World Health Organization

REGIONAL OFFICE FOR Europe

Technical guidance on water-related disease surveillance

PROTOCOL ON WATER AND HEALTH

World Health Organization

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Technical guidance on water-related disease surveillance

Edited by: E. Funari, T. Kistemann, S. Herbst and A. Rechenburg

ABSTRACT

This technical guidance is intended to assist the Parties to the Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes in establishing and/or strengthening outbreak detection and early warning systems, contingency plans and capacity response in accordance with article 8 of the Protocol. The draft guidance reviews the main threats to health related to water services, recalls basic concepts of epidemiology and disease surveillance and provides guidance on data management and analysis. It will therefore also support national efforts towards national and international health security in line with the International Health Regulations (2005). The guidance was approved by the Parties at the second session of the Meeting of the Parties (Bucharest, Romania, 23–25 November 2010)

KEYWORDS

ENVIRONMENTAL MONITORING – methods
EPIDEMIOLOGICAL SURVEILLANCE – methods
WATER POLLUTION – prevention and control
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WATER MICROBIOLOGY
DISEASE TRANSMISSION
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TECHNICAL COOPERATION
GUIDELINES

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CONTENTS

Tables

Figures

Preface

The importance of the impact of water-related diseases on human health has been recognized as a major threat to sustainable human development in some international forums, including the Millennium Development Goals, the World Summit on Sustainable Development (Johannesburg, 26 August – 4 September 2002), the 3rd World Water Forum (Kyoto, Shiga and Osaka, Japan March 2003), the Environment for Europe process and the Dushanbe International Freshwater Forum (Dushanbe, Tajikistan, 29 August – 1 September 2003), among others. Within the WHO European Region, the majority of WHO Member States committed themselves to a coordinated fight against water-related diseases through the Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

Following the entry into force of the Protocol on Water and Health in 2005 and the first Meeting of the Parties in 2007, the decision was made to focus on two groups of water-related diseases: those with a high epidemic potential, including cholera, enterohaemorrhagic *Escherichia coli*, viral hepatitis A, bacillary dysentery and typhoid. A second group of emerging diseases were recognized to be of increasing health concern in the region. These include campylobacteriosis, cryptosporidiosis, giardiasis and legionellosis. In addition, some pathologies are recognized to be locally important, such as helminth infections.

In line with the holistic approach to synchronizing water services and health, this guidance document reviews the main threats to health relating to water services, as well as recalling basic concepts of epidemiology and disease surveillance, and providing guidance on data management and analysis.

This volume will support national efforts towards national and international health security in line with the International Health Regulations (2005), which entered into force on 15 June 2007. It also constitutes a step towards the implementation of the Tallinn Charter: Health Systems for Health and Wealth (WHO European Ministerial Conference on Health Systems: “Health Systems, Health and Wealth”, Tallinn, Estonia, 27 June 2008), in particular ensuring “a holistic approach to health services, involving health promotion, disease prevention and integrated disease management programmes, as well as coordination among a variety of providers, institutions and settings”. It also follows the WHO guidelines (2008) concerning the use of an integrated risk assessment/risk management approach – termed a water safety plan (WSP) – as a basis for the continued provision of safe water.

The document is inspired by a WHO public health initiative on surveillance of water-related diseases in central Asia, organized at the WHO Collaborating Centre for Health Promoting Water Management and Risk Assessment at the University of Bonn, Germany. Every effort has been made to draw on the lessons of this initiative in making the guidance in this document relevant to all countries in the Region, taking into account the different capacities for surveillance and outbreak detection.

The work was carried out by the Task Force on Water-related Disease Surveillance, chaired by the Italian National Institute of Health and supported by the Joint Secretariat.

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Abbreviations

ATXa	anatoxin-a
BMAA	β-N-methylamino-L-alanine
CDC	Centers for Disease Control and Prevention (United States)
CYN	cylindrospermopsin
DBP	disinfection by-product
DDT	Di(para-chloro-phenyl)-trichloroethane
EC	European Commission
EHEC	enterohaemorrhagic *Escherichia coli*
EIEC	enteroinvasive *E. coli*
ELISA	enzyme-linked immunosorbent assay
EOHSP	European Observatory on Health Systems and Policies
EPEC	enteropathogenic *E. coli*
ETEC	enterotoxic *E. coli*
EU	European Union
GDWQ	guidelines for drinking-water quality (WHO)
GIS	geographical information system
GL	guidance level
GP	general practitioner
GV	guideline value
HACCP	hazard analysis and critical control points
HAV	hepatitis A virus
HEV	hepatitis E virus
HuCVs	human calicivirus
HUS	haemolytic uremic syndrome
IARC	International Association for Research on Cancer
IDC	individual dose criterion
IHPC	Institute for Hygiene and Public Health (Bonn, Germany)
LOAEL	lowest observed adverse effect level
LPS	lipopolisaccharidic (endotoxins)
MC	microcystin
MCPA	4-(2-methyl-4-chlorophenoxy) acetic acid
OMT	outbreak management team
OR	odds ratio
POU	point-of-use (treatment)
MMWR	Morbidity and Mortality Weekly Report
NOAEL	no observed adverse effect level
NHMRC	National Health and Medical Research Council
NTU	nephelometric turbidity units
RR	relative risk
STX	saxitoxins
TDI	tolerable daily intake
THM	trihalomethanes
UF	uncertainty factor
UV	ultraviolet
USEPA	United States Environmental Protection Agency
VHH	volatile halogenated hydrocarbons

WSP	water safety plan
WSS	water supply structure

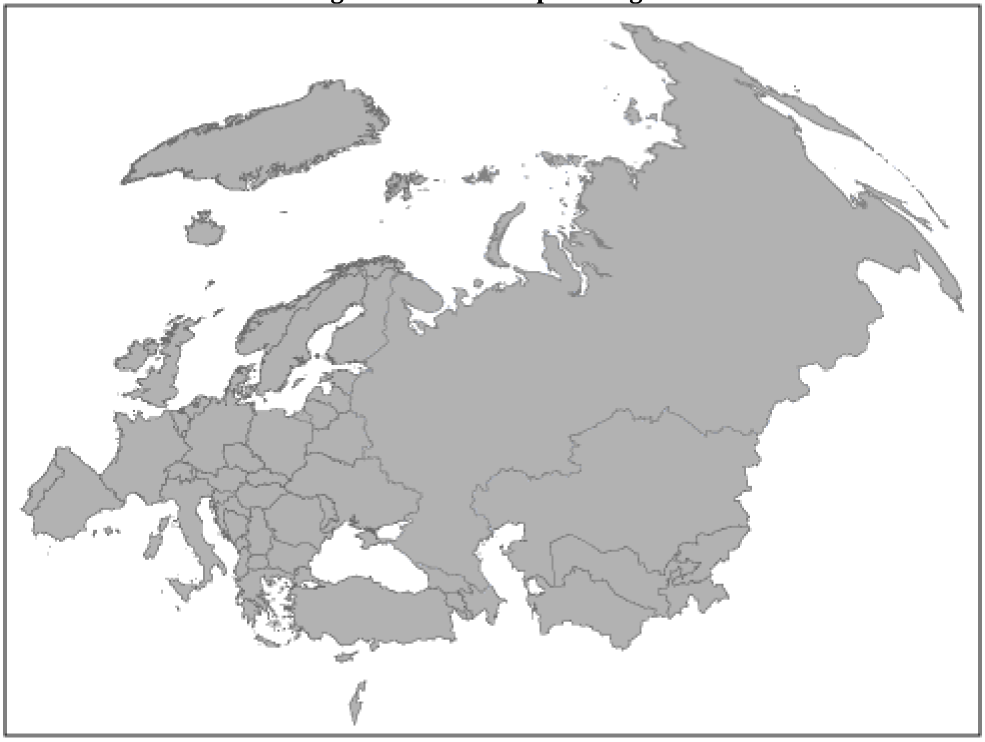
1. Introduction

Lead author: Martin Exner

Over 30 million cases of water-related disease could be avoided globally each year through water and sanitation interventions. Investing in water supply and sanitation has produced benefits far greater than those directly related to the cost of treatment for water-related diseases (Bartram, 2002).

Gastrointestinal infections are one of the principal causes of morbidity and mortality among children. For children under 5 years of age in developing countries it is estimated that a median of 3.2 episodes of diarrhoea occur per child per year (Kosek, Bern & Guerrant, 2003). Estimates of mortality revealed that 4.9 children per 1000 die each year as a result of diarrhoeal illnesses in the first five years of life. In the WHO European Region (Fig. 1.1), a clear distinction has been noted between the mortality resulting from diarrhoeal diseases in the EUR-A, EUR-B and EUR-C regions.[1] Fig. 1.2 shows the standardized death rates from diarrhoeal diseases in the group aged under 5 years in the EUR-A and the EUR-B+C regions, respectively.

Fig. 1.1. WHO European Region



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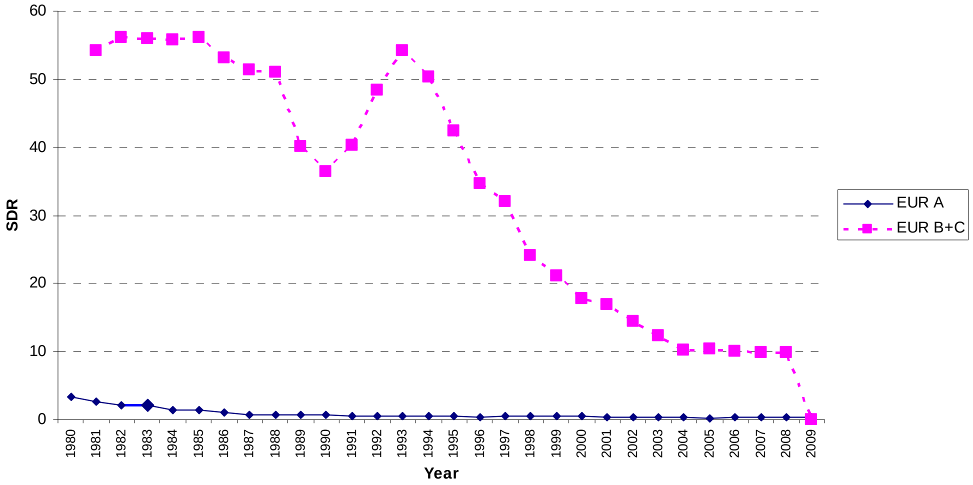
[1] The WHO European Region can be divided into subregions, according to mortality levels, as follows:

- EUR-A: Andorra, Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom;
- EUR-B: Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Montenegro, Poland, Romania, Serbia, Slovakia, Tajikistan, the former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Uzbekistan;
- EUR-C: Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine.

Fig. 1.2. Standardized death rate (SDR) from diarrhoeal disease under 5 years of age



Source: WHO Regional Office for Europe, 2010.

While mortality data are surely the most striking, morbidity figures show that water-related disease continues to be a serious problem in the WHO European Region, hampering sustainable development and imposing prohibitive economic costs.

Waterborne diseases with high potential for developing into epidemics, such as cholera, were brought under control through the works of John Snow (1854), Filippo Pacini (1854) and Robert Koch (1893), among others. Diseases such as hepatitis A, typhoid and paratyphoid, bacillary dysentery and infections by *Escherichia coli* are still significant health concerns in many countries of the Region, while endemic or imported cholera cases demand constant vigilance.

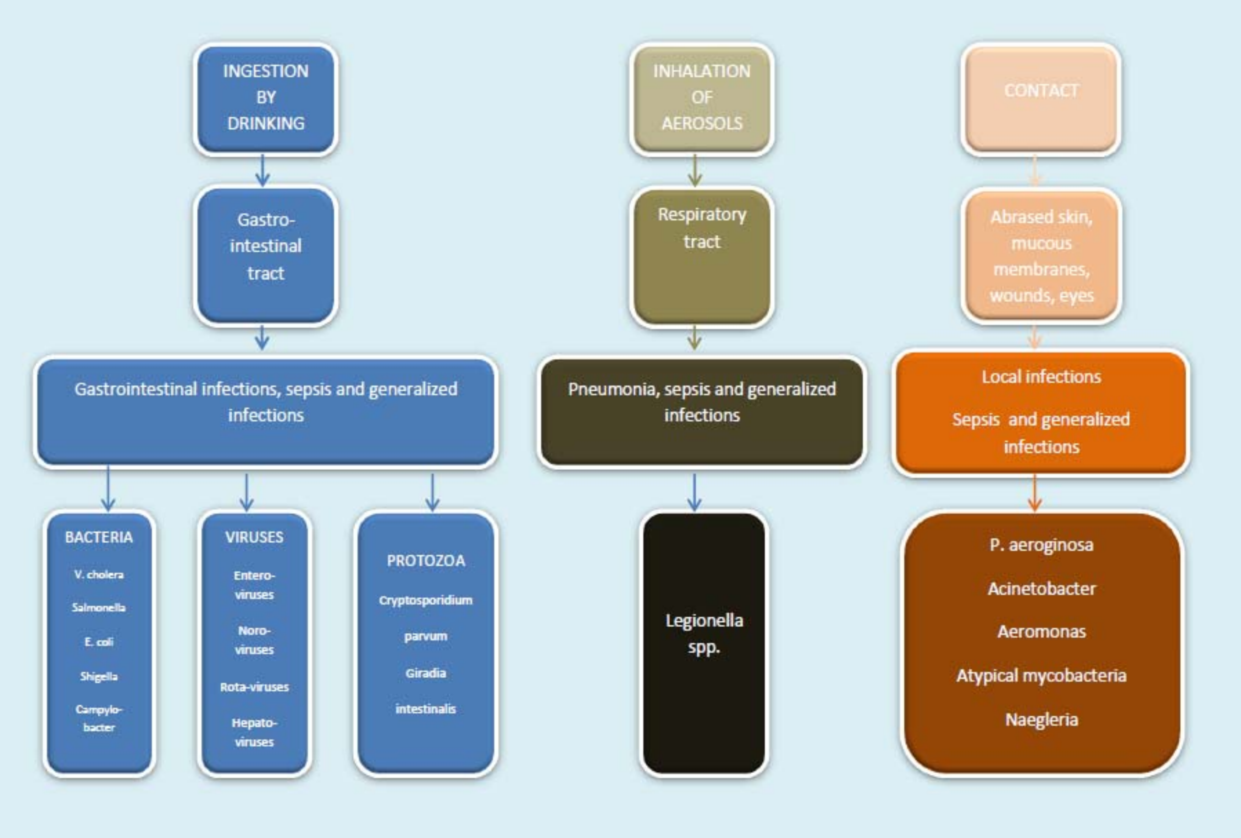
Emerging pathogens in drinking-water have become increasingly important since the late 1980s. The newly identified and re-emerging water-related pathogens include *Campylobacter* spp., human-pathogenic enterohaemorrhagic *E. coli* (EHEC) strains, *Yersinia enterocolitica*, enteric viruses such as rotavirus and norovirus, and the parasites *Cryptosporidium parvum* and *Giardia lamblia*. Such emerging pathogens in drinking-water have led to new demands in drinking-water hygiene, even in countries having achieved a high standard of water treatment since the late 1980s.

In dependency on the route of transmission, waterborne pathogens must be subdivided into those that are transmitted via ingestion and those that are transmitted via inhalation or contact. Infection by *Legionella* spp. is a typical example of use of aerosol as the exposure route. An overview of transmission pathways for some pathogens is given in Fig 1.3. It is important to distinguish between infections transmitted via ingestion and those transmitted via inhalation.

Public health systems throughout the WHO European Region are therefore faced with important challenges: they are at the forefront of reducing the endemic disease burden related to water and sanitation. Public health professionals need to be prepared for outbreaks and make contingency plans, including keeping abreast of new epidemiological insights. The challenges are particularly great in the eastern part of the Region, where strengthening primary health is a priority.

In order to reduce the burden of water-related diseases in Europe, active involvement of all stakeholders is required. In particular, strengthening the relationship between public health services and the utilities managing the production and distribution of drinking-water should be seen as a priority challenge. The links between the two are detailed in the framework for safe drinking-water, as summarized in Fig 1.4.

Fig. 1.3. Transmission pathways



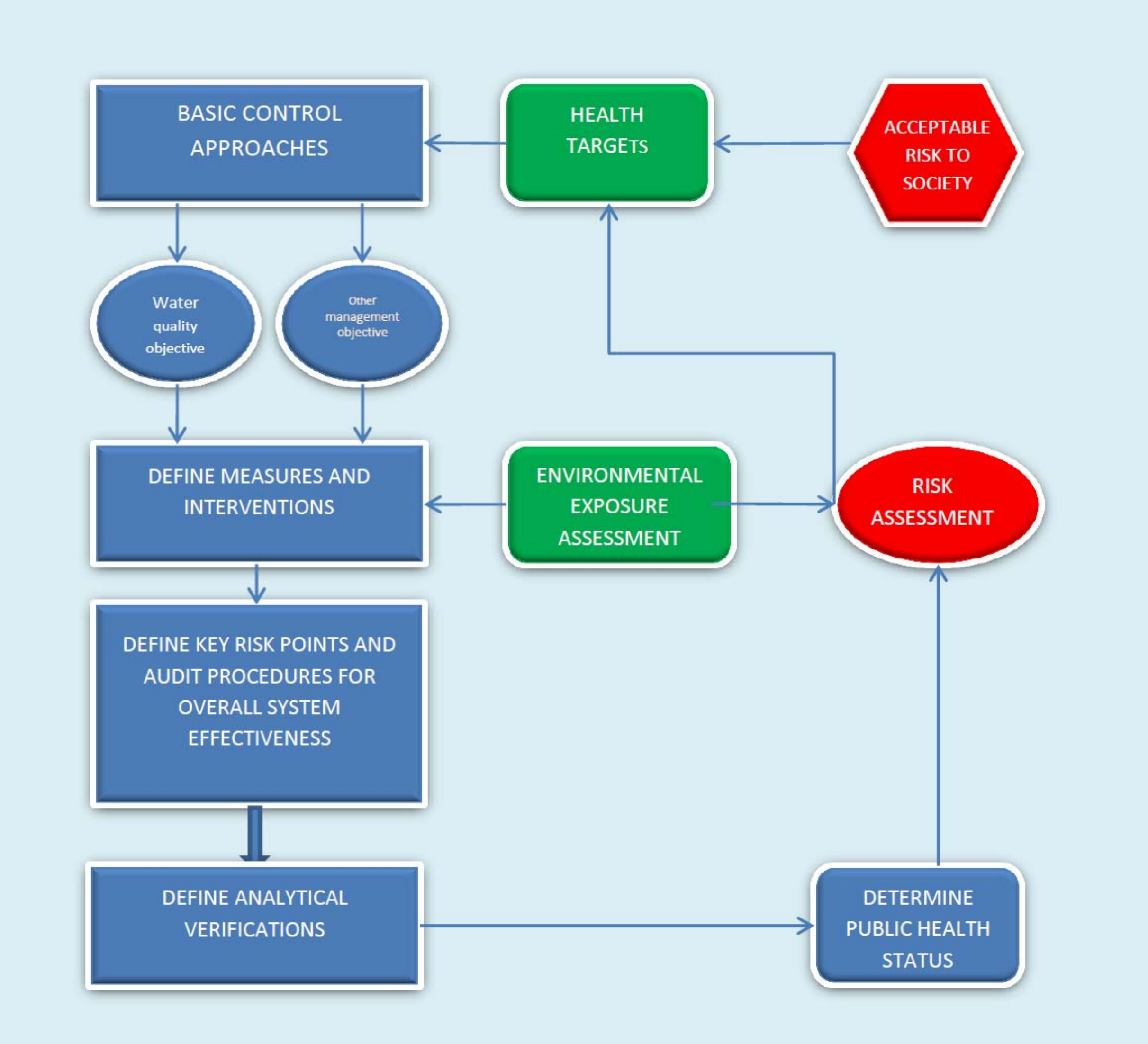
Source: WHO, 2004.

Primary health care promotes a holistic approach to health that makes prevention equally as important as cure. It aims to integrate health into all sectors, pursue collaborative models of policy dialogue, and increase stakeholder participation. In order to assist the cooperation between the different stakeholders involved in the implementation of the health framework, there is a need to strengthen understanding by primary health services of the approach followed by water utilities in their efforts to ensure safe water, and for understanding by the water utilities and other stakeholders of the techniques and approaches applied by (primary) health care services.

The first section of these guidelines summarizes basic information on water-related pathogens and chemical contaminants.

The second section introduces the different risk factors that affect drinking-water quality, from resource over treatment and distribution to the ultimate consumer and the steps taken by the water utilities to diminish the resulting risk through a multi-barrier approach. The basic concepts of the water safety plans (WSP) – as recommended in the third edition of the WHO guidelines for drinking-water quality – are recalled as a holistic framework for risk assessment/risk management. This section should allow health services to gain a fundamental insight into the basic approach to water safety from the viewpoint of a water utility, to identify the precise role of the (primary) health systems (in so far as they are not statutorily defined) and to interact in a meaningful way with water utilities and other stakeholders, particularly those tasked with environmental management.

Fig. 1.4. Expanded health framework



Source: Bartram, Fewtrell & Stenström, 2001.

The third section of these guidelines then focuses on the specific management of health concerns relating to surveillance of water-related diseases. The difference between surveillance of drinking-waterborne infectious diseases and conventional surveillance systems is the integration of data from the drinking-water supply into the surveillance of infectious diseases. The surveillance authority must have the power to determine (a) whether a water supplier will focus on the specific management of health concerns – in a few cases this may result in a water service engaging in the monitoring of water-related disease outbreaks within the service area – and (b) whether a water supplier is fulfilling its obligations, thereby again strengthening the multisectoral approach (WHO, 2006).

In order to promote a multisectoral approach, the guidelines outline basic epidemiological concepts and theoretical models relating to the specific challenges of waterborne disease surveillance. Guidance is offered on the correct formulation of surveillance programmes, including investigative activities undertaken to identify and evaluate risk factors associated with drinking-water. Counsel is offered on the setting up and operation of national surveillance systems, along with data and information management advice. Guidance will also be provided on evaluating existing surveillance systems and on how such systems could be improved.

Primary health care systems in the WHO European Region face different challenges and have varying capacities. These differences have been taken into account as far as possible. It is hoped that this guidance will assist all stakeholders, policy-makers, health professionals and water utility managers, among others, in developing a common course of action to reduce the level of water-related diseases in the WHO European Region, in line with the provisions of the Protocol on Water and Health to the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

2. Health risks from microbial pathogens

Lead authors: Friederike Dangendorf and Dirk Schoenen

2.1. Definitions

2.1.1. Legal definitions

The Protocol on Water and Health defines “water-related disease” to mean “any significant adverse effects on human health, such as death, disability, illness or disorders, caused directly or indirectly by the condition, or changes in the quantity or quality, of any waters”.

“Drinking-water” means “water which is used, or intended to be available for use, by humans for drinking, cooking, food preparation, personal hygiene or similar purposes”.

“Groundwater” means “all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil”.

“Surface water” is all water naturally open to the atmosphere, including rivers, lakes, reservoirs, streams, impoundments, seas, estuaries and so on. The term also covers springs, wells or other collectors of water that are directly influenced by surface waters.

“Collective system” means: “a system for the supply of drinking-water to some households or undertakings; …”.

“Water management plan” means a plan for the development, management, protection and/or use of the water within a territorial area or groundwater aquifer, including the protection of associated ecosystems.”

2.1.2. Epidemiological definitions

Water-associated diseases are classified into five main groups (according to Bradley, 1974):

- **Waterborne diseases** are caused by the ingestion of faecally contaminated water. Cholera and typhoid fever are classical examples of waterborne diseases, where only a few highly infectious pathogens are needed to cause severe diarrhoea. Shigellosis, hepatitis A, amoebic dysentery and other gastrointestinal diseases can also be waterborne.
- **Water-washed (water-hygiene) diseases** occur due to the lack of adequate water supply for washing, bathing and cleaning. Pathogens are transmitted from person to person or by contact with contaminated surfaces. Eye and skin infections as well as diarrhoeal illnesses occur under these circumstances. Waterborne pathogens include bacteria, viruses, protozoa and helminths. A short list of the most important pathogens and their significance in water supplies is shown in Table 2.1 below.
- **Water-scarce diseases** occur due to the lack of water available for washing, bathing and cleaning. Hence, pathogens are transmitted from person to person or from contaminated surfaces to a person and are spread by the faecal–oral route. In particular, eye (trachoma) and skin infections (scabies), as well as diarrhoeal diseases occur under those conditions.
- **Water-based diseases** are caused by organisms, in particular by different species of worms that spend parts of their life-cycle in different habitats. They have spent one development cycle in aquatic molluscs, and another as fully grown parasites in other

animal or human hosts. Because stagnating surface waters, such as reservoirs, are the preferred habitat of parasitic worms, the occurrence of water-based diseases such as dracunculiasis and schistosomiasis can be heavily influenced by anthropogenic activities.

- **Vector-borne diseases** are caused by bites from insects that breed in water. Insect vectors such as mosquitoes transmit diseases such as malaria, Chikungunya and other diseases.

Table 2.1. Waterborne pathogens and their significance in water supplies

Pathogen	Health significance	Persistence in water supplies	Resistance to chlorine	Relative infectivity	Important animal source
Bacteria					
Campylobacter jejuni, C. coli	High	Moderate	Low	Moderate	Yes
E. coli – pathogenic	High	Moderate	Low	Low	Yes
E. coli – enterohaemorrhagic	High	Moderate	Low	High	Yes
Legionella spp.	High	Multiply	Low	Moderate	No
Salmonella typhi	High	Moderate	Low	Low	No
Other *Salmonella* spp.	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholera	High	Short	Low	Low	No
Yersinia enterocolitica	High	Long	Low	Low	Yes
Viruses					
Adenoviruses	High	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Hepatitis A	High	Long	Moderate	High	No
Hepatitis E	High	Long	Moderate	High	Potentially
Noroviruses and sapoviruses	High	Long	Moderate	High	Potentially
Rotaviruses	High	Long	Moderate	High	No
Protozoa					
Cryptosporidium parvum	High	Long	High	High	Yes
Entamoeba histolica	High	Moderate	High	High	No
Giardia intestinalis	High	Moderate	High	High	Yes
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	High	No
Schistosoma spp.	High	Short	Moderate	High	Yes

Source: WHO, 2004 (p. 122).

