done much to redress the perceived balance of risks and bring microbiological parameters back to the fore. At the time, some interpreted the accumulated experience in industrialized countries as suggesting that waterborne infectious disease had been conquered and the most significant risks to health were from chemical contaminants. With hindsight it is easy to see the mistake of directing attention towards the health risk from chemicals at the expense of vigilance with regard to microbial hazards. These two and other incidents have emphasized the fundamental importance of the multiple barrier principle of water treatment and the need to implement a systems approach to preventive risk management as advocated in the current revision of the WHO Guidelines for Drinking-water Quality and the development of WSPs.

## HUMAN MIGRATION

### *Borders are porous and microbes readily cross them.*

Wilson (1995)

Cholera provides a good example of a water-related pathogen that is readily transported over long distances by human migration. In 1849 John Snow wrote: *Epidemics of cholera follow major routes of commerce. The disease always appears first at the seaports when extending into islands or continents.* This observation is pertinent even today. It has been suggested that *V. cholerae* may have been re-introduced to South America in 1991, after a century of absence, from the bilge and ballast water of cargo ships.

Human migrations take many forms and occur for many reasons: some voluntary, some forced. In his account of the environmental history of the 20th century, John McNeill argues that human migration has often mattered more than population growth as a driver of environmental change. He also asserts that the most important migrations, from an environmental perspective, have occurred at the boundaries between natural environments: *...from humid to dry lands repeatedly provoke desertification. Migrations from flatlands to sloping lands often led to faster soil erosion. Migrations into forest zones brought deforestation*



### **Water Quality: Guidelines, Standards and Health.** **Assessment of risk and risk management for water-related infectious disease.**

Edited by L.Fewtrell  
and J.Bartram.

The quality of water is significant for health worldwide. Accordingly, water quality standards and guidelines are developed to protect public health. However, it has become clear that there is a need for a harmonised framework to inform guideline development and revision to support better health protection.

This book contains a series of reviews which address the principal issues of concern linking water and health to the establishment and implementation of effective affordable and efficient guidelines and standards.

Before the development of the sugar estates of Wonji and Metahara in Ethiopia in the 1950s, schistosomiasis was confined to the provinces of Harar, Tigray and the Lake Tana Basins. The irrigated sugar estate ecologies, which favour the propagation of aquatic snails, increased the environmental receptivity to schistosomiasis transmission dramatically. It was the migration of agricultural labourers southwards, however, which triggered the introduction and spread of *S. mansoni*. Seasonal workers coming from the southern districts of Wolayita, Hadya and Kenibata will have picked the newly spread pathogens up at the sugar estate and distributed them further south, including to the irrigation schemes of the Middle Awash Valley. Increased circulation of humans during the 1984–85 droughts exacerbated the spread and intensification of the disease (Meskal, 1987).

(McNeill, 2000). Likewise, the migration of people between natural boundaries has been responsible for the emergence of several infectious diseases. Most notable are diseases that have emerged as humans have encroached upon forest regions, bringing people into closer contact with animal species carrying pathogens that can be transmitted across the species barrier.

Each year, the United Nations High Commission for Refugees (UNHCR) publishes an estimate of the number of refugees. Between 1980 and 2001, the number of refugees has risen by 42.8%, from 8.4 to 12 million (UNHCR, 2002), although it is down from a peak of 17.8 million in 1992. The scale of the situation is confirmed in a recent report by the International Organization for Migration, which indicates that worldwide, one out of every 35 people is a migrant (IOM, 2003).

**Trend in the estimated number of refugees between 1980 and 2001 (UNHCR, 2002)**

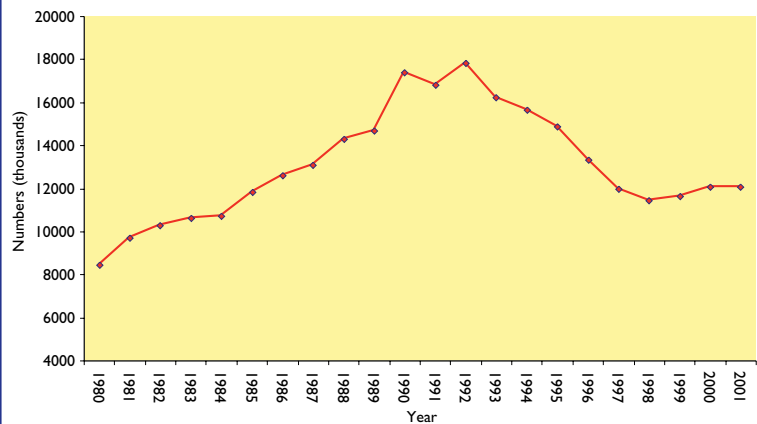


Photo: WHO/P. Virat

High-density peri-urban area

In most developed countries *Cyclospora cayatanensis* has been primarily associated with foodborne disease outbreaks and most cases in Europe and Australia have been associated with international travel in endemic areas. In December 2000 a foodborne outbreak in southwest Germany was reported. Investigation linked transmission to a salad dish. The sources of the lettuce were traced to farms in southern France and Italy. Although the oocysts may have been transmitted to the lettuce via seasonal workers from endemic countries, it is thought possible that contamination was also through local soil or water contact (Döller et al., 2002).