In order to evaluate the health risks of water-associated human-pathogenic microorganisms it is necessary to understand their ecology and epidemiology. In this chapter the ecology and epidemiology is described in detail for some of the most significant water-related infectious diseases.

2.2. Diarrhoeal diseases

Diarrhoea occurs worldwide and causes 4% of all deaths and 5% of health loss due to disability.[2] Diarrhoea is the passing of loose or liquid stools more frequently than is normal for the individual. It is primarily a symptom of gastrointestinal infection. Depending on the type of infection, the diarrhoea may be watery (for example in cholera) or passed with blood (in dysentery for example). In many cases in the WHO European Region the cause of diarrhoeal

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[2] WHO fact sheet (http://www.who.int/water_sanitation_health/diseases/diarrhoea/en/, accessed 11 November 2008).

events remains undetermined, especially when the episode is self-limiting. When reported, the term "diarrhoeal disease of unknown aetiology" is used. It is most commonly caused by gastrointestinal infections. Cholera and dysentery cause severe, sometimes life-threatening forms of diarrhoea.

Diarrhoea due to infection may last a few days, or several weeks (persistent diarrhoea). Severe diarrhoea may be life threatening due to fluid loss in watery diarrhoea, particularly in infants and young children, malnourished people and those with impaired immunity. The impact of repeated or persistent diarrhoea on nutrition, and the effect of malnutrition on susceptibility to infectious diarrhoea can be linked in a vicious cycle among children, especially in developing countries.

Diarrhoea is a symptom of infection caused by a host of bacterial, viral and parasitic organisms, most of which can be spread by contaminated water. It is more common when there is a shortage of clean water for drinking, cooking and cleaning, and basic hygiene is important in prevention.

Diarrhoea is also associated with other infections, such as malaria. Chemical irritation of the gut (such as that from magnesium sulfate or copper) or non-infectious bowel disease can also result in diarrhoea.

Water contaminated with human faeces (for example from municipal sewage, septic tanks and latrines) is of particular concern. Animal faeces also contain microorganisms that can cause diarrhoea.

Diarrhoea can spread from person to person, aggravated by poor personal hygiene. Water can contaminate food during irrigation, and fish and seafood from polluted water may also contribute to the disease.

2.3. Bacteriological pathogens

2.3.1. A brief historical note

The first hygienic-microbiological requirements for drinking-water were set by Fränkel (1887) on the basis of colony count studies in wells in the Berlin area. Fränkel's investigations revealed colony count in the groundwater of 0/ml, exceptionally 10/ml. This groundwater did not present any infection risk. Fränkel proposed that the requirement for drinking-water should be the microbiological quality of groundwater. Before this requirement came into force, a cholera epidemic broke out in Hamburg in 1892, with 8605 dead and 16 956 diseased individuals (Koch, 1893). At that time, water in Hamburg was taken from the Elbe River and supplied to the population without any treatment. Except for boiling, there was no other method for drinking-water disinfection known at that time; filtration was the only technical process available to improve the water quality.

In Altona, which is now a part of Hamburg, but which at the time of the outbreak in Hamburg was a separate town, the epidemic did not break out, although the water for this town was taken from a considerably less favourable site, namely from the river downstream of Hamburg. However, the water was treated by slow sand filtration and the water was microbiologically tested. Based on these observations, Robert Koch (1893) posed the following two requirements: (i) surface water, which is to be used as drinking-water, must be appropriately treated; and (ii) the colony count after the treatment should not exceed 100/ml. The colony count below 10/ml – as required by Fränkel (1887) – could not be attained by slow sand filtration. The highest permissible colony count of 100/ml was introduced as a criterion for assessing the efficiency of the filtration devices, but not as a health risk itself. The abovementioned requirements by Robert Koch were published in 1894, and became legal regulation in Germany in 1899.

In the following period, the colony count gradually lost its character as an assessment parameter, and it was replaced by tests for *E. coli*, coliform bacteria and other faecal indicators. However, this change did not take place as a result of an effort to enhance the quality requirements for drinking-water but because the colony count was taken to be too restrictive as an assessment parameter. The argument was that the use of the colony count for the quality assessment would exclude some water sources from the drinking-water supply, although they were free of pathogens, or that it would pose excessively high demands on water treatment.

2.3.2. Cholera

Faecal contamination of drinking-water is still the most significant cause of cholera outbreaks in many parts of the world, especially in critical situations such as natural disasters, mass migration, military actions and refugee camps. Cholera epidemics occur due to insufficient hygiene and sanitation (Exner, 1996).

Vibrio cholerae is a Gram-negative bacterium and is the classical causative organism of cholera. To date, 139 different serotypes have been identified of which O1 and O139 are pathogenic types. *V. cholerae* 01 is subdivided into the *El Tor* O1 and the *haemolytic El Tor Vibrio*. These strains are replacing the classical *V. cholerae*. In 1992 the strain O139 was identified for the first time in India and Bangladesh. In 1991, cholera occurred in Latin America after 100 years of absence. Within two years, the cholera spread from Peru to Mexico. These cholera epidemics show the potential for modern societies to disseminate an epidemic pathogen globally.

Travel-associated, imported cases were reported in the United States, Japan and Europe (Chin, 2000). Cholera cases are also frequently being reported in the European Union (EU), from all countries; importation by returning tourists is the main cause.

The organism enters the gut via ingestion, colonizes in the mucosa and produces an enterotoxin, which results in an extreme loss of water and electrolytes. The infectious dose of cholera is relatively high. The incubation period, typically 1–5 days, is rather short.

Cholera is an acute infection of the intestine, which begins suddenly with painless watery diarrhoea, nausea and vomiting. The main clinical symptoms include colourless stools, so called rice-water diarrhoea. Severe cases start abruptly with endless streams of watery stools. Due to massive loss of body fluids, dehydration and metabolic acidosis leading to death can occur within hours or a few days. Without treatment, mortality is high (50%) in heavy cases. Children at an early age are particularly at risk. With prompt and adequate treatment, mortality can be reduced to 1% of the cases.

V. cholerae live attached to a particular kind of algae and zooplankton in aquatic environments, which are its natural reservoir, and can infect foodstuffs grown in contaminated areas.

Cholera remains prevalent in areas with poor hygiene and sanitation, close to surface water, with high population density and a high absolute humidity.

2.3.3. Typhoid fever

The causative agent of typhoid fever is *Salmonella typhi*, which is an enteropathogenic organism among other *Salmonella* spp. They belong to the family Enterobacteriaceae and are Gram-negative facultatively anaerobic bacteria. Today *Salmonella* spp. are classified by DNA serotyping into different serotypes. Common human *Salmonella* serotypes are *S. typhi*, *S. paratyphi*, *S. enteritidis* and *S. typhimurium* which cause enteric fever or gastroenteritis (Miller & Pegues, 2000; Chin, 2000).

Symptoms of infection can be mild or severe and include sustained high fever (as high as 39–40 °C), malaise, anorexia, headache, constipation or diarrhoea, rose-coloured spots on the chest area and enlarged spleen and liver. Most people show symptoms 1–3 weeks after exposure. The symptoms of paratyphoid fever are generally milder than in typhoid fever (Chin, 2000).

The incubation period depends on the infectious dose and varies between 3 days and 1 month. For paratyphoid fever it lasts 1–10 days. *S. typhi* and *S. paratyphi* only colonize in humans. Infectious excreta and sewage are therefore the most significant source of infections.

The pathogens can be transmitted from person to person by direct contact to infected individuals or by ingestion of faecal-contaminated food or drinking-water. Important vehicles in some countries include shellfish taken from sewage-contaminated beds, raw fruits, vegetables, contaminated milk and dairy products (Chin, 2000).

S. typhi has been isolated from water and sewage. The persistence in water supplies is moderate; the survival time of *Salmonella* spp. in drinking-water ranges from a few days to over 100 days. Resistance to chlorine is low. Faecal contamination of groundwater and surface water, and insufficient disinfection practices are the main cause of waterborne outbreaks (WHO, 2004).

Although the disease is more common in developing countries, including Asia, recent outbreaks were also reported from eastern Europe, for example from Dushanbe, Tajikistan. In February 1997, a sudden increase in the number of typhoid fever cases was identified in Dushanbe, with about 2000 cases registered during a two-week period. The outbreak occurred due to the contamination of the municipal water supply (Centers for Disease Control and Prevention, 1998).

Children in endemic areas are at highest risk for *S. typhi* infection, owing to their lack of acquired immunity. Outbreaks of typhoid fever in developing countries can result in high morbidity and mortality rates, in particular when caused by antibiotic-resistant strains.

2.3.4. **Shigella**

Shigellosis or bacillary dysentery is an acute bacterial disease characterized by bloody diarrhoea. *Shigella* spp. are small Gram-negative bacteria that belong to the Enterobacteriaceae family. The genus *Shigella* comprises four species: *S. dysenteriae*, *S. flexneri*, *S. boydii* and *S. sonnei*. Bacillary dysentery is the most communicable of the bacterial enteritis. Symptoms are fever, nausea, vomiting, cramps and tenesmus. Mild and asymptomatic cases occur. The illness is usually self-limited and lasts 4–7 days. The incubation time is 1–7 days for all *Shigella* spp. infectious diseases (Dupont, 2000; Gleeson & Gray, 1997).

The severity of the infections depends on the species and the host. Children are more frequently affected by complications. *S. dysenteriae* type 1 (shiga bacillus) cause often severe diseases and complications which can include the haemolytic uraemic syndrome (HUS) (Chin, 2000). *S. sonnei* causes a milder variant.

The infecting strains are generally present in stools in concentrations between 103 and 109 organisms per gram of stool. Volunteer studies have demonstrated that fewer than 200 viable cells can produce the disease in healthy adults (Dupont, 2000). Shigellosis spreads mainly by person to person contact, especially between children in overcrowded conditions (such as schools, nursery care).

Shigellosis is a health problem in developing as well as in developed countries. The infection is recognized to be endemic in the eastern Mediterranean countries and shows a peak of infection predominantly in the warm months. In developing countries the occurrence is influenced by the availability of water and changes in the hygienic behaviour of the population.

Waterborne outbreaks occur more frequently due to faecal-contaminated drinking-water. Epidemics of waterborne shigellosis generally appear in the context of wells contaminated with faecal material and sewage discharge close to water intakes or bathing areas. Because of the low resistance to chlorine, chlorination of water would be an effective prevention measurement (WHO, 2004; Dupont, 2000). So far the disease is not known to be often spread by waterborne transmission, but waterborne outbreaks are occurring more frequently due to faecally contaminated drinking-water.

2.3.5. Campylobacter

Campylobacteriosis is a worldwide zoonotic (passed to humans via animals or animal products), enteritic disease which relates to Gram-negative bacteria of different *Campylobacter* species. *Campylobacter* are bacteria which grow under microaerophilic conditions. There are several species out of which mainly *C. jejuni* and – less commonly – *C. coli* are of human pathogenic importance.

Diarrhoea (often in the presence of mucus and blood), abdominal cramps, fever, malaise and vomiting are characteristics of acute campylobacteriosis. In some individuals, a reactive arthritis (painful inflammation of the joints) can occur. Rare complications include seizure due to high fever or neurological disorders such as Guillain-Barre syndrome or meningitis. The period from the infection until the occurrence of the first symptoms is about 2–5 days. The infective dose ranges from low to moderate.

Campylobacter spp. are organisms often found in the environment; the main reservoir of pathogens are wild birds and poultry, both wild and domestic. The bacteria are common in food animals such as poultry, cattle, pigs, sheep, ostriches and shellfish, as well as in pets, including cats and dogs. The animals themselves may not have symptoms. Therefore, raw milk, undercooked poultry and beef are significant sources of infection. Excretion of *Campylobacter* by domestic and wild animals and sewage discharge may lead to contamination of surface water (Medema et al., 1996). In the aquatic environment, the bacteria can survive for months at about 4 °C. A capability of survival of several weeks could be found in a cold groundwater reservoir (Szewzyk et al., 2000).

The disease can be directly transmitted via the faecal–oral route or indirectly via contaminated foodstuff and drinking-water. *Campylobacter* is often detectable in surface waters. In a study on the microbial contamination of inflows to drinking-water reservoirs in different catchment areas, *Campylobacter* could be detected in 36% of the running water samples in an area which was intensively used for agricultural purposes (Kistemann et al., 1998). The survival of *Campylobacter* during drinking-water purification was examined by Feuerpfeil and colleagues (Feuerpfeil, Vobach & Schulze, 1997). Even after generally effective purification technologies (flocculation, filtration) had been applied, *Campylobacter* could still be detected. *Campylobacter* spp. are sensitive to chlorine and are in general inactivated by disinfection during drinking-water purification (Lund, 1996).

Despite this, drinking-water is regarded as a frequent source of infection. In developing countries, outbreaks of gastroenteritis due to *Campylobacter* spp. are a major cause of morbidity and mortality in young children under two years. Campylobacteriosis is now one of the most frequently identified causes of intestinal diseases in industrialized countries, and should be given increased attention in other countries.

2.3.6. Pathogenic E. coli *strains*

E. coli strains are present in the normal microbial flora of the gastrointestinal tract of human beings and warm-blooded animals. As they occur in high numbers in all faeces, *E. coli* are used as an indicator for faecal pollution in drinking-water surveillance (Gleeson & Gray, 1997).

Some species are of human pathogenic importance, such as EHEC (enterohaemorragic *E. coli*), EIEC (enteroinvasive *E. coli*), ETEC (enterotoxic *E. coli*) and EPEC (enteropathogenic *E. coli*), causing serious, bloody diarrhoea (Mead & Griffin, 1998).

EHEC belongs to the serotype O157:H7 group. It was detected to be human pathogenic in 1982 during two outbreaks of bloody colitis. One year later the link between an EHEC infection and the occurrence of HUS was established. The HUS complex of symptoms includes, among others, bloody diarrhoea and acute renal failure, in particular in children.

The infectious dose is low, with about 102 EHEC bacteria. In about 80% of the illnesses watery diarrhoea occurs and in 20% symptoms of HUS occur in addition (Mead & Griffin, 1998; Doyle, 1990).

The main reservoir of pathogens of the bacteria are cattle, but also sheep, and to a lesser extent goats, red deer, horses, dogs, birds and flies. The bacteria can survive in liquid manure, manure and drinking troughs. The pathogens are mainly transmitted through contaminated foodstuffs such as raw milk and beef but also via vegetables, processed meat (Sönderström et al., 2005; Sartz et al., 2007) and drinking-water. Foods that are irrigated, washed or prepared with polluted water are also a common cause of infection.

The disease can be transmitted from person to person via direct contact to infected human beings, contact with animals, food and consumption of contaminated water. Person-to-person transmission is particularly prevalent in communities where there is close contact between individuals, such as nursing homes or day-care centres. Infants and old people are at high risk of falling ill (Doyle, 1990).

EHEC infections have been reported from more than 30 countries worldwide. In some countries, these types of infection are today already regarded as the third most frequent cause of bacterial intestinal infections after *Salmonella* and *Campylobacter*. In Canada, the United States and some areas of Scotland the annual incidence rates amount to 8 per 100 000 inhabitants (Mead & Griffin, 1998).

2.3.7. Legionellosis

Legionnaires' disease was first reported in 1977 after an outbreak among people attending a convention of the American Legion in Philadelphia, United States. Due to inhalation of contaminated aerosols from an air conditioning system of the hosting hotel, about 221 individuals contracted pneumonia, leading to 34 deaths.

Legionella spp. can cause two different types of disease: (a) Legionnaires' disease, which is a type of pneumonia; and (b) Pontiac fever, which is a milder, flu-like form.

So far 50 species, with about 70 serogroups have been identified in the Legionnellaceae family, of which *L. pneumophila* is responsible for 90% of infections. *Legionella* are Gram-negative aerobic non-spore forming bacteria. *L. pneumophila* is an ubiquitous aquatic organism that grows in warm environments (having an optimal temperature range of 32–45 °C).

Legionellosis is not characterized by distinct symptoms, but non-specific signs such as anorexia, malaise, headache, and rapidly rising fever. Cough, abdominal pain and diarrhoea often occur. The incubation period lasts 2–10 days, generally around 5–6 days and rarely up to 20 days. Pontiac fever is a flu-like legionellosis without pneumonic illness (Bartram et al., 2007; Yu, 2000; Chin, 2000).

Inhalation of contaminated aerosols from technical systems such as cooling towers, showers, air conditioning units and hot- and cold-water installation systems, spas, pools, thermal ponds, springs, humidifiers, and domestic plumbing may cause legionellosis. Infections have also been caused via *Legionella*-contaminated potting soils and compost. Recently, airborne transmission over long distances has been described in France (Nguyen et al., 2006). Transmission can also be categorized according to the place of infection into community-acquired pneumonia and nosocomial infections (Bartram et al., 2007). Person-to-person transmission does not occur.

Sources presenting higher risk for causing legionellosis include hospital water systems, which may cause nosocomial infections, and water systems in contained environments such as hotels, ships and various industrial settings, especially when such water systems are not properly maintained. Water systems in domestic houses may also cause infection.

Legionella is chlorine tolerant and can survive drinking-water treatment processes. It found an ecological niche in water distribution systems and other technical systems. These man-made habitats provide favourable water temperatures, physical protection and nutrients. In order to prevent the growth of *Legionella* organisms in water distribution systems, water has to be kept either below 20 °C or over 50 ºC (Szewzyk et al., 2000). Different biocides, ultraviolet (UV) irradiation and point-of-use filtration are other methods used against *Legionella*.

2.4. Viral diseases – viral hepatitis A

Hepatitis is a broad term for inflammation of the liver. Two viruses that cause hepatitis (hepatitis A and E) can be transmitted through water and food.

Hepatitis A virus (HAV) is relatively stable in the environment after it is excreted with the faeces. The infectivity is retained for several weeks at room temperature. It is stable after incubation at 56 °C, but boiling destroys the virus after 5 minutes.

The illness starts with an abrupt onset of fever, body weakness, loss of appetite, nausea and abdominal discomfort, followed by jaundice in a later stage of the disease.

The shortest incubation period observed was less than 1 week after ingestion of infection dose of 108 viral particles and 7 weeks after infection dose of 10^1 viruses (Feinstone & Gust, 2000).

There is an inverse correlation of symptoms with the age of the patients. Children under 6 years have mostly mild or no symptoms. In contrast, most adults develop jaundice and other symptoms. However, there is no evidence that HAV causes chronic diseases. HAV comprises only a single serotype. Infected individuals acquire a life-long immunity to strains from any part of the world.

Humans are considered to be the only important reservoir of HAV. The main transmission route is ingestion of contaminated faeces. This can occur from person to person via contaminated hands or by consumption of contaminated water or food. Usually food which is eaten uncooked, such as salads, fruit, vegetables, ice and some dairy products are responsible for foodborne outbreaks. HAV can also be transmitted via food contaminated by infected food handlers, uncooked foods, or foods handled after cooking. Hepatitis A has also caused outbreaks transmitted through injecting or non-injecting drug use. Outbreaks have been reported after the consumption of partially cooked shellfish, proposing that even steaming is not sufficient to destroy HAV (Feinstone & Gust, 2000).

The virus can appear in swimming pools and coastal areas used for bathing and swimming. In particular, sewage can be a source of the virus. It can persist in waste water, seawater, soils, surface waters and water supplies for periods from days to months. It is also quite resistant to free chlorine, particularly when the water contains organic matter (WHO, 2003; Feinstone & Gust, 2000).

Hepatitis A is particularly frequent in countries with poor sanitary and hygiene conditions. In low-endemicity countries, it will more often occur as an outbreak. Countries with economies in transition and some regions of industrialized countries in which sanitary conditions are substandard are also highly affected, including southern and eastern Europe.

In addition to hepatitis, viral gastroenteritis is a very important cause of diarrhoeal disease, and seems to be on the increase, at least in the United Kingdom (Hunter, 1997). Human caliciviruses (HuCVs) are of high health significance, with a high relative infectivity, moderate resistance to chlorine and long persistence in water supplies. They include the genera *Norovirus* (Norwalk-like viruses), previously referred to as "small rounded particles". Similarly, rotavirus strains also have high health significance and high relative infectivity, as well as moderate resistance to chlorine (Guillot & Loret, 2010).

However, diagnosis of viruses using such relatively advanced techniques as electron microscopy and enzyme-linked immunosorbent assay (ELISA) is still often beyond the routine capabilities of surveillance systems.

2.5. Protozoan diseases

2.5.1. Cryptosporidiosis

Cryptosporidium spp. are protozoan parasites. Several different species are recognized, of which *C.. parvum* is primarily responsible for clinical illnesses.

The single-celled intestinal parasite (oocysts) which can cause severe diarrhoea reaches the gastrointestinal tract via ingestion. The incubation period is generally 7 days, although 5 to 28 days can also be observed. It is possible that the disease can occur without the parasite being detected. Even when the parasite remains undetected, the infected individual is a source of infection for others. Diarrhoea, abdominal pain, vomiting, malaise and fever are the characteristic signs of the disease. The duration and seriousness of the disease strongly depend on the immunocompetence of the infected person. Cryptosporidiosis can become chronic in AIDS patients and can lead to death (Haas, Rose & Gerba, 1999).

The disease can be transmitted directly from person to person or animal to person through contact (at home, in nursery schools, old people's homes, animal farms, and so on) or indirectly via ingestion of recreational water, contaminated foodstuffs and drinking-water. The parasite is very resistant to chlorine-based disinfectants, but not resistant to ozone. Outbreaks in public water supplies have been linked to faulty filters.

The infectious dose is recognized to be very low. In theory, the ingestion of one viable oocyst could cause infection. In healthy adult volunteer studies, 30 oocysts caused a 20% infection rate. The virulence of *Cryptosporidium* strains is recognized to vary widely (Gibson, Haas & Rose, 1998).

The infectious oocysts come from the faeces of infected human beings and warm-blooded animals. About 40 species of mammals are known to be reservoirs of pathogens, among which domestic (cattle, pigs, dogs, cats) and wild animals. Calves in particular play an important role as animal reservoirs of pathogens. They can excrete 7×10^6 oocysts per gram of faeces.

According to studies, the pathogens can be found in about 65–97% of surface waters. High numbers were also found in surface water receiving untreated or treated wastewater, while the parasites occur much less frequently in groundwater. Significantly high numbers of *C. parvum* are found during extreme rainfalls (Kistemann et al., 1998; Karanis & Seitz, 1996; Juranek et al., 1995; Teunis et al., 1997).

Drinking-water extracted from surface waters polluted with human or animal faeces is a major source of contamination. The *Cryptosporidia* detected in raw water can be found in drinking-water (in lower concentrations) after standard treatment methods. The parasite is characterized by high tenacity, low infection dose and high resistance to disinfectants (Exner, 1996).

Its significance as a parasite that can be transmitted via drinking-water is confirmed by the documentation of numerous waterborne outbreaks. In 1983 and 1984 the first documented waterborne outbreaks occurred in the United Kingdom and the United States. Outbreaks have been frequently reported, with very high numbers of cases in some instances (Hunter, 1997).

2.5.2. Giardiasis

Giardia spp. are flagellate protozoan parasites of the genus *Giardia*. *G. lamblia* (also called *G. duodenalis* or *G. intestinalis*) is believed to be the most frequent cause of diarrhoeal disease and the most frequent intestinal parasite in humans worldwide. Clinical symptoms after infection with cysts include asymptomatic cyst passage; acute, usually self-limiting diarrhoeal episodes; and chronic diarrhoea syndrome. Further symptoms may be abdominal cramps, malabsorption and weight loss.

The infectious dose is very low. The incubation period is usually about 1–2 weeks. Generally, the acute illness heals after 10 days, but can last for 4–12 weeks (Hunter, 1997).

In developing countries, *Giardia* is one of the first enteric pathogens to infect children with prevalence of 15–20% occurring in children under 10 years old.

The parasite is widely distributed in the environment occurring in the small intestine of human beings and many vertebrates, and entering the water resources via sewage, stormwater discharge or droppings of infected animals. The cysts are able to survive in the aquatic environment for long periods of time without losing their infectivity (Gibson, Haas & Rose, 1998; Gleeson & Gray, 1997).

Water plays a major role in the transmission of *Giardia*. Most waterborne outbreaks occur due to inadequate chlorination or/and insufficient filtration methods of drinking-water. Like *C. parvum,* the parasite is relatively resistant to chlorine and has a high tenacity.

According to some studies the most frequent association between *Cryptosporidium* and *Giardia* had been found in surface water sources with a high density of domestic and wild animals. Whereas, on one hand, *Cryptosporidium* occurred almost ubiquitously at concentrations that correlate with dairy farming and density of fallow deer in the catchment area, on the other hand *Giardia* cysts were principally associated with the presence of sewage (Atherholt et al., 1998; Kistemann et al., 2002; Ong et al., 1996; Payment et al., 2000; Robertson & Gierde, 2001).

2.6. Diseases of high local importance

The previous section has summarized some key information on water-related diseases recognized as being of importance by the Parties to the Protocol on Water and Health. However, contributors to this volume also recognize that, while of local rather than regional importance, two additional pathologies need to be mentioned.

2.6.1. Helminthic diseases

Although not regarded as a health problem of general importance in all countries that ratified the Protocol, Parties concurred that helminthic diseases can be of considerable local importance. This is the case when water supply is insufficient to meet basic hygiene needs, as is common in rural areas in central Asia. These diseases may also be of local importance when the decision has been made to use treated wastewater in agricultural applications, for example as a climate change mitigation measure. In view of their localized importance, a short description was deemed appropriate here.

Helminths are generally known as parasitic worms. They usually invade their hosts in a larval stage and migrate through the body before maturing in the gut. They can cause serious tissue and organic damage, as well as malnutrition.

The major helminth infections of humans are caused by nematodes (roundworm), trematodes (flukes) and cestodes (tapeworms). The transmission route is through the ingestion of eggs and contact with faecally contaminated soil and food (Mahmoud, 2000b). A problem is the use of inadequately treated wastewater in irrigation and faecal sludge in soil fertilization. This practice is often associated with an elevated prevalence of intestinal helminth infections and diarrhoeal diseases in workers, farmers and consumers (Mara & Cairncross, 1989).

Infections with nematodes comprise ascariasis, trichuriasis and hookworm. Trichuriasis is among the most prevalent human helminthiasis. About 800 million cases occur worldwide, mostly in warm and moist regions (Mahmoud, 2000a). In humans the infection may manifest as mild anaemia, bloody diarrhoea or chronic gastrointestinal diseases. Malnutrition and growth retardation can also occur. The worldwide prevalence of ascaris infections is estimated to be more than 1 billion people. The disease occurs in individuals of all ages but is most common in pre-school and young school-aged children. Predominant symptoms include pulmonary and nutritional disorders. The present geographic distribution of hookworm diseases lies in tropical and subtropical zones. Anaemia and malnutrition are the major manifestation of the infection (Mahmoud, 2000a).

Flukes are parasitic worms which cause schistosomiasis, clonorchiasis and fasciolasis. Humans are the definitive host for five schistosome species. Each species has a specific geographic distribution. Two major factors are responsible for the occurrence of schistosomiasis: the presence of the snail intermediate host and the method of disposal of human excreta. Chronic disease affects commonly the intestine and the liver. *Clonorchis sinensis* is a parasite of fish-eating mammals. Although humans are incidental hosts, millions of people are infected in the far East, where traditionally raw or undercooked fish is eaten (Mahmoud, 2000c).

Common cestode parasites of humans are the fish tapeworm, beef tapeworm and pork tapeworm. The names indicate the main transmission source. Cysts are ingested via freshwater or fish, or contaminated meat. Symptoms associated with infection are usually minimal but infected individuals can also show abdominal discomfort (King, 2000).

Transmission of helminth infection depends on the interruption of the parasitic life-cycle. Transmission can be reduced or eliminated by careful disposal of human sewage to limit environmental spread, the use of safe feeds for vector animals such as cattle, swine or fish, meat inspection and thorough cooking to kill the cysts.

2.6.2. Cyanobacteria in drinking-water

Cyanobacteria are ubiquitous prokaryotic microorganisms that occur in particular in inland and coastal surface waters. In favourable conditions they reach high densities and may form blooms and scums. As secondary metabolites, most cyanobacteria produce cyanotoxins, which can be grouped according to their biological effects (Codd, Morrison & Metcalf, 2005) into:

- hepatotoxins (microcystins (MCs) and nodularines);
- neurotoxins (saxitoxins (STX), anatoxin-a (ATXa), homoanatoxin-a, anatoxin-a(s));
- cytotoxins (cylindrospermopsin, CYN);

- irritants and gastrointestinal toxins: aplysiatoxin, debromoaplysiatoxin, lyngbyatoxin (produced by marine cyanobacteria);
- lipopolisaccharidic (LPS) endotoxins;
- other cyanotoxins, the toxicological or ecotoxicological profile of which is still only partially known, such as microviridin J and β-N-methylamino-L-alanine (BMAA).

The production of BMAA, a non-essential amino acid, by a wide variety of both free-living and symbiont cyanobacteria (Cox et al., 2005) is of particular interest. Indeed, although with contrasting opinions, BMAA has been considered as a potential etiological agent of some serious neurodegenerative diseases (Miller, 2006; Lobner et al., 2007). In favourable conditions for their growth (that is, with optimum nutrient availability, temperature and light levels), cyanobacteria can form blooms and scums. The toxicity of a given bloom is determined by its strain composition (toxic/non-toxic genotypes). The amount of MCs produced by a cyanobacterial population in culture is directly proportional to its growth rate; the highest amount being produced during the late logarithmic phase. Beyond population dynamics, MC concentrations in water bodies are influenced by some environmental parameters, such as nutrient availability, temperature, pH, light, and so on (Sivonen & Jones, 1999). Cyanotoxins may be localized both within the cyanobacterial cells and dissolved in water, depending on both the nature of the toxin and the growth stage (Chorus & Bartram, 1999; Van Apeldoorn et al., 2007). The highest cyanotoxin levels have been reported in blooms and scums, hence their total concentrations in surface waters are strongly influenced by the occurrence of these forms of biomass. Total concentrations up to 25 000, 12.1 and 3 300 μg/litre have been reported in surface waters for MCs, CYN and anatoxin-a(s), respectively (Sivonen & Jones, 1999; Rücker et al., 2007). Intracellular MCs' content is generally higher than that dissolved in the surrounding water (Van Apeldoorn et al., 2007; Ibelings & Chorus, 2007). However, higher CYN levels are reported in dissolved form than within cells (Rücker et al., 2007). Scant information is available on the proportion of the dissolved relative to the total level for the other cyanotoxins. After a collapse of ageing, declining blooms or their treatment with algaecides, high concentrations of dissolved cyanotoxins can be found in the surrounding water (Van Apeldoorn et al., 2007; Jones & Orr, 1994).

2.6.2.1. Risk associated with cyanotoxin exposure

Humans may be exposed to cyanotoxins via several routes: orally is by far the most significant, occurring through consumption of contaminated drinking-water or food (including dietary supplements) or by ingesting water during recreational activities. Dermal and inhalation exposure may also occur due to recreational, sports and professional activities (such as fishery) in infested waters, or to the domestic use of water containing cyanotoxins, for example through showering. The parenteral route of exposure is also possible when water from contaminated superficial water bodies is used for hemodialysis. The human risk associated with the different routes of exposure to cyanotoxins has been assessed and reviewed in several publications (Chorus & Bartram, 1999; Funari & Testai, 2008; Van Apeldoorn et al., 2007; Ibelings & Chorus, 2007).

2.6.2.2. Episodes of human intoxication attributed to drinking-water contamination by cyanobacteria

Human exposure to cyanotoxins has been associated with several episodes of disease. The most significant of these was reported in Brazil, where 56 patients out of 130 in haemodialysis treatment died after receiving water, which subsequently turned out to be contaminated by MCs (Jochimsen et al., 1998; Azevedo et al., 2002). Indeed, the parenteral route of exposure considerably increases the internal dose of toxins directly entering the bloodstream; therefore, it represents an extremely relevant route of exposure in terms of the risk evaluation for human health (Funari & Testai, 2008). Taking into account this particular exposure route, together with the pathological conditions of patients, the water used for haemodialysis should be free of cyanotoxins. When infested surface waters serve as drinking-water supply, cyanotoxins can contaminate drinking-water if they are not properly removed by treatment systems. From this point of view, the highest risk of dangerous exposure coincides with the use of unfiltered/untreated surface waters. Depending on cyanotoxin levels in drinking-water, both acute/short-term and chronic effects may occur in humans (Chorus & Bartram, 1999; Funari & Testai, 2008). Acute/short-term effects are associated either with the consumption of raw waters infested by cyanobacteria or with high cyanotoxin concentrations dissolved in drinking-water as a consequence of either the breakdown of a natural cyanobacterial bloom or its artificial lysis, followed by the failure of water treatments.

Many episodes of human intoxication have been reported so far, some of which are indicated in Table 2.2.

Table 2.2. Episodes of human intoxication from cyanobacteria

Etiological agent	**Place**	**Outbreak**	**Effects**
Blooms of *Anabaena* and *Microcystis* spp.[a]	Brazil	2000 cases of gastroenteritis and 88 deaths in a period of 42 days	–
Treatment with copper sulfate of a *Cylindrospermopsis raciborskii* bloom[b]	Australia	140 children and 10 adults required hospitalization for liver and kidney damage within a week	Total recovery of all patients
Different cyanobacteria blooms[c]	Australia, Austria	Gastroenteritis and liver damage	–

Sources: [a] Teixeira et al., 1993; [b] Byth, 1980; Hawkins & Griffiths, 1993; [c] Botes et al., 1985; Fawell, 1993; Zielberg, 1996; El Saadi et al., 1995; Falconer, 1989, 1994.

Acute/short-term effects can be prevented through adequate reduction of both cell number (> 99%) and dissolved cyanotoxins (Jones & Orr, 1994; Dietrich & Hoeger, 2005).

For poor countries, recommendations can be made not to use surface waters infested by cyanobacterial blooms without filtering to remove cells (that is, using simple sand filters), and to avoid the use of water when the bloom is senescent (deteriorating with age) and extracellular cyanotoxin concentration is expected to be higher (Funari & Testai, 2008). Chronic effects are difficult to identify and demonstrate; information from epidemiological studies carried out in China (Ueno et al., 1996) and in Florida (Fleming et al., 2001; 2002) failed to demonstrate that cyanotoxin exposure is the actual cause of the observed effects (that is, hepatic and colorectal tumours), instead just giving an indication of the most likely cause. The poor quality of the available epidemiological data – due to the study design and/or the presence of strong confounding factors – has led the International Association for Research on Cancer (IARC, 2006) to the conclusion that it is not possible to associate the excess risk of hepatocellular carcinoma and of colorectal cancer specifically with exposure to MCs. Although the epidemiological data are not conclusive, some toxicological data are available and can be used, at least for some cyanotoxins, to evaluate the risk associated with contaminated drinking-water consumption, making use of consolidated, internationally accepted risk assessment procedures. In the case of MC-LR, WHO (2004) selected the subchronic no observed adverse effect level (NOAEL) was found to be 40 µg/kg bw/day (Fawell, James & James, 1994). The choice of this

NOAEL represents an example of the application of a conservative approach, since it has been obtained in a study on mice, more sensitive to acute effects of MC-LR than rats; the effects at LO(A)EL (200 µg/kg bw/day) are slight and involve a limited number of animals; the route of exposure is gavage rather than dietary, which gives a higher NOAEL value (Funari & Testai, 2008). By applying an uncertainty factor (UF)=1000 (taking into account inter-and intra-species variability (100) and the lack of chronic toxicity data) a provisional tolerable daily intake (TDI) value of 0.04 µg MC-LR/kg bw/day is obtained: this means that an adult with a body weight of 60 kg could be orally exposed to 2.4 µg per day all life long, without experiencing any toxicological effect. In light of the approach used, this value is conservative enough to consider that the exposure for a limited period of time to MC-LR values similar to or slightly exceeding the TDI value do not represent a real risk for the human population. On this basis, WHO (2004) has calculated a provisional guideline value (GV) of 1µg/litre for MC-LR in drinking-water, considering a daily consumption of 2 litres of drinking-water and an allocation factor (AF)=0.8 (meaning that drinking-water was assumed to contribute for the 80% of the total intake of MC-LR).

Specific GVs for different MC congeners (endowed with different acute toxicity, generally lower than MC-LR) are not available, therefore a recommendation to use concentration equivalents as the default value for the total concentration of all MC variants has been suggested (Chorus & Bartram, 1999). WHO has not derived GVs for any other cyanotoxins due to the lack of adequate toxicological data; however, some considerations leading to provisional risk assessment can be made (Funari & Testai, 2008). Regarding ATX-a, an actual NOAEL has not been identified, since no effects were observed at the highest tested doses in a subchronic study (510 µg/kg bw/day) (Astrachan, Archer & Hilbelink, 1980; Fawell et al., 1999). However, by using the highest value as a NOAEL, a provisional TDI=0.51 µg/kg bw/day can be derived by applying a UF=1000, as for MC-LR, leading to a GV 1.2 µg/litre (Duy et al., 2000). Based on these considerations, it has been proposed that a GV=1 µg/litre for the total concentrations of anatoxins in drinking-water could provide an adequate margin of safety to protect the (human) health of potentially exposed populations (Fawell et al., 1999). The limit=6 µg/litre established by New Zealand for total anatoxins content in drinking-water and that adopted by Australia equal to 3µg/litre for ATX-a (Chorus, 2005) are in agreement with these considerations.

As far as CYN is concerned, starting from the subchronic NOAEL=30 µg/kg bw/day (Humpage & Falconer, 2003) and dividing it for an UF=1000, as previously carried out for the other cyanotoxins, a TDI value=0.03 µg/kg bw/day is derived. Therefore no risk is expected to be associated with CYN ingestion up to 1.8 µg per person (weighing 60 kg) every day during the lifespan. Since CYN metabolites have been suspected of genotoxic potential, this TDI should be updated, once more data become available. A GV=0.81 µg/litre (rounded to 1 µg/litre) can be derived (Humpage & Falconer, 2003; Codd, Morrison & Metcalf, 2005) by using the same approach described for MC-LR. Toxicological data can be also used for defining safe concentrations with regard to the acute risk. The starting point is the identification of an acute dose inducing no effects (the acute NOAEL). In the oral acute toxicity studies with MC-LR, signs of hepatic toxicity were present even at the lowest dose tested (lowest observed adverse effect level LOAEL=500 µg/kg bw); however, some intraperitoneal acute studies are available, indicating that doses in the range of 25–50 µg/kg bw produced no effects in the mouse liver, the target organ (Fromme et al., 2000).

Considering that MC-LR is 30–100 times more toxic than after oral exposure, a correction factor=10 should be applied, in addition to an UF=100 to account for inter- and intra-species variability. An acute no-effect dose of 2.5 µg/kg bw is then obtained, corresponding to 150 µg/person for an adult weighing 60 kg bw. Since the dose–response curves in the intraperitoneal studies are very steep, special attention should be paid when the exposure to MC-LR is close to the acute no-effect dose. At this level of exposure to total MCs, no acute effect is expected, considering in addition that the evaluation has been based on MC-LR data, which is among the most toxic variants. Although no evidence of human intoxication from drinking-water contaminated by STX has been reported so far, this could also represent a source of concern in terms of acute effects, due to the occurrence of STX in freshwater up to 2700 µg/litre (Batorèu et al., 2005). For this reason, some countries proposed GVs or adopted mandatory regulatory requirements: a guideline concentration of 3 µg/litre STX equivalents in drinking-water has been adopted in Australia (NHMRC, 2001) and 1µg/litre in New Zealand (Orr, Jones & Hamilton, 2004). Considering a daily intake of 2 litres of drinking-water, these regulatory limits correspond to 2–6 µg STX/person, which is only a small fraction of the limit established by the EU for bivalve mollusks, in order to protect consumers from acute effects (European Union, 1991).

2.7. Monitoring

The discovery of pathogenic organisms in the second half of the 19th century quickly led to the realization that these pathogens may be transmitted by drinking-water. Towards the end of the 19th century, the pathogens of two diseases – cholera and typhoid fever – were the first to be recognized as being transmitted by drinking-water. The following period witnessed the recognition of many other pathogens as also being transmitted by water. Table 2.3 lists water-transmissible pathogens that can occur in source water in health-endangering concentrations (Schoenen, 1996).

Table 2.3. Water-transmissible pathogens

Bacteria	Viruses	Protozoans
Vibrio cholerae	Poliovirus type 1 2 and 3	*Entamoeba histolytica*
Salmonella typhi	Hepatitis A and E virus	*Giardia lamblia*
S. paratyphi	Enteroviruses	*Cryptosporidium parvum*
S. enteritidis	Rotaviruses	*Toxoplasma gondii*
Shigella spp.	Adenoviruses	
Yersinia enterocolitica	Noroviruses (Norwalk-like viruses)	
Campylobacter jejuni	Coxackieviruses	
E. coli (pathogenic strains)		
Leptospira spp.		

Source: Schoenen, 1996.

No attention is paid here to pathogens which are found in water in amounts insignificant to health, but which can reproduce in the water-distribution networks (see Table 2.4 for a list of such pathogens); the minimization of the health risk posed by these pathogens requires special preventive measures that are not discussed here.

Table 2.4. Pathogens that can reproduce in the water distribution system

Pathogen
Pseudomonas aeruginosa
Legionella spp.
Aeromonas hydrophila
Flavobacterium spp.
Acinetobacter spp.
Amoebae (Acanthamoebae, Naeglerias)
Atypical mycobacteria

Source: adapted from Ainsworth, 2004:5–8.

With the exception of *Leptospira*, the pathogens listed in Table 2.3 are transmitted via the faecal–oral route; that is, these pathogens are excreted from the human or animal digestive tract and are ingested orally. The pathogens can be transmitted directly from person to person, or from animal to person, or the transmission can take place via food, drinking-water or other objects, since they are highly resistant to environmental damage. In contrast, *Leptospira* usually arises via contact of the skin with contaminated objects or, exceptionally, also via ingestion of contaminated water.

In recent years, attention has turned to the possibility of health risks posed by emerging parasitic pathogens such as *G. lamblia* and *C. parvum*, as discussed earlier in this chapter.

3. Health risks from chemicals

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3.1. Basic chemical considerations

A human being is able to survive without oxygen for three minutes, without water for three days and without food for thirty days. Therefore, water is extremely important for humans. The medium water is a solution of different ingredients which stem from different sources:

- naturally occurring chemicals (for example carbonate, calcium, magnesium, chloride, sodium and potassium, but also arsenic, fluoride and radioactive substances);
- chemicals from drinking-water treatment and reaction products (aluminum, chlorine, phosphate, trihalomethanes (THMs));
- chemicals which enter drinking-water through contact with materials within the drinking-water distribution network (iron, lead, copper);
- chemicals which enter the drinking-water resource through anthropogenic activities (pesticides, antibiotics, estrogenic substances).

3.1.1. Organoleptic assessment

The senses of smell, appearance, taste are important criteria in assessing drinking-water quality. Smell can be impaired by putrefaction products, such as hydrogen sulfide. The sense of smell may provide a warning mechanism for the presence of toxic substances or microbiological pollution, for example by gas producing pathogens. Smell can be categorized as metallic, earthy, aromatic, putrid, and so on. The human nose can detect trace amounts of chemicals many times lower than the analytical detection limits. However, although the sensory assessment is important, it is not capable of assessing all health risks and cannot be regarded as the sole and sufficient assessment method.

Appearance of drinking-water is assessed mainly by turbidity and colouring. Coloured or turbid water can point to the fact that the water is polluted and can indirectly indicate microbiological contamination. Water quality assessment using appearance might warn the human being, as the smell does. Chemically reduced ground water can contain Fe^{2+} and Mn^{2+} salts in high concentrations. Coming from the tap the water might be clear, but when exposed to air, iron and manganese are oxidized and change from colourless, dissolved forms to coloured, solid forms. The use of water containing iron or manganese causes brown or black stains on household goods and clothes as well as deposits in the pipes and heaters. Both iron and manganese are essential to human health but adverse effects can result from overexposure (WHO, 2004).

The taste of water should be refreshing. Hence, drinking-water of a good quality should be free from smell, colouring and turbidity and should be appetizing. Depending on the dissolved chemical substances, the taste of water can be salty, bitter, metallic, soapy, and so on. At levels above 2.5 mg/litre, copper imparts a bitter taste to the water. Water containing high levels of sodium and chloride (taste threshold 200–300 mg/litre) taste salty. The avoidance of water with a high concentration of salt protects the body from negative influences on intra- and extra-cellular water distribution. An increase in the concentration of electrolytes disturbs the enzyme activities which are essential to life. As with the two other sensory parameters, taste may indicate the presence of a harmful substance.

3.1.2. Undesired effect in drinking-water preparation

Further tests are necessary in order to detect toxic ingredients which cannot be realized by sensory parameters. The drinking-water extraction process must be observed. Drinking-water is influenced by:

- the choice of the drinking-water resource
- the water treatment measures
- the choice of the materials of the drinking-water distribution system.

For geological reasons, the drinking-water resource can contain undesirable substances, such as arsenic. Other contamination arises mostly from anthropogenic origin (nitrate, lead, and so on).

For anthropogenic reasons, the drinking-water resource can contain several undesirable substances:

- industrial products (for example heavy metals, solvents);
- products resulting from extensive agriculture (for example pesticides, nitrates, nitrites, fattening aids such as antibiotics and estrogenic substances);
- products from accidents (for example oil, radioactive substances).

In water treatment, different materials are used for filtration, precipitation and disinfection in order to improve the quality and quantity of the water. In order to avoid a negative influence of the water quality at this stage of the process, the materials used must not release substances in toxic concentrations.

Undesirable concentrations of by-products (for example trihalomethanes THMs) must be avoided during the process of disinfection.

The capacity of the finished drinking-water to dissolve products or leach contaminants from products with which it comes into contact must be taken into account when choosing the materials of the water distribution network. Undesirable substances can be released by the good solvent properties of water. Water can release asbestos and heavy metals from the pipe system. The soluble property of water is increased by pH values below 7. The use of different metals that are in contact has also negative influences on the water quality. Electrochemical elements are formed as a result of which the base metal (for example lead) decomposes.

3.1.3. Basis for calculating the guideline values

Chemicals in drinking-water can have acute and chronic effects on human beings. WHO has established guidelines for several chemicals in drinking-water in order to protect human health from long-term exposure. The threshold values are based on a TDI:

$$\text{TDI} = (\text{NOAEL or LOAEL})/\text{UF}$$

For the chemicals in the drinking-water the GV is valid:

$$\text{GV} = (\text{TDI} \times \text{BW} \times \text{P})/\text{C}$$

whereby

BW = body weight
P = fraction of the TDI allocated to drinking-water
C = daily drinking-water consumption.

3.2. Selected parameters

In this following section, some chemicals are described which have toxic or possibly toxic effects on human beings. A comprehensive review of GVs are given in WHO (2004), while detailed descriptions relating to chemical risk assessment may be found in WHO (2007) as well as in the detailed index of background documents on chemical hazards in drinking-water.[3]

3.2.1. Inorganics

3.2.1.1. Arsenic

Arsenic gets into drinking-water primarily through the dissolution of naturally occurring minerals and ores. Commercially, industrial arsenic is used as an alloying agent in the manufacture of transistors, lasers, and semi-conductors.

The provisional GV is 0.01 mg/litre.

It is technically feasible to achieve arsenic concentrations of 5 µg/litre or lower by optimizing treatment, but a more reasonable expectation is that 10 µg/litre should be achievable by conventional methods, for example coagulation.

3.2.1.2. Fluoride

Nearly all waters contain traces of fluorides. The most important source of fluoride is natural rocks.

The GV is 1.5 mg/litre. Where the intake from other sources is likely to approach, or be greater than, 6 mg/day, it would be appropriate to consider setting standards at a lower concentration than the GV.

A concentration of 1.0 mg/litre should be achievable using activated alumina (not a conventional treatment process, but relatively simple to install filters). However, in areas with high natural fluoride levels in drinking-water, the GV may be difficult to achieve, in some circumstances, with the treatment technologies available.

3.2.1.3. Cadmium

Occurrence of cadmium in drinking-water sources is mainly of anthropogenic origin. Cadmium is a concomitant element of zinc, and is discharged when generating and processing zinc. Cadmium is also contained in fossil fuels and discharged to the environment through burning. Furthermore, batteries contain cadmium. The GV for cadmium is 0.003 mg/litre. Treatment achievability is 0.002 mg/litre using coagulation or precipitation softening.

3.2.1.4. Aluminium

Mobilization of aluminium occurs via precipitation, when rain and snow transport acids from the atmosphere to the earth's surface. Sulfur dioxide from industrial and domestic emissions in precipitation reduces the pH by forming acids. At these low pH values, Al^{3+} can be re-mobilized

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[3] The index is available on the Internet (http://www.who.int/water_sanitation_health/dwq/chemicals/en/index.html, accessed 17 November 2008).

from the soil and from sediments. Furthermore, Al^{3+} can enter the hydrologic cycle through an inexpert flocculation process in drinking-water and bathing-water processing.

In acid water, aluminium is already highly toxic for fish in concentrations below 0.1 mg/litre and plankton is killed. For human beings a connection between neurodegenerative diseases and aluminium in drinking-water cannot be excluded.

Although there is no health-based GV for aluminium, high concentrations reaching distribution systems can result in deposits of aluminium flocs, which can cause subsequent problems. Concentrations can normally be maintained below 0.2 mg/litre, and 0.1 mg/litre should be achievable in well-run, large treatment works.

3.2.1.5. Nitrates and nitrites

Nitrates can be detected in nearly all waters in low quantities. High concentrations can be caused by leachates from saltpetre stocks, agricultural fertilizers and by degradation and oxidation processes of organic and inorganic substances. Increased nitrate content in drinking-water can cause methaemoglobinaemia in infants. Nitrate is latently cancerous, as reduction to nitrite can occur in the body.

The GV for nitrate stands at 50 mg/litre to protect against methaemoglobinaemia in bottle-fed infants (short-term exposure).

The GV/provisional GV for nitrite stands at:

- 3 mg/litre for methaemoglobinaemia in infants (short-term exposure)
- 0.2 mg/litre (provisional) (long-term exposure).

The GV for chronic effects of nitrite is considered provisional owing to uncertainty surrounding the relevance of the observed adverse health effects for humans and the susceptibility of humans compared with animals.

A treatment achievability of 5 mg/litre for nitrate should be possible using biological denitrification (surface waters) or ion exchange (groundwaters), while 0.1 mg/litre should be achievable from nitrite using chlorination.