The rate of urban growth and urbanization are important characteristics of human settlement in the late 20th and early 21st centuries. The rate of growth is increasing, with much of the growth occurring in developing or low- to middle-income countries. In the year 2000, 2.8 billion people lived in urban settlements, equivalent to 47% of the global population (UN-HABITAT, 2003a). By 2007 more people will live in urban areas than rural areas for the first time ever in human history (UN-HABITAT, 2003b).

Two processes drive the growth in population in urban areas: natural increase due to high fertility rates, and rural urban migration (McMichael, 2000). Often, however, the burden of population growth is not evenly distributed across the urban settlement, with the most rapid increases occurring in low-income areas. In developing or low-income countries the peri-urban areas are often characterized by high density, poor quality housing, a low level of health and social services, and limited access to basic services such as water and sanitation. The social and often unsanitary environmental conditions that prevail in these areas are conducive to the emergence and rapid spread of infectious disease.





Water-based recreation is highly popular

Another significant form of human migration is tourism. In 2001, 690 million international arrivals were recorded by the World Tourism Organization. This volume of human movement is unprecedented and, combined with the speed and accessibility of modern methods of transport, has increased the potential for diseases to be transmitted over great distances within a very short time. With the growth of tourism the popularity of recreational activities which involve contact with water has grown; moreover, ease of travel has altered the public use of water for recreational purposes. Due to travel to warm climates, prolonged periods of immersion are now becoming normal and activity occurs throughout the year, and not just during bathing seasons.

Severe illness due to dermal contact with toxic cyanobacteria mats has been reported from tropical marine bathing sites (Edwards, *et al.* 1992). Many infections occur on a seasonal basis and therefore users will be exposed to different and unfamiliar pathogens in the water in different locations. Many cases of schistosomiasis in Europe for example are imported where travellers to tropical and sub-tropical areas have been infected by the parasite whilst undertaking water-related activities.



### Guidelines for Safe Recreational-water Environments

Recreational use of water can have benefits to health and also adverse health effects if it is polluted or unsafe. Recreational-water users may also be exposed to hazards such as excess heat, cold and sunlight.

WHO produces international norms on recreational-water use and health in the form of Guidelines. The first edition of the WHO *Guidelines for Safe Recreational-water Environments* is published in two volumes: **Volume 1: Coastal and Freshwaters**; and **Volume 2: Swimming Pools, Spas and Similar Recreational-water Environments**.

**Volume 1** of the Guidelines provides an authoritative referenced review and assessment of the health hazards associated with recreational waters.

**Volume 2\*** provides Guidelines on the health hazards associated with swimming pools, spas and similar recreational-water environments.



### Serious illness in Recreational-water Environments\*

The vast majority of research to date concerning recreational waters has focused on gastro-enteric outcomes arising from contamination of water by sewage and excreta and it has become apparent that mild gastro-enteric symptoms are widespread and common amongst recreational-water users.

As the use of water for recreational purposes becomes ever more popular and travel becomes easier, users will be exposed to different types of pathogens in the water, some of which may produce more severe potential health outcomes resulting in symptoms which are not self limiting and require medical attention.

This book systematically reviews the evidence for, and credibility of transmission of a broad range of pathogens encountered through recreational use of water resources. It provides invaluable reading for environmental health officers, medical practitioners, water-quality scientists and environmental regulators.

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The Water Sanitation and Health (WSH) activities at WHO aim to reduce water-related disease and optimize the health benefits of sustainable water and waste management. Our objectives are to support the health sector in effectively addressing water and waste-related disease burden and engaging others in its reduction. WSH also assists non-health sectors in understanding and acting on the health impacts of their actions.

Activities carried out include:

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- Assessing status and trends.
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*'Of all our natural resources, water has become the most precious...In an age where man has forgotten his origins and is blind even to his most essential needs for survival, water along with other resources has become the victim of his indifference'. Rachel Carson, Silent Spring.*

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