3.2.1.6. Lead

Increased levels in the environment are found close to lead mining areas and lead treatment plants. The main source of lead in drinking-water is plumbiferous pipes and fittings. The lead concentration in the pipe system increases in cases of longer stagnation periods. A layer of calcium carbonate may prevent contact of the water with the metallic surface. Corrosion increases concentration, particularly in acidic water. Chemical and electrochemical treatment methods exist to minimize plumbosolvency.

The GV for lead is 0.01 mg/litre.

3.2.1.7. Pesticides

Several pesticides are used in agricultural activities (some 500 are sold in Europe). In spite of this, only few of them are found at detectable levels in ground and surface waters.

Indeed, after agricultural application, pesticides can leach into groundwater or be transported to surface water through run-off or drainage. Often a very small fraction, if any, of the amount of pesticides applied reaches the water compartment. Indeed, once in the environment, pesticides are subject to many degradation processes. Moreover, several pesticides exhibit more affinity for soil than water, giving them limited mobility.

The environmental fate of pesticides is controlled by their physicochemical properties (Gustafson, 1989; Singh, Walker & Wright, 2002; Dagnac et al., 2002; Turusov, Rakitsky & Tomatis, 2002). Beyond their intrinsic properties, other factors play a role in the contamination process of water bodies, such as the type of cultivation/treatment, the rate and frequency of application and total use, the nature of soil (texture and organic matter content), the hydrogeological features and climate conditions (Giuliano, 1995; FOCUS, 2000; Worrall & Kolpin, 2004).

Pesticide contamination of the water compartment has specific features. Pesticide contamination of surface water is seasonally dependent and generally short-lived. Groundwater pesticide contamination is less – if at all – dependent on the season. Furthermore, groundwater is generally speaking more protected than surface water from contamination processes and represents a source of high drinking-water quality.

Many monitoring studies are available on this issue (Senseman, Lavy & Daniel, 1997; Garmouma et al., 1997; Thurman et al., 1998; Funari et al., 1995, 1998; Kreuger, 1998; Spliid & Koppen, 1998; EEA, 1999; Tuxen et al., 2000; Scribner, Thurman & Zimmerman, 2000; Younes & Galal-Gorchev, 2000; Barbash et al., 2001; Van Maanen et al., 2001; Squillace et al., 2002; Cerejeira et al., 2003; Papadopoulou-Mourkidou et al., 2004; Lapworth & Gooddy, 2006; Comoretto et al., 2008). The main outcome from these studies is that the bulk of water contamination is represented by relatively few compounds. For example, atrazine, terbuthylazine, metolachlor, bentazone, mecoprop, isoproturon, exazinone, diclorobenzamide, desethylatrazine and desethylterbuthylazine are frequently determined in groundwater; and atrazine, desethylatrazine, bentazone, diuron, MCPA, metolachlor, molinate, oxadiazon, terbuthylatrazine and desethylterbuthylatrazine are found in surface water.

Lipophilic compounds such as dioxins and DDT (Di(para-chloro-phenyl)-trichloroethane) strongly interact with soil particles, are substantially immobile and are not considered to be water contaminants.

3.2.1.8. Disinfection by-products

Disinfection by-products (DBPs) can be classified into four major groups: THMs, chlorinated acetic acids, chlorinated ketones and haloacetonitriles. Of particular concern is bromate, formed by oxidation of bromide.

The basic strategies that can be adopted for reducing the concentration of DBPs are:

- changing process conditions (including removal of precursor compounds prior to application);
- using a different chemical disinfectant with a lower propensity to produce by-products with the source water;
- using non-chemical disinfection and/or;
- removing DBPs prior to distribution.

In attempting to control DBP concentrations, it is of paramount importance that the efficiency of the disinfection is not compromised, and that a suitable residual level of disinfectant is maintained throughout the distribution system.

3.2.2. Radioactivity

WHO calculates guidance levels (GLs) for radio-nuclides in drinking-water by the following equation:

$GL = IDC/(h_{ing}.q)$

whereby
GL = guidance level of radionucleide in drinking-water (Bq/litre)
IDC = individual dose criterion equal to 0.1 mSv/y for this calculation
h_{ing} = dose coefficient for ingestion by adults (mSv/Bq)
q = annual ingested volume of drinking-water, assumed to be 730 L/y

GLs for selected radionuclides in drinking-water are as follows:

Radionuclide	**GL**
^{210}Pb	0.1 Bq/litre
^{224}Ra, ^{225}Ra and ^{226}Ra	1 Bq/litre
^{228}Ra	0.1 Bq/litre
^{210}Po	0.1 Bq/litre
^{235}U and ^{236}U	1 Bq/litre
^{237}U	100 Bq/litre
^{238}U	10 Bq/litre (the provisional GV for uranium in drinking-water is 15µg/litre based on its chemical toxicity for the kidney)
^{229}Th	0.1 Bq/litre

Detailed analysis of individual radioactive species and determination of their concentration is usually not justified. A more practical approach is a screening procedure, whereby the total radioactivity in the form of alpha and beta radiation is first determined, without regard to the specific radionucleides. Screening levels for drinking-water below which no further action is required are 0.5 Bq/litre for gross alpha activity and 1 Bq for gross beta activity.

4. Health risks in the water system

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The vast majority of health-related water quality problems is caused by the presence of pathogens. Control of microbial quality is essential, and must never be compromised. Nevertheless, it should be recognized that serious health outcomes are still being caused by chemical contaminants. Chemical threats should not be considered solved but their assessment should form an integral part of any holistic risk assessment/risk management programme aimed at ensuring water safety.

Securing safety of drinking-water supplies is based on the use of multiple barriers, operating from the water resources in the catchment area to the consumer, in order to prevent contamination of drinking-water, to reduce such contamination as might exist to negligible levels which are not injurious to health through appropriate treatment in a series of unit operations, and to ensure that the safe water so produced reaches the consumer without deterioration in the distribution network.

The holistic risk assessment/risk management that characterizes successful water services is termed a WSP, and is at the core of a well-managed water service.

4.1. Vulnerability of the resource

4.1.1. General considerations

In general, raw water quality is influenced by both natural factors and those relating to human use. Important natural factors which may affect quality include wildlife, climate, topography, geology and vegetation. Human-use factors include point sources of contamination (for example, municipal wastewater and industrial wastewater discharges) and non-point sources (such as urban and agricultural run-off including agrochemicals, livestock or recreational use). For example, discharges of municipal wastewater can be a major source of microbial pathogens; urban run-off and livestock can contribute substantial microbial load; body contact with water during recreation can be a source of faecal contamination and agricultural run-off can create challenges to water treatment.

It is important that the characteristics of the local catchment area or aquifer are well understood, and that hazards that could lead to water pollution are identified and managed. The extent to which potentially polluting activities in the catchment area can be reduced may appear to be limited. However, introducing good practices to ensure containment of hazardous agents is often possible without substantially restricting activities. The development of collaboration between stakeholders may be a powerful tool to reduce pollution without reducing beneficial development (WHO, 2003).

4.1.2. New water services

Prior to the selection of a new resource, it is important to ensure that the quality of the water is satisfactory for drinking, or can be treated to an adequate level in an economically sustainable manner with available technology. Furthermore, the quantity available should be sufficient to meet continuing water demands, taking into account daily and seasonal variations and projected demand growth in the community being served. Such growth may result not only from an increase in the population, but also from increasing living standards or an increase in certain industrial activities.

Proper selection and protection of the water resource is of prime importance in the provision of safe drinking-water. It is always better to protect water from contamination than to treat it after it has become contaminated. While contamination events are likely to occur from time to time, a large proportion of drinking-water problems can be prevented through adequate source protection.

To ensure that the best source is selected, a thorough analysis of source water quality should be undertaken, along with a comprehensive assessment of the vulnerability of the source to contamination. The assessment should be undertaken under "worst case" conditions whenever possible. A sanitary inspection and pollution vulnerability assessment of the source should also be undertaken under "worst case" conditions. A sanitary inspection should indicate the risk to the source from microbiological contamination in the immediate surroundings, resulting in the identification of measures that could be taken to protect the source from continued contamination. A pollution vulnerability assessment will provide information on the risk to the source of contamination from a wider perspective and identify potential risk from chemical contamination.[4]

4.1.3. Groundwaters

Rainwater or surface water, which seeps into the soil, can collect pathogens during its passage through the upper soil layers and transport them into the deeper layers. In particular, pre-formed soil capillaries can horizontally or vertically transport dissolved as well as particulate substances rapidly over considerable distances. In the saturated phase of the groundwater, the particulate substances transported by water can be adsorbed on the surface of soil materials. This process removes from the water both the inanimate particulate materials and the microorganisms, including bacterial, viral and parasitic pathogens. The adsorption capacity of the soil changes with the pore volume (the smaller the pore volume the better the filtration rate) and the length of the water flow route in the saturated phase. Water from a well-protected groundwater reservoir is free of pathogens and exhibits only a very low count of unspecific microorganisms. Such sources meet the most stringent hygienic and microbiological requirements for an optimal drinking-water supply.

Groundwater is vulnerable to pollution, although this is often neglected due to historical conceptions, as well as to the "out of sight out of mind" mindset. The concept of groundwater vulnerability is derived from the assumption that the physical environment may provide some degree of protection of groundwater against natural and human impacts, especially with regard to pollutants entering the subsurface environment. In arid and semi-arid regions, such as the Caspian countries, evapotranspiration rates are often higher, recharge lower and flow paths longer than in humid areas. This often results in high residence times and means pollution incidents can have far-reaching consequences. As regards the maintenance of groundwater quality, as with many other things, prevention is better than cure.

Potential hazards that can impact on the quality of resource and source water that should be taken into consideration as part of a hazard assessment are provided in Table 4.1 (WHO, 2004)

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[4] WHO seminar packs for drinking-water quality are available from WHO headquarters (http://www.who.int/water_sanitation_health/dwq/dwqtraining/en; accessed 23 December 2010).

Table 4.1. Examples of hazards to resource water

Catchments	- Geology - Rapid variations in raw water quality - Sewage and septic system discharges - Industrial discharges - Chemical use in catchment areas (for example, use of fertilizers and agricultural pesticides) - Major spills/accidental spillage - Public roads - Human access (recreational activity) - Wildlife (native and feral) - Unrestricted livestock - Inadequate buffer zones - Surrounding land use (e.g. animal husbandry, agriculture, forestry, industrial area, waste disposal, mining) - Changes in surrounding land use - Poorly vegetated riparian zones and failure of sediment traps/soil erosion - Stormwater flows and discharges - Existing or historical waste-disposal or mining sites/contaminated sites/hazardous wastes - Unconfined or shallow aquifers - Groundwater under direct influence of surface water - Inadequate well-head protection and unhygienic practices - Uncased or inadequately cased bores - Saline intrusion of coastal aquifers - Contaminated aquifers - Climatic and seasonal variations (e.g. heavy rainfall, droughts) - Bush fires, natural disasters, sabotage

Source: WHO, 2004.

The most logical approach to the definition of groundwater pollution risk is to think of it as the interaction between:

- the contaminant load that is, or might be applied to the subsurface environment as a result of human activity; and
- the pollution vulnerability, which is determined by the characteristics of the strata separating the aquifer from the land surface (WHO, 2008).

Understanding how groundwater originates and moves in aquifers is essential for understanding its vulnerability to pollution and subsequently in setting up groundwater protection strategies, designing pollution control or remediation measures and establishing monitoring networks.

Representation of the vulnerability of groundwater to pollution can be achieved using maps. However, the inevitable limitations of such maps must be explained to the users by the groundwater specialists preparing them. These limitations come from the simplifications imposed by the scale of heterogeneity of soils and aquifers compared to the scale of the map, and from deficiencies in the data available for whatever method of depicting vulnerability is adopted. Given an appreciation of these limitations, vulnerability maps have demonstrated that they can play a valuable role in groundwater protection.

Legislation plays an important part in protecting groundwater quality. Laws should be based on a proper process of consultation to ensure that policies are well founded and attract widespread support. However, policies and laws relating to groundwater protection can only be effective when the socioeconomic conditions permit their implementation without incurring undue costs to communities and societies.

The development and application of groundwater protection zones forms a key component of WSPs for groundwater supplies. Protection zones, in which land-use and pollutant discharges are controlled, represent a commonly used approach to managing pollution risks in aquifers. They pay particular attention to the prevention of pollution within the recharge area. The use of protection zones is important for both microbial and chemical contaminants and, when properly implemented, provides an effective barrier to pollution of groundwater sources. Many protection zones are based upon the time taken for contaminants to reach abstraction points for groundwater from the point of discharge. Some specific components of protection zones that may be used as control measures are outlined in Table 4.2, and Table 4.3 provides an indication of the additional supporting programmes that may be required to maintain effective control of groundwater quality.

The control of agricultural practices can lead to minimizing the pollution of groundwater resulting from these activities. It is also important to consider the implementation of protection zones. For example, correct application of fertilizers and pesticides, appropriate crop selection and sowing time can significantly reduce the movement of excess chemicals from the soil horizons into the groundwater system. In agricultural regions, widespread diffuse pollution tends to occur as the pollutants are used over large areas. Irrigation can also lead to pollution if contaminated water is used as a source of irrigation, or if irrigation is not applied in an efficient manner, thereby leading to increased soil salination. Furthermore, the management of livestock and waste materials can also be optimized to minimize pollution, and this is particularly important for intensive facilities. These are all-important factors to consider in the protection of groundwater resources and quality.

Table 4.2. Control measures for groundwater protection zones

Control measure	**Monitoring and evaluation**
Define zones of protection for microbial quality, based on travel time and local hydrogeological conditions	- Monitor land-use within zone and ensure restricted uses are controlled - Tracer tests - Verify with microbial indicators (faecal streptococci, *E. coli*, bacteriophages)
Define zone of protection for chemical quality, based on travel time and local hydrogeological conditions	- Monitor land-use within zone and ensure restricted uses are controlled - Tracer tests - Verify with chemical analysis
Define nitrate vulnerable zones	- Monitor fertilizer (inorganic and organic) applications - Verify with chemical analysis
Define recharge protection zone to maintain resource protection	- Monitor fertilizer (inorganic and organic) applications - Audits of pumping
Control pumping to ensure effect of draw down does not increase risk of leaching	- Monitor water levels around pumping wells with piezometers - Pumping tests to measure draw-down.

Source: WHO, 2006.

4.1.4. Sources and springs

Some specific measures can be employed to protect sources. Springs, for example, make good water supplies provided they are properly protected against contamination. To protect a spring, a retaining wall or box is constructed around the "eye" of the spring, where the water emerges from the ground. The area behind the wall or box is backfilled with sand or stones to filter the water as it enters the box. The backfilled area is capped with clay, and grass is planted on top.

Table 4.3. Supporting programmes for groundwater protection

Supporting programme	Monitoring and verification
National and local programmes of hydrogeological mapping	- Hydrogeological maps produced at national and local levels.
Vulnerability assessments of major and minor aquifers	- Vulnerability maps produced
Development of flow and contaminant transport models for aquifers	- Models available - Models calibrated
Prioritization of aquifers for protection zones	- Priority of aquifers indicated on maps and reports
Hydrogeological research programme into emerging issues and improved understanding of aquifers	- Research programme funded - Results and outputs of research incorporated into groundwater management plans
Training of hydrogeological staff in modelling and analytical methods	- Training courses available - Training audits to establish training needs and capacities - Certification/designation of course by professional bodies
Public education campaigns and awareness raising about groundwater protection	- Campaigns implemented and developed - Efficacy verified through assessment of changes in knowledge and attitude to groundwater protection
Training of farmers and developers regarding acceptable land-uses	- Training available - Number of farmers/ developers trained - Numbers of farmers/ developers using codes of practice
Development of legislation controlling groundwater abstraction and land-use	- Legislation exists and is updated - Abstraction with specified target levels

Source: WHO, 2006.

The whole area should be fenced and a ditch dug above the spring to prevent surface water from eroding the backfill area and contaminating the spring. The collection area should be covered with concrete and sufficient space left beneath the outlet pipe for people to place collecting cans if people take water directly from the spring. A lined drain should be constructed to carry spilled water away from the spring. To prevent mosquito breeding, water from the spring should not be allowed to form pools.

4.1.5. Surface water

Surface water as a source of drinking-water always needs to be treated. This also holds true when contamination occurs only periodically.

Protection of open surface water is problematic in the absence of proper management (WHO, 2008). It may be possible to protect a reservoir from major human activity, but, in the case of a river, protection may be possible only over a limited reach, if at all. Often it is necessary to accept existing and historical uses of a river or lake and to design the treatment accordingly. However, it is important that both localized and wider measures are undertaken to protect sources for drinking-water supplies. Local measures are required to ensure that the actual water source is not at risk from contamination in its immediate environment. Large-scale measures are required to ensure that valuable water sources are not lost because of contamination of the water body some distance away from the drinking-water source.

Effective resource and source protection include the following elements:

- developing and implementing a catchment area management plan, which includes control measures to protect surface and groundwater sources;
- ensuring that planning regulations include the protection of water resources from potentially polluting activities and are enforced; and
- promoting awareness in the community of the impact of human activity on water quality.

Where surface water is used as a source of drinking-water, then land use within the catchment area must be controlled and preferably limited to activities that are relatively non-polluting. This may be problematic as some activities may be well established and, in these cases, adequate standards of effluent quality should be established and enforced. In some countries, this is dealt with using discharge permits set by a government agency.

Land-use control has tended to be more effective when applied to artificial reservoirs, mainly because these are often located away from intensive human activities. However, land-use controls may be difficult to introduce where large-scale industry is located or intended to be located close to the water body. Reservoirs may attract intensive arable agriculture, which uses fertilizers, and pesticides which may pollute the water body.

The rigorous enforcement of compliance with effluent quality standards – backed up with adequate legislation that has penalties reflecting the severity of a pollution event – can make a significant contribution to the improvement of surface water quality. However, positive influence should also be exerted to assist industry in employing wastewater treatment in their plants. This may include raising awareness in the industry sector as well as imparting technical advice concerning technology choices. It may also involve other incentives to industry, such as tax breaks or subsidies.

Where some water sources are available, there may be flexibility in the selection of water for treatment and supply. It may be possible to avoid taking water from rivers and streams when water quality is poor (for example, following heavy rainfall) in order to reduce risk and prevent potential problems in subsequent treatment processes. On the other hand, economic considerations, particularly energy costs, may make the use of groundwater resources prohibitively expensive and force reconsideration towards more easily accessible surface water resources.

4.2. Water treatment

After source water protection, the next barrier to preventing contamination of drinking-water is the use of physical and chemical water treatment processes. Most treatment systems are designed to remove microbiological contamination and those physical constituents that affect its acceptability or that promote the survival of microorganisms. Treatment processes usually function either through the physical removal of contaminants by means of filtration or settling, or through the biological removal of microorganisms. There are some options available to treat water for potable purposes, depending on resources available for operation and maintenance, the level of operator training and the origin of the water source. However, it is usual for treatment to take place in a number of stages, with initial pre-treatment by settling or pre-filtration through course media, flocculation and sedimentation, or sand filtration (rapid or slow), followed by chlorination. This is called the **multiple barrier principle**. It provides a system to prevent complete treatment failure due to the breakdown of a single process.

4.2.1. Basic local water treatment

In many rural areas, water supply is a responsibility of the local community which, with limited financial means and technical insight, needs to provide water to the population of a small settlement. Community water supplies in both developing and developed countries are more frequently associated with outbreaks of water-related diseases than centralized supplies. Community water supplies and how best to manage them has been a topic addressed in Volume 3 of the WHO *Guidelines for drinking-water quality* (third edition) (WHO, 2004). Today's national and international policy frameworks recognize that further attention must be paid urgently to this neglected topic if the water and sanitation targets known as the Millennium Development Goals are to be met.

To create a coordinated global response, an International Network on Small Community Water Supply Management has been formed. This Network is open to all working on the topic from a policy, academic or practitioner perspective. It identifies common management and technical issues and problems in relation to community supplies, and attempts to find workable solutions in terms of the relevant geographical and cultural contexts.[5]

In small communities in rural areas, protection of the source of water (see subsections 4.1.2–4.1.4) may be the only preventive measure possible. Where communities are large, the demand for water is high and can often be met only by using additional sources which may be of poor microbiological quality. Such waters will require all the resources of water treatment to yield safe and palatable drinking-water.

Many rural supply programmes aim to develop water sources that can be fully managed by users, with only limited additional support from local government. Although this can make a sense of community ownership more achievable, it also requires communities to commit to the programmes. Such commitment may be short-term, such as a financial contribution towards the construction, or long-term, such as the regular provision of maintenance services. Maintenance is vital but its importance is often underestimated. If this is not carried out then the water supply may deteriorate in quality. It is therefore important to involve all community members during all stages of development of the improved water supply.

There are some types of water sources, which may be available to rural communities, as detailed here.

1. Although **protected springs** require very little maintenance, the following basic checks should be carried out every 1–3 months.
    - Does the water change colour after rain?
    - Has a water quality test been carried out recently?
        - Did the community receive the results of the test?
    - Is the area behind the retaining wall losing the grass cover?
    - Does the retaining wall show signs of damage?

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[5] Further information on the Network is available on the WHO headquarters web site (http://www.who.int/water_sanitation_health/dwq/smallcommunity/en/index.html, accessed 23 December 2010).

    - Can this be repaired locally?
- Does the uphill ditch need clearing?
- Does the downhill ditch need clearing?
- Does the fence need repairing?
- Does the grass behind the retaining wall need cutting?
- Do the outlets leak?

2. **Ponds and lakes** have traditionally been used as sources of drinking-water. Although they are easily contaminated, the water quality can be improved through careful use. As a minimum, the water should be treated with a disinfectant. The most commonly used disinfectant is chlorine, although others can be used. Chlorine can be added as a solution of calcium or natrium hypochlorite, as chlorine gas or as other chlorine compounds. Achieving the correct ratio of chlorine and water is complicated – using too little chlorine will not kill the pathogens, but adding too much will make the water taste unpleasant and may create high levels of chlorination by-products.

   Pre-constructed treatment systems, called “package plants” are available. However, if they fail they usually require specialist repairs and equipment which can be costly.

   Retention of water in reservoirs can reduce the number of faecal microorganisms through settling and inactivation, including solar (ultraviolet) disinfection. Most pathogenic microorganisms of faecal origin (enteric pathogens) do not survive indefinitely in the environment. Substantial die-off of enteric bacteria will occur over weeks. Enteric viruses and protozoa will often survive for longer periods (weeks to months) but are often removed by settling. Retention also allows suspended material to settle, which makes subsequent disinfection more effective and reduces the formation of DBPs. During impoundment in lakes or reservoirs, reductions of faecal indicator bacteria, *Salmonella*, and enteroviruses amount to about 99%, being greatest during the summer and with residence periods of about 3–4 weeks.

3. Although **groundwater** is often seen as a pure and safe resource, any new well should have a comprehensive suite of chemical and microbial parameters tested in order to ensure its safety. Chlorination is the most common form of groundwater treatment. Consequently, it is used as a primary disinfectant only for ground waters, not directly influenced by surface waters, where there is no risk of *Giardia* or *Cryptosporidium* contamination. Ozone is another possibility, although this may not be suitable for small rural systems as it must be generated on site as required. This is also the problem when considering chlorine dioxide.

The most common problems relating to quality in rural groundwater and possible treatment solutions are outlined in Table 4.4.

4.2.2. Centralized water treatment

There are many different water treatment processes available. This subsection gives an outline of the main processes involved in the full treatment of water. All are important but it should be noted that not all waters require full treatment. In any given case the amount of treatment required has to be determined before consideration is given to the best means of providing it. It is imperative that the selection of technology for treatment plants is carried out taking into account costs, operator training, and the type of source water. Consideration must also be given to the seasonal variations in the raw water quality and the possibility of long-term changes due to development in the catchment area. Many texts are available providing detailed descriptions of the engineering processes involved in water treatment, which are beyond the scope of these guidelines.

Table 4.4. Contaminants associated with rural groundwaters, and possible treatment

Contaminant	Sources	Treatment
Nitrate	Natural, fertilizers, human and animal waste percolation	Blending with low-N waters, reverse osmosis, membrane filtration, electro-dialysis reversal, ion exchange
Iron and manganese	Anaerobic, reduced waters, bacteria on well walls	Aeration, oxidation, ion exchange, addition of a sequestering agent to prevent precipitation.
Tastes and odours	Dissolved gases, biological growths or by organic or inorganic contaminants	Aeration, granular activated carbon

Source: adapted from WHO, 2006.

Water treatment consists of a range of steps carried out in sequence (Gray, 1994), listed here:

1. pre-treatment
2. coagulation
3. flocculation
4. clarification
5. filtration
6. adjustment of the pH
7. disinfection
8. softening
9. sludge removal.

Normally, not all of the steps are carried out at any one particular plant and will depend on the quality of the raw water entering the treatment plant and the quality of the finished water required.

4.2.2.1. Pre-treatment

Pre-treatment can broadly be defined as any process used to modify water quality prior to entering the treatment plant, and includes storage, preliminary screening, micro-straining and aeration. Pre-treatment options may be compatible with a variety of treatment processes ranging in complexity from simple disinfection to membrane processes. Pre-treatment can have the advantage of reducing or stabilizing the microbial load to the treatment process.

4.2.2.2. Coagulation, flocculation, sedimentation and filtration

Coagulation, flocculation, sedimentation (or flotation) and filtration are unit operations used to remove particles, including microorganisms (bacteria, viruses and protozoa) from the water. It is important that operations are optimized and controlled to achieve consistent and reliable performance. Often, these are the only operating treatment processes that are effective at removing protozoal pathogens such as *Cryptosporidium*.

4.2.2.2.1. Coagulation

After fine screening, most of the remaining suspended solids will be very small. Coagulation removes particles (including microorganisms) that are too small to settle naturally. A coagulant is added to the water to destabilize the particles and to induce them to aggregate into larger particles known as floes. A variety of coagulants can be used. The most common are: aluminium sulphate, aluminium hydroxide, polyaluminium chloride, iron (II) chloride, iron (III) chloride, iron (III) sulphate and lime. Chemical coagulation is the most important step in determining the removal efficiency of coagulation/flocculation/clarification processes. It directly affects the removal efficiency of granular media filtration units and has indirect impacts on the efficiency of the disinfection process. While it is unlikely that the coagulation process itself induces any new microbial hazard to finished water, a failure or inefficiency in the coagulation process could result in a high microbial risk to drinking-water consumers. There have been many reported incidents of *Cryptosporidium* due to failure at this stage of treatment (see Rose, Huffman & Gennaccaro, 2002, for a review).

Coagulation and flocculation require a high level of supervisory skill. If too little coagulant is added to the water ineffective coagulation will occur and the filtration apparatus may become blocked too quickly: too much coagulant results in excess chemical being discharged with the finished water. Although a slight excess of coagulant may not have any significant short-term health effects, high concentrations of coagulant can have a severe impact on the health of consumers, as experienced during the 1988 accident in Camelford, United Kingdom (David & Wessley, 1995). Before it is decided to use coagulation as part of a treatment process, careful consideration must be given to the likelihood of a regular supply of chemicals and the availability of qualified personnel.

4.2.2.2.2. Sedimentation

The purpose of sedimentation is to remove particulate matter, including the floes formed during the coagulation process. In water treatment the water flows in an upward direction from the base of the sedimentation tank. The floes, which are heavier than the water, settle towards the bottom, so the operator must balance the rate of settling against the upward flow of water to ensure that all the particles are held within the tank as a sludge blanket. Correct operation of the sedimentation tanks is vital to minimize particulate matter passing through the plant. The most serious problem to avoid is fluctuating flow rates, which cause the sludge blanket, through which the water flows, to expand too much. This will cause particles to be lost from the tank with the treated water.

Among the factors that influence sedimentation are: size, shape and weight of the floe; viscosity and hence temperature of the water; detention time; number, depth and areas of the basins; surface overflow rate; velocity of flow; and inlet and outlet design. The sludge is a concentrated mix of all the impurities found in the water, especially bacteria, viruses and protozoan cysts. Therefore, plans must be made for the collection and safe disposal of sludge from sedimentation tanks. Infrequent desludging can cause particles to be lost from the tank with the treated water. Flotation is an alternative to sedimentation when the amount of floating matter is slight.

4.2.2.2.3. Filtration

After sedimentation, the water only contains fine solids and soluble material. Filtration is required to remove this residual material. Various filtration processes are used in drinking-water treatment, including granular, rapid and slow sand filters, precoat, and membrane filtration (microfiltration, ultrafiltration, nanofiltration and reverse osmosis). With proper design and operation, filtration can act as a consistent and effective barrier for microbial pathogens. Granular media filtration may in some cases be the only barrier (for example for removing *Cryptosporidium* oocysts by direct filtration when chlorine is used as the sole disinfectant).

4.2.2.2.4. Rapid and slow sand filtration

Rapid sand filters contain coarse grades of quartz sand (1 mm diameter) so that the gaps between the grains are relatively large and the water passes rapidly through the filter. These are used for water that has previously been treated by coagulation and sedimentation, and are less effective in removing microorganisms. Turbidity varies through the duration of the run between backwashings. Immediately after backwashing, performance is poor, until the bed has compacted. Performance will also deteriorate progressively at the stage when backwashing is needed, as floes may escape through the bed into the treated water. These features emphasize the need for proper supervision and control of filtration at the waterworks.

Slow sand filtration is simpler to operate than rapid filtration, as frequent backwashing is not required. It is therefore particularly suitable for developing countries and small rural systems, but it is applicable only if sufficient land is available.

When the slow sand filter is first brought into use, a microbial slime community develops on the sand grains, particularly at the surface of the bed. This consists of bacteria, free-living ciliated protozoa and amoebae, crustaceans, and invertebrate larvae acting in food chains, resulting in the oxidation of organic substances in the water and the conversion of ammoniacal nitrogen to nitrate. Pathogenic bacteria, viruses, and resting stages of parasites are removed, principally by adsorption and by subsequent predation. When correctly loaded, slow sand filtration brings about the greatest improvement in water quality of any single conventional water treatment process. Bacterial removal will be at least 98–99.5% effective, *E. coli* will be reduced by a factor of 1000, and virus removal will be even greater. A slow sand filter is also very efficient in removing parasites (helminths and protozoa). Nevertheless, the effluent from a slow sand filter might contain a few *E. coli* and viruses, especially during the early phase of a filter run and with low water temperatures. The disadvantage with this type of filter is that it is operationally expensive and labour intensive because the dirt layer that collects on the surface of the sand impedes drainage and must be removed after the filter has been drained.

The operation of both rapid and slow sand filters is complex, and poor operation can lead to problems. The most serious problem is if the sand bed cracks, allowing unfiltered water to pass though.

4.2.2.2.5. Disinfection

Disinfection should be regarded as obligatory for all piped supplies using surface water, even those derived from high-quality, unpolluted sources, as there should always be more than one barrier against the transmission of infection in a water supply. In large, properly run waterworks, regulatory standards can then be met with a very high degree of probability of success.

Although slow sand filters are extremely efficient at removing bacteria, and the coagulation process is good at removing viruses, the finished water may still contain pathogenic viruses and bacteria that need to be removed or destroyed. In practice it is impossible to sterilize water without using a very high concentration of chemicals that would make the water unpleasant and probably dangerous to drink. Terminal disinfection of piped drinking-water supplies is therefore of paramount importance and is almost universal, as it is the final barrier to the transmission of waterborne bacterial and viral diseases. Although chlorine and hypochlorite are most often used, water may also be disinfected with chloramines, chlorine dioxide, ozone, and ultraviolet irradiation.

The efficacy of any disinfection process depends upon the water being treated beforehand to a high degree of purity, as disinfectants will be neutralized to a greater or lesser extent by organic matter and readily oxidizable compounds in water. Microorganisms that are aggregated or are adsorbed into particulate matter will also be partly protected from disinfection, and there have been many instances of disinfection failing to destroy waterborne pathogens and faecal bacteria when the turbidity was greater than 5 nephelometric turbidity units (NTU). It is therefore essential that the treatment processes preceding terminal disinfection are always operated to produce water with a median turbidity not exceeding 1 NTU and not exceeding 5 NTU in any single sample. Values well below these levels will regularly be attained with a properly managed plant.

An example of the difference between baseline removal of waterborne diseases and a maximum removal rate is shown in Table 4.5.

In many countries, much of the unit operations that together form a drinking-water production plant do not work at the designed level of efficiency. Poor design, bad execution of the design, and faulty installation of design components aggravate the problem. A comprehensive hazard assessment and risk analysis programme will need to identify the vulnerable points within the production plant, and will become one of the key components of a WSP.

The best way to observe plant operation and identify the vulnerable points is to follow the same route that the water takes, that is, starting with the raw water intake and continuing through the plant to the treated water reservoir, first observing the operation of each unit, noting obvious problems, and then starting to identify possible solutions. The next step is to review the results of routine sampling to assess the performance of each unit.

The importance of plant maintenance is obvious, yet maintenance may be often poor so that continued emphasis on operation and management from the management side is required to ensure that the importance of this is understood by the workers. This is a large subject field and covering it in depth is beyond the scope of these guidelines. Maintenance includes the use and care of plant structures and equipment, in a way that will extend their useful life and will avoid breakdowns and emergencies. General rules can be set out which cover the broad maintenance picture, as listed here.

- Provide good housekeeping – everything clean, orderly, and organized.
- Develop a plan of daily operation and follow it.
- Modify the daily plan as experience and conditions indicate.
- Follow manufacturers’ recommendations for operation and maintenance of equipment.
- Establish and follow an inspection and lubrication routine for each piece of equipment.
- Keep records of maintenance and repair for each piece of equipment.

Table 4.5. Removal rates of unit processes

Treatment process	**Enteric pathogen group**	**Baseline removal**	**Maximum removal possible**
Pre-treatment			
Roughing filters	Bacteria	50%	Up to 95% if protected from turbidity spikes by dynamic filter or if used only when ripened
	Viruses	No data available	
	Protozoa	No data available; some removal likely	Performance for protozoan removal likely to correspond to turbidity removal
Microstraining	Bacteria, viruses, protozoa	Zero	Generally ineffective
Off-stream/bankside storage	All	Recontamination may be significant and add to pollution levels in incoming water; growth of algae may cause deterioration in quality	Avoiding intake at periods of peak turbidity equivalent to 90% removal Compartmentalized storages provide 15–230 times rates of removal
	Bacteria	Zero (assumes short circuiting)	90% removal in 10–40 days actual detection time
	Viruses	Zero (assumes short circuiting)	93% removal in 100 days actual detention time
	Protozoa	Zero (assumes short circuiting)	99% removal in 3 weeks actual detention time
Bankside infiltration	Bacteria	99.9% after 2 minutes 99.99% after 4 minutes (minimum based on virus removal)	
	Viruses	99.9% after 2 minutes 99.99% after 4 minutes	
	Protozoa	99.99%	
Coagulation/ flocculation/ sedimentation			
Conventional clarification	Bacteria	30%	90% (depending on coagulant, pH, temperature, alkalinity, turbidity)
	Viruses	30%	70% (as above)
	Protozoa	30%	90% (as above)
High-rate clarification	Bacteria	At least 30%	
	Viruses	At least 30%	
	Protozoa	95%	99.99% (depending on use of appropriate blanket polymer)
Dissolved air flotation	Bacteria	No data available	

Treatment process	**Enteric pathogen group**	**Baseline removal**	**Maximum removal possible**
	Viruses	No data available	
	Protozoa	95%	99.9% (depending on pH, coagulant dose, flocculation time, recycle ratio)
Lime softening	Bacteria	20% at pH 9.5 for 6h at 2–8 °C	99% at pH 11.5 for 6h at 2–8 ° C
	Viruses	90% at pH<11 for 6h	99.99% at pH>11, depending on the virus and on settling time
	Protozoa	Low inactivation	99% through precipitative sedimentation and inactivation at pH 11.5
Ion exchange	Bacteria	Zero	
	Viruses	Zero	
	Protozoa	Zero	
Filtration			
Granular high-rate filtration	Bacteria	No data available	99% under optimum coagulation conditions
	Viruses	No data available	99.9% under optimum coagulation conditions
	Protozoa	70%	99.9% under optimum coagulation conditions
Slow sand filtration	Bacteria	50%	99.5% under optimum ripening, cleaning and refilling and in the absence of short circuiting
	Viruses	20%	99.99% under optimum ripening, cleaning and refilling and in the absence of short circuiting
	Protozoa	50%	99% under optimum ripening, cleaning and refilling and in the absence of short circuiting
Precoat filtration, including diatomaceous earth and perlite	Bacteria	30–50%	96–99.9% using chemical pre-treatment with coagulants or polymer
	Viruses	90%	98% using chemical pre-treatment with coagulants or polymers
	Protozoa	99.9%	99.99% depending on the media grade and filtration rate
Membrane filtration – microfiltration	Bacteria	99.9–99.99% providing adequate pre-treatment and membrane integrity conserved	
	Virus	<90%	

Treatment process	**Enteric pathogen group**	**Baseline removal**	**Maximum removal possible**
	Protozoa	99.9–99.99% providing adequate pre-treatment and membrane integrity conserved	
Membrane filtration – ultrafiltration	Bacteria	Complete removal, providing adequate pre-treatment and membrane integrity conserved	
Nanofiltration and reverse osmosis	Viruses	Complete removal with nanofilters, with reverse osmosis and at lower pore sizes of ultrafilters, providing adequate pre-treatment and membrane integrity conserved	
	Protozoa	Complete removal, providing adequate pre-treatment and membrane integrity conserved	
Disinfection			
Chlorine	Bacteria	Ct_{99}:0.08 mg.min/litre at 1–2°C, pH 7; 3.3 mg.min/litre at 1–2 °C, pH 8.5	
	Viruses	Ct_{99}:12mg.min/litre at 0–5°C; 8 mg.min/litre at 10 °C, both at pH 7–7.5	
	Protozoa	*Giardia* 230 mg.min/litre at 0.5°C; 100 mg.min.litre at 10°C; 41 mg.min/litre at 25°C; all at pH 7–7.5 *Cryptosporidium* not killed	
Monocholoramine	Bacteria	Ct_{99}: 94mg.min/litre at 1–2°C, pH 7; 278 mg.min/litre at 1–2 °C, pH 8.5	
	Viruses	Ct_{99}:1240mg.min/litre at 1°C; 430 mg.min/litre at 15 °C, both at pH 6–9	

Treatment process	**Enteric pathogen group**	**Baseline removal**	**Maximum removal possible**
	Protozoa	*Giardia* Ct$_{99}$ 2250 mg.min/litre at 1°C; 1000 mg.min/litre at 15°C both at pH 6–9 *Cryptosporidium* not killed	
Chlorine dioxide	Bacteria	Ct$_{99}$: 0.13mg.min/litre at 1–2°C, pH 7; 0.19 mg.min/litre at 1–2 °C, pH 8.5	
	Viruses	Ct$_{99}$: 8.4mg.min/litre at 1°C; 2.8 mg.min/litre at 15 °C, both at pH 6–9	
	Protozoa	*Giardia* Ct$_{99}$ 42 mg.min/litre at 1°C; 15 mg.min.litre at 10°C; 7.3 mg.min/litre at 25°C; all at pH 6–9 *Cryptosporidium* Ct$_{99}$: 40 mg.min/litre at 22°C, pH 8	
Ozone	Bacteria	Ct$_{99}$: 0.02mg.min/litre at 5°C, pH 6–7	
	Viruses	Ct$_{99}$: 0.9mg.min/litre at 1°C; 0.3 mg.min/litre at 15 °C	
	Protozoa	*Giardia* Ct$_{99}$ 1.9 mg.min/litre at 1°C; 0.63 mg.min.litre at 15°C pH 6–9 *Cryptosporidium* Ct$_{99}$: 40 mg.min/litre at 1°C; 4.4 mg.min/litre at 22°C	
UV irradiation	Bacteria	99% inactivation: 7mJ/cm^2	
	Viruses	99% inactivation: 59 mJ/cm^2	
		Giardia: 99% inactivation: 5 mJ/cm^2 *Cryptosporidium* 99.9% inactivation: 10 mJ/cm^2	

Note. Ct and UV apply to microorganisms in suspension, not imbedded in particles or in biofilm.

Source: adapted from LeChevallier & Kwok-Keung Au, 2004.

- Establish a plan for maintenance of the plant structures. Most of the water treatment is carried out in corrosive conditions and protective coatings need to be periodically repaired. The failure to repair concrete surfaces can cause exposure of reinforcing steel, with eventual structural weakening and loss. Good preventative maintenance avoids expensive waste.
- Maintain a well-equipped workshop with a competent electromechanic, having a reasonable stock of pipes, electrical wire and essential repair parts.

Due to the dangerous nature of many of the chemicals used and activities undertaken at treatment plants, strict health and safety guidelines must be drawn up and followed. The core components of this should examine the following issues:

- electrical and mechanical hazards
- water treatment chemical hazards
- chemical storage and handling hazards
- flammable situations
- chlorine toxicity and handling
- traffic control in work areas
- on-site construction work and/or trenching hazards
- working in confined and/or poorly ventilated spaces
- hearing and vision hazards
- first aid.

4.3. Vulnerability in the distribution system

A distribution network transports water from the place of treatment to the consumer. Its design and size will be determined by the size of the service area, and by its topography. The aim is always to ensure that the consumer receives a sufficient and uninterrupted supply of wholesome drinking-water; deterioration of the water quality during transportation needs to be avoided as this can pose a significant health risk. Yet, such deterioration can occur because of failure of the network's integrity, or because of chemical and microbial changes in the water during transport.

4.3.1. Compromised network integrity

Water services play an important role in ensuring the integrity of the network and thus ensuring the continued safety of the water.

Water entering the distribution system must be microbiologically safe and ideally should be biologically stable. The distribution system itself must provide a secure barrier to post-treatment contamination as the water is transported to the user. Residual disinfection will provide partial protection against recontamination, but may also mask the presence of such contamination.

Water distribution systems should be fully enclosed and storage areas should be securely roofed, with external drainage to prevent contamination. Backflow prevention policies should be applied and monitored. There should be effective maintenance procedures to repair faults and burst mains in a manner that will prevent contamination. Positive pressure should be maintained throughout the distribution system. Appropriate security needs to be put in place to prevent unauthorised access to and/or interference with water stores.

Contamination can occur in the distribution system in the following ways.

- In **infiltration**, contaminated subsurface water is drawn into the distribution system when the distribution system enters a low-pressure zone in an inadequately protected section of the network. Pressure waves in the distribution system may cause changes within the network thereby facilitating ingress of contaminated water in the distribution network.
- **In back-siphonage**, faecally contaminated water is drawn into the distribution system or storage reservoir through a backflow mechanism resulting from a reduction in line pressure and a physical link between contaminated water and the storage or distribution system.
- Microbial contamination can also be introduced into the distribution system through **open reservoirs** for the storage of drinking-water.
- **In line construction and repair**, when existing mains are repaired or replaced, or when new water mains are installed, strict protocols need to be followed with regard to disinfection and flushing to prevent the introduction of contaminated soil into the system.
- Human error can result in the unintentional **cross-connection** of wastewater or stormwater to the distribution system, or through illegal or unauthorized connections.
- **Direct connection** occurs when a physical link exists between the piping of a potable and a non-potable system.
- **Indirect connection** occurs when water makes the connection; for example, a hose connecting the drinking-water supply to contaminated water, or sewer leakage entering the drinking-water pipes.

When the physical integrity of the distribution network is compromised – even when a small residual concentration of disinfectant is present – pathogens may occur in concentrations that could cause outbreaks of water-related disease.

Repair work on mains provides an opportunity for contamination to occur. Local loss of pressure may result in back-siphonage of contaminated water unless check valves are introduced into the consumer’s water system. When repairs are completed it is essential that the pipes are cleaned, disinfected, and then emptied and re-filled with mains water. The water should then be tested bacteriologically after 24 hours.

If the main has been damaged, there is a threat of contaminated water from a fractured sewer or drain entering. The level of chlorination should be increased and the main not returned to service until the quality of the water is established as being satisfactory.

Underground storage tanks and service reservoirs must be inspected for deterioration and for infiltration of surface water and groundwater. It is desirable for the land enclosing underground storage tanks to be fenced off, both to prevent access by people and animals and to prevent damage to the structures.

Storage is in general a critical point in ensuring safety at the point of consumption. Structural integrity and safe management of storage tanks above ground – including modest storage areas at the household level – are essential to protect human health.

Intermittent supplies – either because of planned discontinuation of supplies at certain points in time or because of (unplanned) failure in the power supply structure – are common in many countries. The control of water quality in intermittent supplies represents a very significant public health challenge, as the risk of infiltration and back-siphonage significantly increases. The risk may be elevated seasonally, as soil moisture conditions increase the likelihood of a pressure gradient developing from the soil to the pipe. Once an intermittent water supply has been contaminated, restoration of the supply may increase risk to consumers when a concentrated "slug" of contaminated water is forced out of the distribution pipes and into the homes. Intermittent supplies are also often associated with household storage of water, which may also become of risk to human health.

It is estimated that over half of the urban water supplies in Asia operate intermittently. Intermittent water supply is a significant constraint on the availability of water for hygiene. While the average intermittent system is reported to operate for more than half the time, this disguises large local variations between systems and within each distribution network. When the systems function intermittently, contamination may also occur by means of intrusion of contaminated water into the pipelines through faulty joints, cracks, and so on. In addition, the pipelines are subject to additional stress caused by transient flows, affecting the durability of the system and weakening pipes and joints (WHO/UNICEF Joint Monitoring Programme, 2000).

Control measures include using a more stable secondary disinfecting chemical (such as chloramines instead of free chlorine); making operational changes to reduce the time that water spends in the system (avoiding stagnation in storage tanks and looping dead-end sections); undertaking a programme of pipe replacement, flushing and relining; and maintaining positive pressures in the distribution system.

The monitoring technique most often used to determine if a distribution system has delivered water of an acceptable quality is testing for the presence or absence of microbial indicator bacteria. However, there are pathogens that are more resistant to chlorine disinfection than the more commonly used indicator organisms, such as thermotolerant coliforms and/or *E. coli* and enterococci.

4.3.2. Deterioration of microbial water quality

A drinking-water distribution system provides a habitat for microorganisms that are sustained by organic and inorganic nutrients present in the distributed water.

Bacteria and fungi grow freely in the water, and form films on the side of pipe walls, which make them more resistant to residual chlorination. Among the major genera found in distribution systems are Acinetobacter, Aeromonas, Listeria, Flavobacterium, Mycobacterium, Pseudomonas and Pleisiomonas. The type of microorganisms and the number of them depend on numerous factors such as the water source, type of treatment, residual disinfectant and nutrient levels in the treated water. The development of biofilms leads to the survival of other bacteria, for example *Legionella* spp. (Steinert, Hentschel & Hacker, 2002). The development of non-pathogenic coliforms is possible in biofilms but the operator should not dismiss a non-faecal cause.

Drinking-water entering the distribution system may contain free-living amoebae and environmental strains of various bacterial species, often referred to as heterotrophic bacteria. Many environmental strains of bacteria such as *Citrobacter*, *Enterobacter* and *Klebsiella* may also colonize distribution systems (Van der Kooij, 2003). There is no evidence at present to implicate the occurrence of these microorganisms from biofilms (except, for example, *Legionella* or *Mycobacterium*) having adverse health effects in the general population, with the possible exception of immunocompromised population groups.

Harmless bacteria may be present in the distribution system, even in the presence of residual disinfectant, and this water can still be without health risks. However, excessive microbial activity can lead to a deterioration of aesthetic quality and can interfere with the methods used to monitor parameters relating to health significance.

Water temperatures and nutrient concentrations are not generally elevated enough within the distribution system to support the growth of *E. coli* (or enteric pathogenic bacteria) in biofilms. Thus the presence of *E. coli* should be considered as evidence of recent faecal contamination. Chemical hazards may be introduced from materials such as pipes, solders/jointing compounds, taps and chemicals used in cleaning and disinfection of distribution systems.

Certain steps can be taken to reduce microbial growth within the distribution system. Maintaining a disinfectant residual throughout the distribution system can provide protection against recontamination and limit problems of re-growth of microorganisms. Where a disinfectant residual is used within a distribution system, minimization of the production of DBPs known to be carcinogenic at higher concentrations than those found in water needs to be considered. Chloramination has proved successful in controlling *Naegleria fowleri* in water and sediments in long pipelines.

The growth of fungi and actinomycetes is controlled by temperature, with optimum growth occurring at 25 °C. It is therefore essential to prevent water in distribution systems from standing for long periods and warming up. Long residence times also encourage organic material to flocculate and settle, which then acts as a source of food for microorganisms. Where the water contains appreciable assimilable organic carbon and where the water temperature exceeds 20 °C, a chlorine residual of 0.25 mg/litre may be required to prevent the growth of *Aeromonas* and other nuisance bacteria.

Maintaining good water quality in distribution will also depend on the operation and design of the distribution system and maintenance and survey procedures to prevent contamination and to remove and prevent the accumulation of internal deposits. Well-documented hygiene procedures are essential to prevent contamination when maintenance work is being undertaken.

4.4. WSPs

WSPs were introduced in the third edition of WHO's *Guidelines for drinking-water quality* (WHO, 2004) as "the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer". Its aim is clear: "to consistently ensure the safety and acceptability of a drinking-water supply". The great advantage of the WSP strategy is that it is applicable to ensuring the safety of water in all types and sizes of water supply systems, no matter how simple or complex. A further important specificity of the WSP approach is that it is dynamic and practical, and not a standardized, fixed operating procedure. It is therefore suited to dealing with the changes in quantity and quality expected to result from extreme weather events. In the following subsections, the key steps of a WSP are reviewed on the basis of the official WHO guidelines. Special manuals were released shortly thereafter (Bartram et al., 2009).

4.4.1. WSP team creation

Technical expertise for the development of a WSP needs to be brought together as the first step towards that development. Team members are usually sourced from within the utility, but may also include members from a wider group of stakeholders, with collective responsibility for understanding the water supply system and identifying hazards that can affect water quality and safety throughout the water supply chain. The team will be responsible for the day-to-day development, implementation and maintenance of the WSP as a core part of their functions. It is essential that all involved play an active role in the development of the WSP, support the approach and have the visible support of senior management.

A vital early task of the team is to set out how the WSP approach is to be implemented and the methodology that will be used, particularly in assessing likelihood and consequences of risks.

4.4.2. Describe the water supply system

Many water utilities have a description of their system. This documentation needs to be extensively reviewed, including through inspections in the field. Experience shows, however, that such descriptions may have to be updated, especially with regard to older parts of the system and with new developments in the resource capture area in mind. Also, existing and potential connections between one system and other systems need to be taken into consideration as part of the descriptive process. Two types of connections need to be considered:

- those from which the water utility concerned would receive support in case of accident, disturbance or other emergency;
- those to which the water utility concerned would need to provide support in case of emergency conditions prevailing in that (external) service area.

The latter should include not only service areas reachable through cross-connections of the different distribution systems, but should also take into account the potential to come to the aid of populations in areas which cannot be reached by piped connections.

The objective is to ensure that subsequent documentation of the nature of the raw, interim and finished water quality – as well as of the system used to produce the water of that quality – is accurate enough to allow risks to be adequately assessed and managed. Each supply needs to be assessed on its own. Data should be gathered for that supply, and all other steps taken leading to a WSP should be exclusive to that particular supply.

4.4.3. Identify hazards and hazardous events and risks

At this stage:

- all potential biological, physical and chemical hazards associated with each step in the drinking-water supply need to be identified;
- all hazards and hazardous events that could result in the water supply being, or becoming, contaminated, compromised or interrupted need to be identified; and
- risks identified at each point of the flow diagram need to be evaluated and ranked.

4.4.4. Determine and validate control measures, reassess and prioritize risks

The WSP team should document existing and potential control measures, as well as considering whether existing controls are effective. Depending on the type of control, this could be carried out by site inspection, manufacturer's specification, or monitoring data. The risks should then be recalculated in terms of likelihood and consequence, taking into account all existing control measures. The reduction in risk achieved by each control measure is an indication of its effectiveness. Any remaining risks after the control measures have been taken into account – and/or which the WSP team considers unacceptable – should be investigated with a view to additional corrective action.

4.4.5. Develop, implement and maintain an improvement/upgrade plan

Improvement plans address controls that were found to be inexistent or faulty at the previous stage. Each identified improvement needs an "owner" to take responsibility for implementation, and a timeline. Improvement/upgrade plans can include short-, medium- and long-term programmes and might include capital investment, but may also include revisions of documentation, standard operational procedures, and so on. Significant resources may be needed, and therefore a detailed analysis and careful prioritization should be carried out in accordance with system assessment. Implementation of improvement/upgrade plans should be monitored to confirm improvements have been made and are effective, and the WSP upgraded accordingly.

4.4.6. Do operational monitoring

Operational monitoring includes defining and validating the monitoring of control measures and establishing procedures to demonstrate that the controls continue to work. These actions should be documented in the management process. This also requires the inclusion of corrective actions that become necessary when operational targets are not met.

4.4.7. Verify the effectiveness of the WSP

Having a formal process for verification and auditing of the WSP ensures that it is working properly. Verification involves three activities which are undertaken together to provide evidence that the WSP is working effectively:

- compliance monitoring
- internal and external auditing of operational activities
- assessment of consumer satisfaction levels.

Verification should provide the evidence that the overall system design and operation is capable of consistently delivering water of the specified quality to meet the health-based targets. If it does not, upgrade/improvement plans should be revised and implemented.

4.4.8. Prepare management procedures

Two types of documentation form an integral part of a WSP: documented management procedures when the system is operating under nominal conditions, the so-called standard operating procedures (SOPs), and corrective actions when the system is dealing with an "incident". The procedures should be written by experienced staff, and should be updated as necessary, particularly in light of the implementation of improvement/upgrade plans and reviews of incidents, emergencies and near misses. It is preferable to interview staff and ensure their activities are captured in the documentation. This also helps to foster ownership and eventual implementation of the procedures.

4.4.9. Develop supporting programmes

Supporting programmes frequently relate to training, research and development but can also cover strengthening indirect services such as (among others) laboratory improvement, accreditation, and equipment upgrades. Examples of other activities include continuing education, calibration of equipment, preventive maintenance, hygiene and sanitation, legal aspects of water supply and so on.

4.4.10. Conduct periodic review

The WSP team should periodically meet and review the overall plan, and learn from experiences and new procedures (in addition to regularly reviewing the WSP through analysis of the data collected as part of the monitoring process). The review process is critical to the overall implementation of the WSP and provides the basis from which future assessments can be made. Following an emergency, incident or near miss, risk should be reassessed and may need to be fed into the improvement/upgrade plan.

4.4.11. Revise after incident

It is important that a WSP is reviewed **after every emergency, incident or near miss** to ensure that the situation does not recur and to establish whether the response was sufficient or the situation could have been handled better.

4.4.12. Typical challenges

Table 4.6 summarizes the challenges and expected outputs of each step in the WSP process.

4.5. Point-of-use treatment

Point-of-use (POU) treatment refers to simple, acceptable, low-cost interventions that can be implemented at the community or household level and that offer the possibility of dramatically improving the microbial quality of water. The techniques can be applied in situations in which people can rely only on their own initiative to ensure microbial safety, but also in locations in which the quality of piped water has been compromised. POU treatment also needs to be accompanied by safe storage (Arnold & Colford, 2007; Fewtrell et al., 2005; Clasen et al., 2007; Clasen et al., 2006; Clasen et al., 2005; Clasen & Bastable, 2003; Trevett, Carter & Tyrrel, 2005). A variety of technologies for treatment of household water have been described, and many are widely used in different parts of the world.

Pre-treatment, either by settling or coagulation, will often also help to reduce faecal contamination to some extent. Pre-treatment technologies for removal of turbidity (suspended matter) from water suitable for such applications potentially include the following options.

- In **settling or plain sedimentation**, where water is cloudy, a simple treatment is to allow particulates in the water to settle overnight. Clear water at the top of the container is then poured into a clean container. Adding certain chemicals can help settling, such as aluminium sulphate, or powder from the ground seeds of Moringa olefera (horseradish tree) onto the water surface. Settling does not remove all pathogens, silt or clay. Water should be boiled or disinfected before consumption.
- **Candle filters** are commercially produced. Contaminated water is allowed to filter slowly through a porous ceramic material. Larger microorganisms – ova, cysts and most bacteria – are left in the outer layer of the filter material, which is periodically cleaned by gentle scrubbing of the filter under clean, running water. Smaller microorganisms – such as viruses that cause hepatitis A – may not be removed by candle filters.

Table 4.6. Challenges and outputs of the different steps in a WSP

WSP Step	Challenges	Outputs
1. Assemble the WSP team	• Finding skilled personnel • Organizing the workload to fit with existing structures and roles • Identifying and engaging external stakeholders • Keeping the team together throughout the WSP exercise • Getting the team to communicate effectively with the rest of the utility and the stakeholders	Establishing an experienced, multidisciplinary team that understands the components of the system, and is well-placed to assess the risks that may be associated with each component of the system. The team needs to understand the health and other targets to be achieved, and have the expertise to confirm, following an assessment, whether the system can meet relevant water quality standards.
2. Describe the water supply system	• Lack of accurate maps of the origin of the water, its geohydrological characteristics, recharge patterns and interconnections • Lack of maps showing the distribution system, and its interconnection with neighbouring systems • Lack of knowledge of industry, landfills and historically contaminated sites • Identifying all government and local agencies with potential information or a role to play • Time required by staff to undertake field work • Out-of-date procedures and documentation	1. A detailed, up-to-date description of the water supply system, including a flow diagram 2. An understanding of water quality currently being provided by the water utility 3. Identifying the users and uses of the water
3. Identify hazards and risks	• Possibility of missing new hazards and hazardous events (Risk assessments should be reviewed on a regular basis in order not to miss new hazards. This will increase in importance as better predictive models with higher geographic resolution become available.) • Uncertainty in assessment of risks due to the lack of availability of data, poor knowledge of activities within the water supply chain and their relative contribution to the risk generated by the hazard or hazardous event • Properly defining likelihood and consequence with sufficient detail to avoid subjective assessment and to enable consistency	1. Describing what could go wrong and where in terms of hazards and hazardous events. 2. Assessing risks expressed in an interpretable and comparable manner, such that more significant risks are clearly distinguished from less significant risks.
4. Assess risks	• Identifying staff responsibilities in terms of who will undertake the	1. Identifying the controls

WSP Step	Challenges	Outputs
	fieldwork to identify the hazards and determine the control measures • Ensuring appropriate controls are identified that are cost-effective and sustainable • Uncertainty in prioritizing the risks due to lack of availability of data; poor knowledge of activities within the water supply chain and their relative contribution to the hazard type generated by the hazardous event, as well as the risk score of that event	2. Validating the effectiveness of the controls 3. Identifying and prioritizing insufficiently controlled risks
5. Develop, implement and maintain an improvement / upgrade plan	• Ensuring that the WSP is kept up to date • Securing financial resources • Lack of human resources, including technical expertise, to plan and implement needed upgrades • Ensuring new risks are not introduced by the improvement programme	1. Developing a prioritized upgrade/improvement plan for each significant uncontrolled risk 2. Implementing the improvement plan according to the planned schedule of short-, medium- and long-term activities 3. Monitoring the implementation of the upgrade/improvement plan
6. Define monitoring of the control measures	• Lack of sufficient laboratory facilities to carry out analysis • Lack of sufficient human resources to carry out monitoring and analysis • Financial implications of increased monitoring • Inadequate or absent evaluation of data • Changing the attitude of staff members who are used to certain monitoring methods • Ensuring that corrective actions identified for control measures are agreed between the water safety management department and the operations department • Ensuring that resources are available to the operations department to carry out corrective actions	1. Assessing the performance of control measures at appropriate time intervals 2. Establishing corrective actions for deviations that may occur
7. Verification	• Lack of capable external auditors for WSPs • Lack of qualified laboratories to process analysis of samples • Lack of human and financial resources • Lack of knowledge of consumer satisfaction or complaints	1. Confirmation that the WSP itself is sound and appropriate 2. Evidence that the WSP is being implemented in practice, as intended, and is working effectively 3. Confirmation that the water quality meets defined targets

WSP Step	Challenges	Outputs
8. prepare management procedures	• Keeping the procedures up to date • Ensuring that staff are aware of changes • Obtaining information on near misses	1. Response actions 2. Operational monitoring 3. Responsibilities of the utility and other stakeholders 4. Plans for emergency water supplies 5. Communication protocols and strategies, including notification procedures and staff contact details 6. Responsibilities for coordinating measures to be taken in an emergency 7. A communication plan to alert and inform users of the supply and other stakeholders (e.g. emergency services) 8. A programme to review and revise documentation as required 9. Plans for providing and distributing emergency supplies of water
9. Develop support programmes	• Human resources • Equipment • Financial resources • Support of management • Not identifying procedures and processes as part of the WSP	Programmes and activities that ensure that the WSP approach is embedded in the water utility’s operation
10. Conduct periodic review	• Reconvening the WSP team • Ensuring continued support for the WSP process • Ensuring that where original staff have left the utility, their duties are maintained by others • Keeping records of changes • Keeping in contact with stakeholders	A WSP that is up to date and continues to be appropriate to the needs of the water utility and stakeholders
11. Revise after incidents	• An open and honest appraisal of causes, chain of events, and factors influencing the emergency, incident or near-miss situation • Focusing and acting on the positive lessons learned, rather than apportioning blame	1. Comprehensive and transparent review of why the incident occurred and the adequacy of the utility’s response 2. Incorporation of the lessons learned into WSP documentation and procedures

Source: WHO, 2009.

- **Stone or ceramic filters** are similar to candle filters except they are carved from porous local stone. They may be difficult to clean and heavy to lift but are relatively inexpensive if they can be produced locally. It is important, however, to test water with a representative sample to determine the efficiency of the faecal contamination removal.
- Although **slow sand filters** are very efficient at removing microorganisms from contaminated water, they require a continuous flow of water in order to function effectively. They are the least likely to be implemented and the least sustainable at the household level. This is because the preferred filter designs and installations are often larger than necessary and capable of treating more water than needed by individual households, and also because they require technical skills for maintenance and operation that may not be practical for individual users.

Once particulate matter has been removed, several POU treatment techniques exist. The most common are listed here.

- Although some authorities recommend that **water be brought to a rolling boil** for 1–5 minutes, the WHO guidelines for drinking-water quality recommend bringing the water to a rolling boil as an indication that a high temperature has been achieved. These boiling requirements are likely to be well in excess of the heating conditions needed to dramatically reduce most waterborne pathogens, but observing a rolling boil assures that sufficiently high temperatures have been reached to achieve pathogen destruction. For every 1000 m above sea level, 1 minute of extra boiling time should be added. The disadvantages associated with boiling are that large amounts of fuel are required, which may be costly; it may give an unacceptable taste to the water; very hot water can cause accidents; and boiled water can become re-contaminated once it has cooled. The environmental consequences of deforestation in arid areas should be considered as well as health implications due to smoke inhalation.
- **Solar disinfection** by the combined action of heat and UV radiation has been shown to effectively treat water, but can take longer than chlorine disinfection. Solar disinfection can be achieved by heat alone, so-called “solar cooking”, while specially constructed lamps allow UV disinfection without the application of health.
- The **addition of chlorine** will kill most bacteria and some viruses. Since the taste of chlorine disappears when water is left in open containers, a very small lump of bleaching powder or one drop of household bleach can be added to a 20-litre water container and the mix left to stand for at least 30 minutes. After this time, if a faint smell of chlorine can be detected in the water, it should be low-risk and palatable to drink. Chlorine should only be added to clear water, otherwise it will be absorbed by the dirt in the water. In addition, chlorine that has been stored for some time will be less efficient. The use of disinfectants as a household treatment system has been successfully implemented in Asia and South America.
- **Combined systems of chemical coagulation/filtration and chlorine disinfection** can be used. Even the most promising household water treatment systems remain a challenge. This is because microbial reductions are decreased or prevented by turbidity particles that reduce access to target microbes or otherwise protect them from inactivation by other mechanisms. Suspended matter in water reduces the microbiocidal efficacy of chlorine and other chemical disinfectants, and it physically shields microbes from the UV radiation that is present in sunlight and emitted from mercury arc lamps and is responsible for much of its disinfection activity.

As a final step in POU treatment process, the safety of the final product needs to be guaranteed. Water treated at the point of use, if not consumed immediately, should be safely stored.

5. Essential epidemiology

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5.1. Basic definitions

Epidemiology is the study of the distribution and the determinants of health-related states or events in specified populations, and the application of this study to control health problems (Last, 2001). Waterborne disease epidemiology includes the study of the occurrence, distribution and control of waterborne diseases in populations and their origin, spread or communication, along with the eradication of these diseases. Knowledge about the burden of waterborne diseases within populations is essential for action by health authorities, to use the available limited resources most effectively for prevention and care.

There are some fundamental epidemiological terms that are also important for waterborne disease epidemiology, detailed in the following subsections.

5.1.1. Surveillance

Surveillance is the systematic collection, analysis and interpretation of health data in the process of describing and monitoring a health event.

5.1.2. Mortality

The death rate (or crude mortality rate) for all deaths or a specific cause of death is calculated as follows (Bonita, Beaglehole & Kjellström, 2006):

$$Crude\,mortality\,rate = \frac{Number\,of\;deaths\;during\,a\,specified\;period}{Number\,of\;persons\,at\,risk\,of\;dying\,during\,the\,same\,period} * 10^{n}$$

The main disadvantage of the crude mortality rate is that it does not take into account factors such as age, sex, socioeconomic class and so on, meaning that further refinements are usually required, such as the calculation of the age-specific death rate, the infant mortality or child mortality rate.

Mortality rates in waterborne disease epidemiology can be calculated, for example for investigating the relationship between the access to safe drinking-water and child mortality rates. Here, a countrywide comparison would be carried out of death rates of children under the age of 5 years with the percentage of the population that has access to safe drinking-water.

5.1.3. Morbidity

Morbidity describes any departure from a state of well-being (Last, 2001). It describes the proportion of patients with a particular disease during a given year per unit of population. More specifically, it describes the incidence of a particular disease or disorder within a population, usually expressed as cases per 100 000 or per million in one year. This includes all cases, both fatal and non-fatal. An example of this would be morbidity due to hepatitis A infections, including all diseased and dead individuals. For diseases with a low case fatality level, such as self-limiting diarrhoea, data on morbidity are more useful than mortality rates. In many countries, some morbidity data are collected to meet legal requirements, for example in respect of notifiable waterborne diseases.

5.1.4. Prevalence and incidence

Prevalence and incidence measure the occurrence of a disease in the population or in special population subgroups.

Prevalence is a measure of the proportion of the diseased population (percentage) at a specified point in time (Last, 2001). Another formulation of the term is: “the number of affected persons present in a population at a specific time, divided by the number of persons in the population at that time” (Gordis, 2000). The term “point prevalence” refers to a condition in a population at a given point in time; the term “period prevalence” is a combination of point prevalence and incidence. Prevalence data provide an indication of the extent of a condition and may have implications regarding the provision of services needed in a community. An example relating to prevalence would be the occurrence of bladder cancer on 1 January 2003 in a country that chlorinates its drinking-water.

Prevalence per 1000 =

$$\frac{\textit{No. of cases of a disease of a disease in the population at a specified time}}{\textit{No. of persons at risk at that specified time}} * 1000$$

Incidence is the number of new cases of a disease in a defined population within a specified period of time, for example during a year (Last, 2001; Gordis, 2000). The incidence rate uses new cases in the numerator: individuals with a history of the condition are not included. The denominator for incidence rates is the population at risk.

Incidence per 1000 =

$$\frac{\textit{No.of new cases of a disease in the population during aspecified period of time}}{\textit{No.of persons at risk of developing the disease during that period of time}} * 1000$$

Mathematically, incidence is often expressed as X cases per a given population base (for example, 10 000 or 100 000).

The choice whether to calculate the incidence or prevalence depends on the character of the disease and the purpose of the investigation.

5.1.5. Endemic, epidemic and pandemic disease distribution

The terms endemic, epidemic and pandemic describe distribution patterns of infectious diseases, which are important for infectious waterborne diseases.

An **endemic** disease is a disease constantly present in a given population, for example hepatitis A in several eastern European countries or regions.

A disease that occurs **epidemically** shows an abnormally high local incidence; that is, an occurrence of cases of disease in excess of what is usually expected for a given period of time.

This could be, for example, a typhoid fever outbreak in a community with sewage contamination of the drinking-water source, as took place in southern Kyrgyzstan at the end of 2003.

A **pandemic** is a disease that has an abnormally high incidence over a large geographic area. Cholera pandemics are the best-known pandemics of waterborne diseases. The seventh pandemic, which was caused by the bacterium *V. cholerae El Tor*, broke out in Indonesia in 1961 and has since spread to India, the mainland of Asia, West Africa and Latin America. The last (eighth) pandemic began in 1992 in India and Bangladesh and is caused by *V. cholerae non-01–0139 Bengal*.

Confusion sometimes arises because of overlap between the terms epidemic, outbreak and cluster. Although they are closely related, epidemic may be used to suggest problems that are geographically widespread, while outbreak and cluster are reserved for problems that involve smaller numbers of people or are more sharply defined in terms of the area of occurrence.

5.1.6. Outbreak

An outbreak is a short-term local increase in a disease (Last, 2001). WHO defines an outbreak as two or more cases of illness arising from the same source (Andersson & Bohan, 2001). A possible source of a waterborne disease outbreak could be a contamination of the central drinking-water supply. The considerable difficulty of detecting small outbreaks – whether from water or any other source – is well recognized (Quigley, Gibson & Hunter, 2003); however, it may prove to be even more difficult to detect outbreaks affecting a higher number of people but occurring in a larger population, such as metropolitan areas (Kožišek, personal communication, 2010).

5.1.7. Population at risk

In waterborne disease epidemiology, the population at risk must be defined. This is the part of the population which is susceptible to a disease, for example children, pregnant women, or people connected to the public water supply and therefore at risk when the water quality no longer meets the quality criteria (Beaglehole, Bonita & Kjellström, 1993).

5.2. Basic study designs

Descriptive and analytical studies can be used to carry out epidemiological investigations of waterborne disease outbreaks. The most important descriptive studies are ecological studies and surveys. Case-control and cohort studies are the most important studies used for analysing outbreaks of waterborne diseases.

5.2.1. Descriptive studies

In general, **descriptive studies** describe the pattern of disease in a community. They are an essential starting point in the investigation of any outbreak or possible waterborne disease, and help to generate hypotheses for further studies.

For the most part, data from routine surveillance – such as death reports, notifications of infectious diseases, laboratory reports, or case-finding exercises – are used as data sources. For case-finding exercises, information is sought regarding the temporal, geographic and demographic distribution of the disease (time, place, person). Thus, within these studies, data are collected relating to the date-of-onset, place of residence, travel history, age, sex as well as food and water consumption of those affected (Hunter, 1997).

In descriptive studies, the possibility to analyse is usually restricted to summarizing and presenting the data in tabular and graphical form.

One of the most important variants of descriptive studies is the so-called **ecological study**. This study design is based on conclusions relating to disease causation that are drawn by correlating incidence or prevalence rates for population groups (for example, communities) with possible risk factors, such as the proportion of people drinking well water or the proportion of unemployed people (Hunter, 1997). Though they have the advantage of being simple and economical to conduct, and that population data with widely differing characteristics can be used, they also have some major disadvantages. The most important factor is that no individual link can be made between exposure and effect. This problem is called “ecological fallacy”. They are also unable to control for many effects of potentially confounding factors. Because of these limitations, no reliable conclusion can be drawn from this type of study (Beaglehole, Bonita & Kjellström, 1993; Hunter, 1997).

An ecological study design could be the investigation of the relationship between chlorinating by-products and cancer rates in populations with differing water supplies. An example of an ecological study is that of Munger and colleagues (1997). Here, the intrauterine growth retardation in 13 Iowa communities that received water from the herbicide-contaminated Rathbun water system was compared to other Iowa communities of similar size. The results showed a higher rate of intrauterine growth retardation with maternal exposure to Rathbun drinking-water. However, limitations of this ecological study design led to the conclusion that the association can be only considered as a preliminary finding.

Surveys are another variant of descriptive studies. Here, the characteristics of individuals in the population are described, including their personal attributes, their experience of a particular disease and their exposure to putative causal agents (for example, well water) (Hunter, 1997). This means that exposure and effect are measured at the same time. For data collection, a sample of the population is interviewed by means of personal interview, telephone interview or postal questionnaire. The most important advantage of this type of study design is that these surveys are relatively easy and economical to conduct (Beaglehole, Bonita & Kjellström, 1993). When using this study design template, the problem of bias should be taken into account, in particular selection bias. For example, individuals having recently experienced diarrhoea are more likely to participate in the study on diarrhoeal disease. On the contrary, if a high proportion of people with diarrhoea are admitted to hospital they may not be available for interview in the community (Hunter, 1997). In an outbreak situation, a cross-sectional survey involving the measurement of multiple exposures is often the first step in an investigation to unveil the cause (for example, contaminated drinking-water).

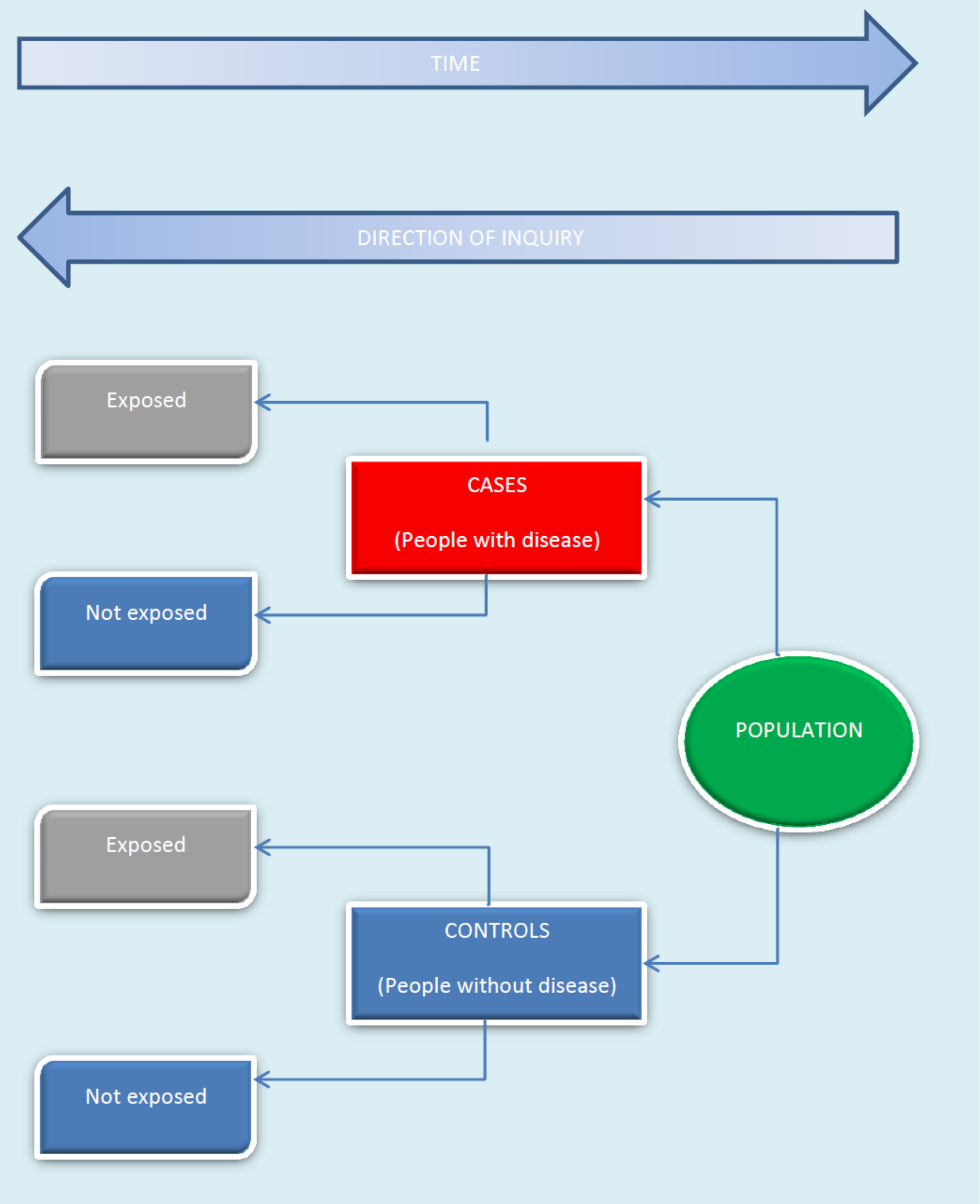
5.2.2. Analytical studies

Although descriptive studies are often used because of their advantages, analytical studies mostly lead to conclusions and evidence that cannot be extracted from descriptive studies.

Case–control studies are the most common analytical epidemiological investigation of potential waterborne outbreaks. Here, hypotheses are tested by comparing the incidence of a preceding event in those individuals with disease (cases) with those people in a group of individuals unaffected by the disease (controls) (Hunter, 1997). The advantages of case–control studies are that they are simple, quick and economical to carry out, and that a multiple exposure can be examined. Although they are limited to the examination of only one disease, a case–control study has the advantage of being able to examine multiple exposures at any one time, so that the relative contribution of each can be estimated (for example, food, water, and so on).

Fig. 5.1 demonstrates the procedure for conducting case-control studies. Case–control studies are retrospective, which means that the direction of the enquiry is into the past.

Fig. 5.1. Basic waterborne disease surveillance studies



Source: the WHO Collaborating Centre for Health Promoting Water Management and Risk Communication (Bonn, Germany).

Case–control studies normally proceed as follows. First, cases have to be selected that should represent all the cases from a specified population. Then controls have to be selected to sample the exposure prevalence in the population that generated the cases. The controls should represent people who would have been designated study cases if they had developed the disease. The controls need to be recruited in a timely fashion, to avoid a recall bias. The cases and controls can be restricted to specified subgroups (females, children). The key to success in case-control studies is the correct definition of cases and the selection of controls. The case definition may include clinical, epidemiological and microbiological or other laboratory features. Controls should be free of the disease; that is, free of symptoms such as diarrhoea or vomiting. The methods that can be used for selecting the cases may include telephone recruitment or the use of administrative registers (Beaglehole, Bonita & Kjellström, 1993).

After identifying cases and controls, a matching of controls to cases has to be carried out. One case can have up to four controls. It is important to ensure that there is sufficient similarity between cases and controls when the data are to be analysed by, for example, age group or social class (Beaglehole, Bonita & Kjellström, 1993). The proportions of cases and controls that, for example, are exposed to drinking-water are then compared and deductions can be made regarding whether or not drinking-water is a risk factor. The exposure can be defined by using hypotheses or specific disease experiences. In the case of the occurrence of gastroenteritis of unknown origin in a community, the food consumption, consumption of unsafe drinking-water or consumption of drinking-water contaminated with chemicals could be taken into account as exposure routes.

The measured value in a case-control study is the odds ratio (OR). An example of calculating an OR is given in Table 5.1. The OR is the ratio between the probability that someone with disease has experience of the potential environmental factor and the probability that someone without the disease has experience of the same factor (Hunter, 1997). In the given example the test deals with whether people with cholera were exposed to a specific risk factor – for example, had consumed seafood – or not. In Table 5.1 the OR is given as 11.6. This suggests that the cases were 11.6 times more likely than the controls to have recently ingested seafood (Beaglehole, Bonita & Kjellström, 1993). In case-control studies, a relative risk (RR) – which is the measured value of cohort studies, explained later in this subsection – cannot be calculated, because cases and controls are not random samples of the entire population.

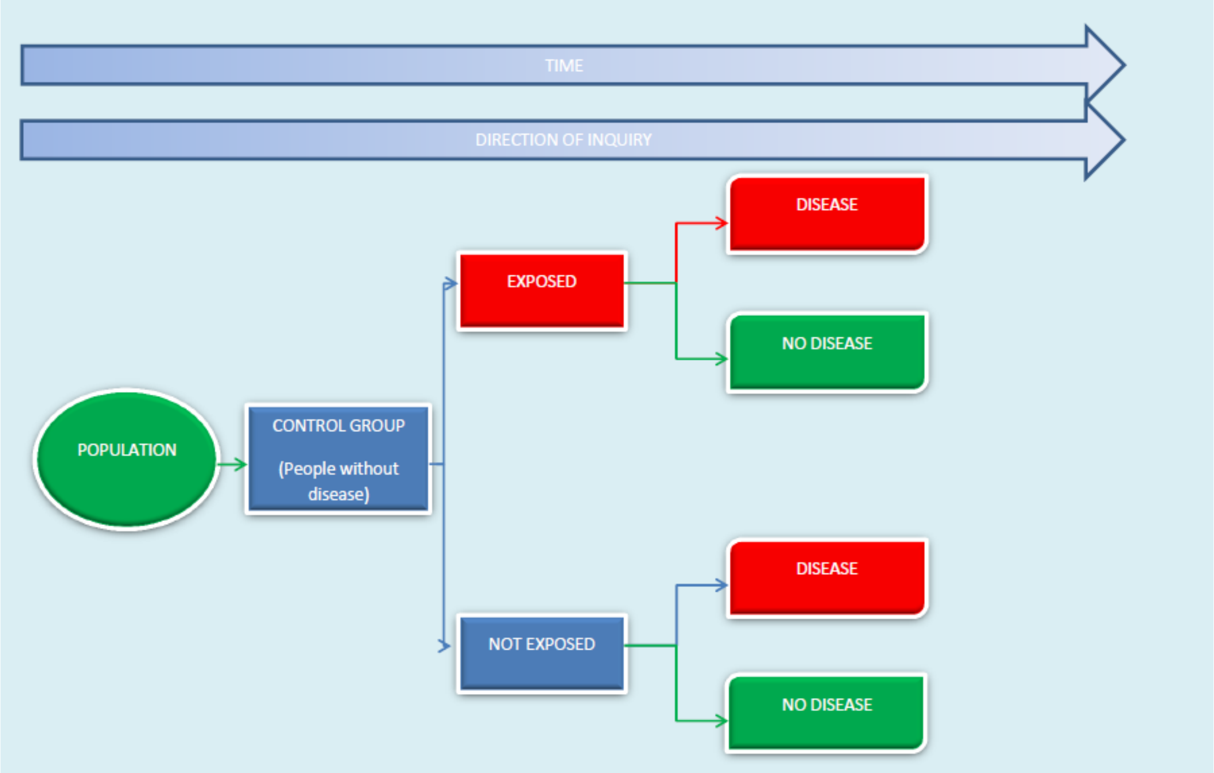
Table 5.1. Calculation of the OR

		Exposure: consumption of seafood		**Total**
		Yes	**No**	
Disease (cholera)	**Yes**	50^a	11^b	61
	No	16^c	41^d	57
	Total	66	52	118

Note. OR = (a*d)/(b*c) = (50*41)/(11*16)=11.6.
Source: Bonita, Beaglehole & Kjellström, 2006.

Contrary to case–control studies, cohort studies are studies of a group of individuals for whom exposure data are known. The direction of the inquiry is normally into the future, and the level of risk is investigated with which the exposure leads to diseases. Fig. 5.2 details the characteristics of a cohort study.

Fig. 5.2. Characteristics of a cohort study



Source: WHO Collaborating Centre for Health Promoting Water Management and Risk Communication (Bonn, Germany).

In a cohort study a cohort (group of people) free of disease is selected first. This group is classified into subgroups according to exposure to a potential cause of disease or outcome. Then variables of interest are specified and measured and the whole cohort is followed up to see how the subsequent development of new cases of the disease differs between the groups with and without exposure (Beaglehole, Bonita & Kjellström, 1993). As examples, exposures can be named, for example, chemicals in water, such as nitrate, arsenic, trihalomethanes or different kinds of water supplies (groundwater versus bank filtrate).

As cohort studies start with exposed and unexposed people, the difficulties associated with measuring exposure or finding existing data on individual exposures are significant in determining the ease with which this type of study can be carried out.

The advantage of cohort studies is that they provide the best information about causation of disease and the best measurement of risk. The RR is used to compare the incidence of disease between those exposed and those not exposed to a potential causative agent (Hunter, 1997). Cohort studies are conceptually simple. The basic disadvantage of this type of study is that it is a major undertaking and requires extended follow-up periods due to the disease often occurring a long time after exposure.

Retrospective cohort studies are a special type of cohort study typically used for outbreaks affecting water supplies within small communities. This type of study is performed when all people are potentially exposed to a single risk factor (for example, if they are supplied by water from a single well) (Hunter, 1997). One example of the application of a retrospective cohort study is described later in this volume. As a cohort group all primary schoolchildren of a small region in Germany were selected, where a Giardiasis outbreak had occurred during May and August 2000. Questionnaires were used to investigate potential exposures, such water and food consumption habits, contact with animals and bathing in recreational water. The RR indicated that the exposure to contaminated tap water from a special water supply zone was responsible for developing the disease in some members of the cohort group.

5.3. Sources of errors in epidemiological studies

Epidemiological studies are sometimes vulnerable to potential errors, confounding factors and biases.

5.3.1. Random error

Random errors can occur due to individual biological variation, as well as sampling errors and measurement errors. They can be reduced by careful measurement of exposure and outcome, thus making individual measurements as precise as possible, but they can never be completely eliminated. This is because it is only possible to study a sample of the population (for example, children), because individual variation always occurs (for example, morning and evening differences in blood pressure in the same person) and because no measurement is perfectly accurate (for example in the case of laboratory investigation of stool samples) (Beaglehole, Bonita & Kjellström, 1993).

5.3.2. Systematic error

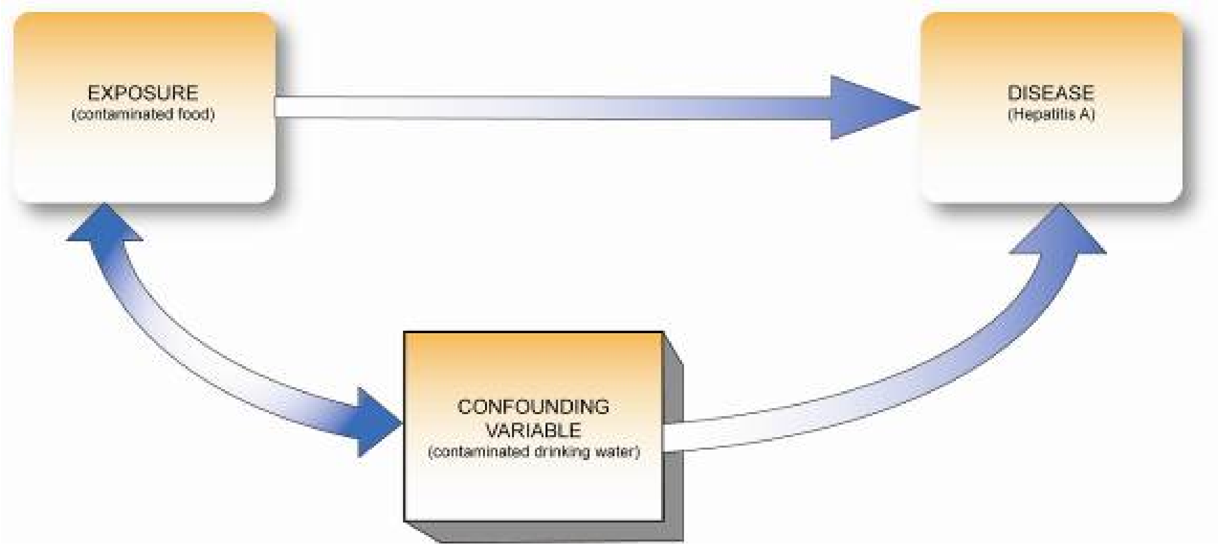
Systematic errors or biases can also occur and must always be taken into account in outbreak investigations. An error is systematic when there is a tendency to produce results that differ in a systematic manner from the true values. Principal biases include the selection, the measurement and the recall bias. The systematic difference between the characteristics of the people selected for a study and the characteristics of those who are not is called selection bias, which can occur when participants select themselves for a study. The measurement (or classification) bias occurs, for example, when different laboratories measure different concentrations of pathogens. An example of a recall bias is the recall difference in food consumption between ill and healthy individuals that participate in a case-control study.

Confounders or confounding factors can also lead to potential errors. Confounding factors provide misleading estimates of effects. They arise because the non-random distribution of risk factors in the source population also occurs in the study population. In a study of the association between exposure to a cause (or risk factor) and the occurrence of a disease, confounding can occur when another exposure exists in the study population and is associated both with the disease and the exposure being studied. The relationship between the exposure, the disease and the confounding factor is depicted in Fig. 5.3. In investigating a hepatitis A outbreak, there could be a confounder in contaminated drinking-water, for example, if only contaminated food were to be taken into account as the exposure factor.

5.4. Specific methodological challenges of conducting epidemiological studies

Most gastrointestinal illnesses, such as those related to drinking-water, can be spread by more than one route. Epidemiological study is the only method that can utilize real data to separate the risk of the illness caused by contaminated water from other risk factors for the outcome illness. Without such control, risk can be overestimated. The use of epidemiology has been criticized because the approach used to collect the data is not experimental in nature. Although there are a large number of variables associated with risk from drinking contaminated water, it is possible to carry out credible studies by following standard practices. Epidemiological studies must be well designed and conducted in order not only to estimate health risk with a good degree of accuracy, but also to control for other risk factors and/or confounders of the outcome illness being studied.

Fig. 5.3. Confounding: contaminated food and water and hepatitis A



Source: adapted from Beaglehole, Bonita & Kjellstrom, 1993.

5.4.1. Study design

There are some methodological challenges that must be addressed when designing and conducting epidemiological studies, in order to minimize the biases that can occur. The type of study employed is dependent on:

- the objectives of the study
- the nature of the exposure and illness under study
- available epidemiological and biostatistical expertise
- economic constraints.

It is vital that these four elements are considered at the outset of any investigation. The primary criteria to be considered in the choice of an appropriate epidemiological study protocol are the objectives of the study and the validity of the findings, both of which determine how and to what extent the data acquired can be used.

The limitations and methodological challenges of epidemiological studies lie in the need for unrealistically large sample sizes to detect very small increases in risk, as well as in the costs incurred and the expertise required to conduct a good study. Compared to many other types of scientific endeavour, epidemiological studies take a long time to complete. Often due to the budget limitations, epidemiological studies cannot address all the important aspects or all the population groups. However, it should be borne in mind that inadequately designed studies will result in inadequate outcomes.

Before beginning the study, the following entities must be easily available to enable high-quality epidemiological investigation of outbreaks of waterborne illness (Hunter, 2003):

- relevant information, including maps of water distribution and supply zones (provided by water companies) and population data for the affected area;
- staff with appropriate skills, including epidemiological, statistical, data-handling, interviewing, leadership and organizational skills;
- suitable facilities, including an “incident room” to coordinate the work of the investigations team and collect all the data.

5.4.1.1. Which study design is most suitable?

Experimental or intervention studies are thought to provide the most accurate results, once the potential for selection bias and confounding has been minimized, but these types of design may not be suitable in some cases, due to ethics or cost. Prospective cohort studies are the next best option, but again costs and logistics may prove prohibitive. In such cases, cross-sectional studies can provide useful information, whereby attention is paid to measuring exposure and disease accurately and allowing for potential confounding factors (Blum & Feacham, 1985).

Reducing bias is a major challenge in epidemiological studies. Bias is any systematic error that results in an incorrect estimate of the association between exposure and disease. The main types of bias are selection bias, information bias, recall bias, and confounding.

- **Selection bias** occurs when inclusion of study subjects on the basis of either exposure or disease is somehow related to the disease or exposure being studied.
- **Information bias** occurs when there are systematic differences in the way data on exposure or outcome are obtained from the different study groups.
- **Recall bias** occurs when the reporting of disease status differs depending on the exposure status.
- **Interview bias** occurs where interviewers are aware of the exposure status of individuals and may influence the answers on disease status.
- **Confounding** occurs when the relationship between the exposure and disease is attributable (partly or wholly) to the effect of another risk factor, that is, the confounder (see below for examples of non-water related risk factors for gastroenteritis). This occurs in cases in which the other risk factor is an independent risk factor for the disease and is also associated with the exposure. It can result in an over- or underestimate of the relationship between exposure and disease. For example, personal hygiene is a potential confounder of the association between drinking-water quality and gastrointestinal illness.

5.4.1.2. Examples of non-water related risk factors for gastroenteritis

Kay and Dufour (2000) listed the following factors for gastroenteritis that are not water related and hence can confound studies on water-related disease:

- age;
- gender;
- history of migraine headaches;
- history of stress or anxiety;
- frequency of diarrhoea (often, sometimes, rarely or never);

- current use of prescription drugs;
- illnesses within 4 weeks prior to the trial day lasting more than 24 hours;
- use of prescription drugs within 4 weeks prior to the trial day;
- consumption of any of the following foods in the period from three days prior to seven days after the trial day: mayonnaise, purchased sandwiches, chicken, eggs, hamburgers, hot dogs, raw milk, cold meat or seafood;
- illness in the household within three weeks after the trial day;
- alcohol consumption within the seven-day period after the trial;
- frequency of usual alcohol consumption;
- taking of laxatives within four days of the trial day;
- taking of other stomach remedies within four days of the trial day.

5.4.2. Exposure assessment

Exposure assessment is critical in all epidemiological studies, particularly in drinking-water studies. Many studies assume that a household uses the closest water source or the intervention water supply as the drinking-water source, and very often the actual water supply used is not recorded. Different water supplies may be used for different purposes, and the drinking-water supply may be different from the water source used for bathing or laundry, for example. Children may not drink the same water as adults, and this should be considered in the exposure assessment. In some situations it may be critical to observe water-use patterns, rather than relying on information from questionnaires or interviews, because actual water use may differ from reported water use.

It is important to measure the appropriate parameters of water quality, rather than types of water source, but this is still not a good predictor of water quality. For example, inadequate indicators of microbiological water quality and/or poor laboratory methods are often used when assessing microbiological water quality. Total and faecal coliform concentrations are generally measured in water. Although these are standard indicators of microbiological water quality in temperate climates, they have acknowledged shortcomings. These indicators do not work well in tropical climates because of higher ambient temperatures and nutrient loads. The higher temperatures help the growth of thermotolerant aquatic microorganisms that are well adapted to the higher temperatures used to detect thermotolerant coliforms during water analysis. Some investigators have reported problems of false-positive results due to naturally occurring thermotolerant coliforms in the aquatic environment. In addition, the growth of thermotolerant, non-faecal microorganisms in the test media can make it difficult to detect and enumerate the target indicator organism. In order to overcome these issues in warmer climates, the use of *E. coli* as an indicator of water quality has been shown to be more successful (Hunter, Waite & Ronchi, 2003).

Assessment of the microbiological quality of source water can be complicated by high variability of source water quality, especially in water sources that are impacted by run-off during rainfall. Rainfall can increase run-off entering surface water supplies and bring increased faecal contamination resulting in degradation of water quality. Alternatively, water quality may improve during the rainy season, at which point increased dilution of faecal contamination in the water source may occur. The water quality may degrade during periods of drought due to the concentration of faecal contamination in smaller volumes of water. Groundwater quality can also be affected by precipitation and flooding. The quality of water provided by traditional water supplies can vary considerably and water quality is often variable over time. Some water sources with low average *E. coli* concentrations may have occasional high peaks of contamination that may be missed if water sampling is infrequent or only for a short period of time. It is therefore recommended that for accurate exposure classification of a water source, investigators should consider the average and peak concentrations of a sufficient number of samples collected over an extended time period. However, the associated costs may be high. Generally speaking, unprotected water sources need to be tested more frequently than protected sources. However, even water quality in piped water supplies can show temporal and geographic variability. Water distribution systems can have local peaks of contamination from illegal connections, as well as power outages that result in negative pressure and an influx of contaminated water or sewage.

Depending on the location of the epidemiological investigation, exposure setting may also involve measuring household water quality. The quality of the water stored in the household can be significantly different from the quality at the source. It is important to determine whether the households being studied undertake any forms of water treatment, including boiling, filtration or disinfection. Transport and storage of water in contaminated vessels has been shown to be a cause of water contamination. Withdrawal of water from storage vessels by dipping, which involves hand contact, may result in contamination of the water quality. Contamination of water at the source poses a different health risk than contamination of stored water in the household. Water contaminated outside the household can introduce new pathogens into a household or community. In contrast, household contamination of stored water is likely to involve pathogens that are already within the household that are probably already being transmitted via other routes. Other household members may be exposed to these pathogens by different routes of transmission or may already have immunity.

5.4.3. Measurement of health outcomes

The most common health outcome considered in studies of waterborne disease is diarrhoeal morbidity. It can often be difficult to define an ‘episode of diarrhoeal disease’ because of age, diet or cultural factors. According to international literature, diarrhoea can be defined as “Three or more incidences of fluid stool within 24 hours” or “Two or more incidences of fluid stool with at least one of the following symptoms: abdominal pain, cramps, nausea, emesis or fever” or “The incidence of a single fluid stool with blood or mucus” (Baqui et al., 1991; Isenbager et al., 2001; Wright et al., 2006). In addition, diarrhoea incidence or prevalence is usually measured by periodic household interviews where participants are asked to recall their personal illness history and/or the illness history of their children and other members of their household since the time of the last interview. The longer the time in between interviews the more likely it is that errors will occur in disease reporting. It is therefore important that interviews are conducted as soon as possible after an event.

Egorov and colleagues (2002) undertook a cross-sectional epidemiological study in the Russian Federation to assess an association between decline in residual chlorine concentrations and risk of gastrointestinal illness. The study comprised water quality monitoring and an extensive questionnaire survey of city residents.

In the city of Cherepovets, in the north-western the Russian Federation, a series of epidemiological studies on waterborne diseases were carried out in the first decade of the 21st century. Egorov and various colleagues studied residual chlorine levels and gastrointestinal disease (Egorov et al., 2002), exposure to DBPs (Egorov et al., 2003a), and the relative frequency of *Cryptosporidium* infections (Egorov, 2004). They also assessed the association between drinking-water turbidity and diarrhoeal disease (Egorov et al., 2003b).

All residential areas of Cherepovets receive drinking-water from a single water treatment plant, which uses the Sheksna River as a water source. The water treatment plant uses chlorination with liquid chlorine, coagulation with alum and rapid upward filtration through sand filters. Chlorine is also used as a residual disinfectant. Re-chlorination in the distribution system is not carried out and many residents are regularly exposed to drinking-water with no residual/free chlorine, while concentrations of dissolved organic compounds in treated water are high. This creates a favourable condition for biofilm growth. The study aimed to show that health risks associated with tap water consumption are higher in areas with chronically low concentrations of residual chlorine.

Exposures of study participants were characterized with mean water quality parameters according to predefined areas of the city. Water samples were taken from taps in selected apartments and analysed in accordance with standard analytical methods. In addition, routinely collected effluent water quality data from the treatment plant were also made available for analysis.

Questionnaires were administered by trained interviewers to study participants. Participating families were recruited from among residents of randomly selected apartments within pre-selected areas. The questionnaires allowed for potentially confounding factors, such as socioeconomic and demographic characteristics of the population. The health outcome of interest, an episode of gastrointestinal illness, was defined as diarrhoea or other gastrointestinal symptoms, such as vomiting or abdominal cramps that lasted for one day after at least a two-week symptom-free period. Information was collected on episodes of gastrointestinal illness during a three-month and one-month period prior to the questionnaire survey.

The results demonstrated an association between decline in residual free chlorine concentrations in the distribution system and increase in the risk of gastrointestinal illness in the city of Cherepovets. Rechlorination of water in selected points in the distribution system, such as local pumping stations – to maintain adequate levels of free chlorine throughout the distribution system – is recommended to reduce the burden of gastrointestinal diseases in the population.

5.4.4. Analysis

Epidemiological studies can provide strong evidence linking disease incidence and environmental or other exposures. However, this statistical inference does not provide absolute proof of a direct cause and effect, although the combination of strong statistical association with biological plausibility offers firm evidence of causality.

Analysis of complex data from studies of water and health typically require multivariate regression techniques to control for the effects of potentially confounding factors related to community, household and child characteristics. These confounding factors include income, family size, type of sanitary facility, age and education. Many regression models (for example, logistic, proportional odds) assume that each of the observations are independent. In reality, this is unlikely because the number of diarrhoea episodes experienced by a single individual over time or among individuals together in a household are more likely to be related, and therefore additional analytical approaches are needed to adjust for individual and family clustering (such as Poisson regression or generalized estimating equations) (Zeger & Liang, 1986).

The analytical approach must also examine the potential for interaction between exposure and covariates, such as age or season. A significant covariate indicates that the covariate modifies the effect of water supply on the risk of diarrhoeal disease. If age-specific analysis of morbidity is not undertaken, the effects of a water intervention on specific subgroups of the population may be missed. The rates of many health outcomes vary by age. Some of this difference is due to biological differences in host susceptibility for different age groups. Different age groups have different water-use patterns and different risks from other exposures. For example, children under five have higher rates of diarrhoeal disease and different environmental exposures than older children and adults.

Seasonal effects on morbidity should also be considered in the analysis. In most parts of the world, diarrhoeal disease has specific seasonal peaks that should be considered in studies of the association between diarrhoeal disease and water quality. Water-use patterns may change throughout the year, for example in summer where water is scarcer. The quality of source water can also change quite considerably by season depending on the type of water source and its vulnerability to contamination.

5.4.4.1. Association

It is not possible to detail all the statistical methods and analysis available for undertaking measures of association and potential impact in this guidance; a brief outline is provided below, but the reader is referred to the references for further reading. Measures of association show the degree of relation between two or more variables. In epidemiology, it is usual to use the term “exposure” to denote any explanatory or independent variable that can be considered a possible health determinant. The term “disease” is used to denote any health outcome (“dependent”) variable. Measures of association are calculated to quantify the effect of an exposure on the frequency of disease. It should be clear that an “association” is not the same as “causation”.

5.4.4.2. Absolute measure of association

5.4.4.2.1. Calculation of risk ratio

The risk ratio is the incidence proportion in the exposed group (P_1) divided by the incidence proportion in the non-exposed group (P_0):

Risk ratio = P_1/ P_0

The risk ratio indicates the direction of an association between an exposure and disease. The baseline ratio is 1, indicating no association between the exposure and disease. Risk ratios greater than 1 indicate a positive association, and risk ratios less than 1 indicate a negative association. The risk ratio also quantifies the strength of association. For example, a risk ratio of 5 indicates that the exposed group had 5 times the risk of the non-exposed group.

5.4.4.2.2. Calculation of ORs

When working with incidence proportions and prevalence proportions, the disease frequency can be expressed in terms of odds, and the relationship between the exposure and disease frequency can be expressed in terms of an OR. This calculated as follows:

A_1 = the number of cases in the exposed group

B_1= the number of non-cases in the exposed group

A_0= the number of cases in the non-exposed group

B_0 = the number of non-cases in the non-exposed group

The odds of disease in the exposed group (O_1) = A_1/B_1

The odds of disease in the non-exposed group (O_0) = A_0/B_0

$$\frac{O_1}{O_2} = \frac{A_1/B_1}{A_0/B_0} = \frac{A_1 * B_0}{A_0 * B_1}$$

The OR is:

$$\frac{O1}{O2} = \frac{A1/B1}{A0/B0} = \frac{A1 * B0}{A0 * B1}$$

The final expression ($A_1 * B_0 / A_0 * B_1$) is the cross-product ratio in Table 5.2.

Table 5. 2. Final expression of the OR

	Disease +	**Disease -**	
Exposure +	A_1	B_1	N_1
Exposure -	A_0	B_0	N_0

An OR of 1 indicates no association between the exposure and disease. In addition, the OR is also an index of the strength of association between the exposure and disease – the further it is away from 1 in a positive or negative direction, the stronger the associations. When the disease is rare, the OR is about equal to the risk ratio.

A checklist is provided below to assist in the development of epidemiological studies.

- The design of the epidemiological study is critical because it affects every aspect of the study. It should address why the study is being carried out, and how it will be conducted.
- Health outcomes and exposure should be clearly defined. The endpoint results of exposure to microbiological hazards – as well as the exposure itself – are key factors in describing the results of an epidemiological study. The endpoint might be self-reported symptomatology, indicative of exposure to a potentially broad spectrum of pathogens, or it might be more specific. Where possible, the response-to-exposure endpoint should be as specific as possible.
- The population to be studied should be well defined in terms of the participating individuals. This will include demographic information, the means of selecting the population sample and the nature of exclusions.
- The numerical size of the exposed and non-exposed groups is also critical. The sizes of these groups are determined by the frequency of occurrence of the health effect under study. Illnesses or infections that occur at higher frequencies require smaller groups. The size of the required populations is also affected by the magnitude of the differences in the frequency of illness or infections between exposed and non-exposed groups. The smaller the differences to be detected between exposed and non-exposed groups, the larger the number of subjects required in each group. Expert advice should be sought with regard to population size before conducting an epidemiological study.
- The approaches to be used for collecting exposure and health effects data should be described in detail.

- Data analysis should include the steps taken to control selection, misclassification and confounding bias. The statistical evaluation procedures should be fully described.
- All of the measures taken to ensure the quality of the data should be described, including the technical qualifications of the scientists participating in the study.
- The study plan should be submitted to the appropriate authorities to ensure that any regulatory limitations regarding human studies will be met, particularly in terms of confidentiality restrictions and informed consent procedures.

5.5. Detection, investigation and reporting of water-related disease outbreaks

A waterborne outbreak is recognized as such when two or more individuals (better: more cases than would be expected (Quigley & Hunter, 2003)) experience a similar illness after ingestion of water from the same source. Drinking-water-related outbreaks are not only a demonstration of a breakdown or failure in the water supply system, but also present an opportunity to provide new insights into disease transmission and improvements to the supply system (Andersson & Bohan, 2001).

In this chapter, we discuss the methods for adequately managing a water-related disease outbreak. We will address both the proactive phase (see subsection 5.5.1) and the reactive phase (see subsection 5.5.2) of water-related disease outbreak management. First, however, in order to also facilitate focusing on the major problems of outbreak management, we brief look at:

- (emerging) risk factors of water-related disease outbreaks
- major obstacles in detecting water-related disease outbreaks.

The range of factors attributing to the risk of water-related disease outbreak events is rather wide, including natural, anthropogenic, technical, social, economic and political aspects. The importance of the different factors strongly varies, due both to natural conditions and socioeconomic development of countries, and is affected and triggered by different global change processes. The experience of recent decades shows that no country has yet achieved the goal of minimizing the risk of a water-related disease outbreak to zero.

Among the major risk factors, the following groups should explicitly be mentioned (Kistemann & Exner, 2000):

(a) concerning sources of water supply:

- increasing amount of raw water abstracted from poorly protected surface water bodies, animal husbandry, pasture farming, sewage discharge, industrial activities, transportation, use and disposal of dangerous substances in catchment areas;
- non-existence of legal catchment area protection zones;
- increasing variability of precipitation patterns both in time and space due to climate change;

(b) concerning water processing:

- insufficient, overused and/or inadequate water treatment facilities;

- change of water pressure in water distribution systems causing mobilization of microorganisms and biofilms;
- lack of education and training of waterworks personnel, leading to insufficient planning, running and/or maintenance of facilities;

(c) concerning water use and misuse:

- growing amount of people with reduced immunocompetence, due to age (demographic transition), drugs and medical treatment;
- new and complex technical applications of water, for example in dental units, air conditioning, cooling towers, spas and so on;
- increasing awareness of possible misuse of vulnerable water supply systems for health-threatening attacks.

The issue of emerging pathogens has become a major concern since the late 1990s (NAS, 1992). Emerging pathogens comprise different groups of microorganisms which have newly been detected (for example, for water-related pathogens: *C. parvum*, *Legionella pneumophila*), or of which pathogenic mutants have newly been detected (*V. cholerae 0 139*), or of which human-pathogenic aspects have newly been detected (*Campylobacter* spp.), or which have newly been identified as the cause of a well-known infectious disease (hepatitis E virus), or of which the association with a well-known malignant or degenerative disease has newly been detected (*Helicobacter pylori*).

Detecting and reporting water-related disease outbreaks is often impeded by various obstacles. It is probable that many water-related disease outbreaks remain undetected for several reasons. Cases with only mild symptoms may remain unregistered due to the fact that these patients would not contact health care facilities. Doctors would rarely be consulted if patients have to pay for health services. Medical doctors only rarely allow stool samples of their patients with diarrhoea to be examined, particularly if doing so would stretch their budget. If gastrointestinal symptoms dominate the patient's syndrome, a foodborne disease is often assumed, even by specialists, and water as a potential source is not thoroughly considered.

Many health care systems, even under advanced socioeconomic conditions, are lacking adequate capacity in terms of public health-oriented skills, such as epidemiology, microbiology and toxicology. Another factor is that communication processes between public health and environmental agencies (regularly being responsible for raw water quality and treatment processes) are weak, insufficient and not prepared for emergency situations. This results in the number of outbreaks being difficult to compare between countries, as differences often reflect the readiness of national surveillance systems to detect water-related outbreaks rather than the number of outbreaks itself.

5.5.1. Preparation

The abovementioned facts and obstacles lead to public health services needing to be well prepared to be able to (a) detect water-related outbreaks, and (b) adequately react if a water-related outbreak occurs (Exner & Kistemann, 2003b).

The infrastructure and processes to enable incident and/or outbreak management to deal with such an event must be prepared in place before a water-related disease outbreak occurs. An outbreak management team (OMT) must be established and trained, with the central task of preparation for an outbreak. The OMT should come under the leadership of the local Public Health Officer. Officially designated members of the OMT should include:

- a specialist for hygiene and environmental medicine from a regional centre, if available;
- leading representatives from the water utilities responsible for the water supply of the population;
- representatives from the water department of the regional environmental agency and from the agricultural and/or forest agencies, if necessary;
- representatives from the police and the fire brigade.

The OMT should meet regularly to build a trusting working relationship and reduce communication barriers. Deputies should be established in advance to ensure that representatives of each relevant institution are always available. If an outbreak is suspected, the remit of an OMT comprises:

- reviewing the evidence for an outbreak
- identifying the population at risk
- deciding on control measures
- making arrangements for the commitment of personnel and resources
- monitoring the implementation and effectiveness of measures taken
- deciding when the outbreak has ended
- preparing a report and making recommendations for future prevention.

Sound proactive preparation is necessary to enable the OMT to manage an outbreak of water-related disease under the circumstances of an emergency situation.

A detailed outbreak plan must be developed, and occasional exercises should be performed. Site-specific risk factors must be identified, and each of the above-mentioned general risk factors must be taken into account due to their local and/or regional potential importance. To successfully manage an outbreak situation, it is absolutely necessary to build up a data bank of relevant information, which is readily available to the OMT in case of an outbreak. The entire water supply system and the relevant processes – from the catchment area to the consumers' tap – must be characterized and documented thoroughly. This can be very efficiently carried out by means of a geographical information system (GIS), which is described in more detail in Chapter 7. Key steps in the outbreak management process are defined here.

Communication of information to the public is a key issue in emergency situations. Therefore, it should be clarified in advance how and to whom the work of the OMT will be communicated in an emergency situation. To avoid contradictory information, only one person should be authorized to talk to the public. It will be very helpful to have a professional press officer in the OMT to undertake this task.

5.5.2. Response

The response phase of an outbreak management process can systematically be divided into different stages, as described here:

1. trigger event: outbreak detection and confirmation;

2. acute reaction: outbreak declaration, quick and preliminary descriptive hazard investigation, initial and immediate control measures;
3. analysis: in-depth analytical hazard investigation, continuous re-evaluation of control measures;
4. normalization: conclusion and declaration of normalization;
5. end: evaluation, formal report, learning lessons for the future.

Although the process is generally sequential, more than one step can be undertaken at a time. Furthermore, a good outbreak investigation will continue to iterate back to earlier steps to check its previous conclusions and hypotheses. Finally, all outbreak investigations should be circular, in that lessons learned should feed into preparation and planning for the next outbreak (Quigley & Hunter, 2003).

5.5.3. Trigger event

Possible trigger events have been defined in advance. The most obvious event is an increase in the number of cases of a particular potentially water-related disease being reported through the surveillance system. However, the question has always to be answered whether or not there are really more cases today than we would expect given our previous experience of the disease in question in the supply area. For example, has the outbreak really started? There are several problems in the identification of epidemiological trigger events. They are mostly related to time trends, such as: day-to-day random variation, seasonal variations, secular trends, and effects of previous outbreaks on the assessment of the expected disease rate.

Drinking-water sample results exceeding microbiological or chemical limits are always alarming and should prompt immediate action. Relevant technical failures in water treatment or distribution facilities comprise failure in the water treatment process (flocculation, filtration, disinfection), especially short-circuits, burst pipes in the distribution net or unusual loss of water in the net. Unusual events in the catchment area – such as a transport accident, extreme rainfall and run-off, flooding, sewage or liquid manure accidents – are trigger events which can be recognized very early, if an early-warning mechanism is established. Clusters of customers' complaints from one supply zone concerning changes in organoleptic quality of tap water are to be handled as potential trigger events as well. Effects due to war or terrorist activities may also affect water supply safety. The threat or use of biological and/or chemical weapons within armed conflicts, and the detection of unusual and high potential microorganisms (particularly *Salmonella*, *S. dysenterica*, *E. coli 0 157:H7*, *C. parvum*) should prompt highest possible vigilance.

5.5.4. Acute reaction

Any trigger event should prompt an immediate first meeting of the OMT. The team uses descriptive epidemiological techniques to describe and summarize certain key information regarding the people affected and their illness: who? when? where? A first-case definition should be formulated, based on the disease (clinical symptoms, laboratory results), the time period for dates of onset, and some geographical locators. The main outcomes of the descriptive study are (a) an epidemic curve, and (b) an epidemic map depicting the important information relating to time and place. Based on this information, the epidemiological risk must be assessed and a hypothesis on the causes of the outbreak should be generated. The latter is important for both implementing control measures and designing an analytical study.

The major goal of this phase, though, is to reduce the risk by quickly implementing preliminary control measures. Treatment failures must be corrected and, eventually, an additional disinfection step may help. Where possible, an alternate water supply should be activated. High-risk individuals should be excluded from water consumption (preferably having identified those individuals and institutions in advance), and consumers may be advised to boil all water before consuming it.

Information must be given to the public by only one person, who is authorized by the OMT; it is without any doubt advantageous to have a relevant professional assume this position.

5.5.5. Analysis

The in-depth analysis of the situation is based on three approaches.

1. Different analytical epidemiological study types can be used for the risk assessment of water-related disease outbreaks: ecological, time series, case-control, (retrospective) cohort, intervention and seroprevalence studies.
2. The detailed hygienic–ecological site inspection, including catchment area, treatment plant and distribution net may lead to important hypotheses concerning the causes of an outbreak. Mapping is the central method for this approach.
3. The hygienic investigation of raw water, treated water, disinfected water, and water at the consumers' tap is normally based on the interpretation of the relevant microbiological, physical and chemical standard parameters.

A scheme of criteria for the strength of association of water with human infections has been developed for application in the national surveillance system for water-related disease in England and Wales (Tillett, de Louvois & Wall, 1998).

During the analytical phase, the further development of the outbreak situation must be checked critically: Do new cases occur? Does the incidence of cases increase or decrease? The immediate control measures must be continuously re-evaluated. Recommendations for long-term control measures should be given. This could comprise new controls and/or procedures, an improved plant design, changes in best practice and inspection procedures, or new legal requirements.

5.5.6. Normalization

Before normalization of the situation can be declared, the following questions must be answered.

- Are the causes of the outbreak completely understood?
- Have efficient control measures been implemented?
- With respect to the incubation period, do new cases occur?
- Have water sample results met microbiological or chemical requirements for at least three days?

Finally, the OMT formally declares the end of the outbreak to the public.

5.5.7. Final report

The work of the OMT is not yet at its end after normalization. A formal outbreak report must be written. The efficiency of incidence management must be evaluated: What worked? What could have been done better? Additionally, the costs of the outbreak should be assessed, to give decision-makers an idea of what savings could be made if adequate preventive measures were to be installed. Finally, lessons learned have to be identified, order to prevent or at least to better manage future outbreaks.

6. Essential surveillance

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6.1. General

Public health surveillance has been defined as “the ongoing and systematic collection, analysis and interpretation of health data to describe and monitor a health event” (Klaucke, 1992). Note that in this chapter the word “surveillance” refers to the collection of health data, not water quality data. Information from surveillance systems is used to plan public health interventions and monitor whether they have been effective in improving public health. Surveillance systems vary in their objectives, methods of data collection and data dissemination and in their scope and complexity. This chapter discusses reasons for conducting public health surveillance, describes various approaches for monitoring waterborne disease cases and outbreaks, and examines criteria for evaluating waterborne disease surveillance systems.

6.1.1. Why specific surveillance for water-related disease?

When considering setting up a surveillance system or conducting surveillance activities, it is important to first ask why. Why should a health authority commit financial resources and personnel time to the surveillance of waterborne disease? Is waterborne disease an important health problem? How will the information collected in a waterborne disease surveillance system be used to improve the health of the public? The answers to these questions may be that surveillance data will help to identify communities in which there are problems with waterborne disease that require intervention measures to control and prevent disease. Information on which areas of a country or a city have problems with waterborne disease can help to target resources towards the areas with the greatest needs. After water and sanitation interventions have been implemented, a surveillance system can show whether these interventions have been effective in reducing disease.

In countries with limited resources, the value of disease surveillance and the type of surveillance that is appropriate needs to be very carefully considered. Continuing to use traditional surveillance systems (such as passive disease notification) that do not function well may not meet current public health information needs. Surveillance data must be linked to public health objectives and monitoring the impact of interventions that are feasible, effective and economical. Information on specific diseases related to water and sanitation can suggest specific interventions, depending on the types of disease that are prevalent and the types of water systems that are used. Examples of such information are given here.

- Information on incidence of typhoid fever may indicate the need for targeted vaccine campaigns in specific geographical locations.
- Information on epidemic and endemic giardiasis and cryptosporidiosis in communities that use surface water supplies may indicate the need for water filtration processes because chlorination is not very effective against these pathogens.
- Information on outbreaks of waterborne disease in adequately treated, piped water supplies may indicate intrusion problems in the water distribution system and the need for booster chlorination systems in the distribution system or additional water treatment at household level. Studies in Uzbekistan (Semenza et al., 1998) showed that over 30% of households with piped water had no detectable levels of residual chlorine in their water despite two stages of chlorination at the water treatment plant. Home chlorination of drinking-water

resulted in a 62% reduction of diarrhoea – suggesting that much of the diarrhoea in households with piped water was due to contaminated drinking-water in the distribution system.

- Information showing a high prevalence of helminth infections may suggest the need for improvements in sanitation and increased water availability for hand washing.

6.1.2. Approaches to waterborne disease surveillance

There are several approaches to implementing waterborne disease surveillance systems. Knowing how the data from a surveillance system will be used is important for planning how the surveillance system should be set up and deciding what data are the most important to collect and how quickly they need to be collected and analysed. Planning a surveillance system can be divided into several steps, as described here.

- What information (health outcomes, demographic data, and risk factors) should be collected in the surveillance system?
- What are the sources of target information and who collects the information?
- What mechanisms are used to transfer the information from the data collector to the data compiler, data analyst and data user?

6.1.2.1. Waterborne disease health outcomes

For waterborne disease, there is a spectrum of possible health outcomes ranging from asymptomatic infection to death (Table 6.1). Also, waterborne pathogens are associated with a large range of symptoms. Typically, waterborne disease involves infections of the gastrointestinal tract and symptoms of diarrhoea, nausea, vomiting, abdominal cramps and sometimes fever. However, it is important to recognize that waterborne pathogens can also cause other health outcomes, such as: hepatitis (HAV and Hepatitis E virus), conjunctivitis (enteroviruses), aseptic meningitis (enteroviruses), respiratory symptoms (enteroviruses), HUS (*E. coli* O157:H7), myocarditis (Coxackie viruses), diabetes (Coxackie viruses), reactive arthritis (*Yersinia*, *Shigella*, *Salmonella*), peptic and duodenal ulcers (*Helicobacter pylori*), stomach cancer (*Helicobacter pylori*), and Guillain-Barre syndrome (*Campylobacter*). Toxins from waterborne agents, such as cyanobacteria, have been associated with various adverse health outcomes, such as gastroenteritis, liver damage, nervous system damage, pneumonia, sore throat, earache and contact irritation of skin and eyes (Codd, Bell & Brooks, 1989; Turner et al., 1990).

Surveillance for waterborne disease can focus on the detection of individual cases of infection by waterborne pathogens or it can target outbreaks of waterborne disease. Surveillance systems may monitor broad categories of health outcomes, such as diarrhoeal disease, or a surveillance system may focus on a few specific pathogens such as typhoid fever, hepatitis or cholera.

Table 6.1 categorizes health outcomes by level of severity and indicates various approaches to collecting information on these outcomes. Mild to moderate disease outcomes may result in absenteeism from work or school, self-treatment with anti-diarrhoeal medications, or calls to health care providers. These outcomes can be detected by surveillance approaches, such as monitoring the following indicators: absenteeism from sentinel institutions (such as schools), sales of anti-diarrhoeal medications, nurse hotline calls to large health care facilities, and gastrointestinal illness in sentinel populations (such as nursing homes and within families). Clinical cases of infection may result in visits to health care providers, laboratory-confirmed infections, hospitalizations, or mortality. Sources of information on these outcomes include: automated patient visit records at large health care facilities, hospital emergency room visits, hospital admissions and discharge records, clinical laboratory records of confirmed infections, and death certificates listing underlying and contributing causes of death. Some of these surveillance approaches may provide a relatively rapid means of detecting an outbreak of disease (discussed in more detail later in this chapter). However, the information from these surveillance approaches cannot distinguish between waterborne infections and infections transmitted via food or other routes. Only epidemiological studies that compare health outcomes in populations exposed to different water sources can determine the proportion of illness or infection that can be attributed to waterborne transmission.

Table 6.1. Surveillance approaches for specific health outcomes

Health outcome	Outcomes that could be detected in a surveillance system	Possible surveillance approaches
Asymptomatic infection	Immune response in infected case Possible secondary transmission to contacts	Serological surveys
Mild infection	Absent from school or work Self-treatment with anti-diarrhoeal medications Telephone consultation with health care providers	Telephone surveys of illness in sentinel households Telephone-based or computer-based reporting system of absenteeism from sentinel schools, factories or workplaces Monitoring anti-diarrhoeal medication sales at sentinel pharmacies Monitoring telephone calls to health care providers ("nurse hotline calls")
Moderate infection	Absent from school or work Self-treatment with anti-diarrhoeal medication Seeks medical care	Monitoring medical records from sentinel health care providers. Monitoring hospital emergency room visits records Monitoring hospital laboratory records of school testing and/or pathogen detection.
Severe infection	Absent from school or work Seeks medical care Hospitalization	Monitoring medical records from sentinel health care providers Monitoring hospital emergency room visits records Monitoring hospital admissions and discharge records Monitoring hospital laboratory records of stool testing and/or pathogen detection
Death	Death	Monitoring death certificates Survey of households to identify household members who died of diarrhoeal disease

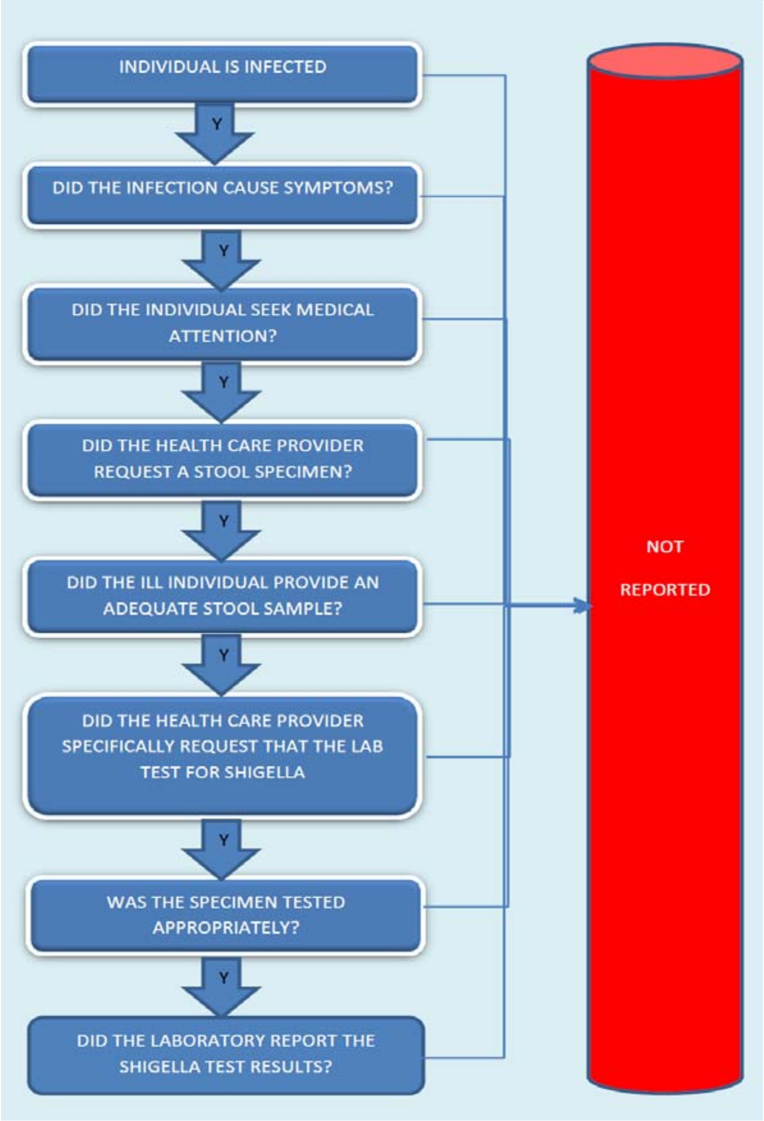
6.1.2.2. Data collection approaches

After decisions regarding which health outcomes the surveillance system will target, the next step is to decide how the surveillance data will be collected and who will collect them. Some surveillance systems are passive, meaning that the system relies on voluntary participation of health workers or laboratories to report specific infections, cases (symptoms or illness) or events (clusters of cases that may indicate an outbreak) to the surveillance authority or coordinator. Many countries have regulations on what diseases must be reported. Harmonization at the global level of these notifiable diseases has been achieved through the 2005 International Health

Regulations.[6] Countries in central Asia usually report cholera, salmonellosis, shigellosis, pathogenic *E. coli*, typhoid and hepatitis A. In some countries, clusters of more than five cases of acute gastroenteritis must be reported. In most parts of the United States, health workers are supposed to report individual cases of salmonellosis, shigellosis, HAV, typhoid fever, cholera, *E. coli* O157:H7, cryptosporidiosis and giardiasis. The following are some disadvantages of this type of system.

- It is not very sensitive. There are many steps in the reporting process and some cases may be lost at each step (see Fig. 6.1). Many cases are probably never reported.
- It is slow. Because there are many steps in the reporting process, it may take several weeks from the time a case occurs to the time it is reported to health authorities.
- It relies on voluntary participation of health workers who are very busy and may not take the time to report cases. There is no enforcement of reporting and no penalty for failure to report cases.

Fig. 6.1. Sequence of events before an individual shigellosis infection is reported



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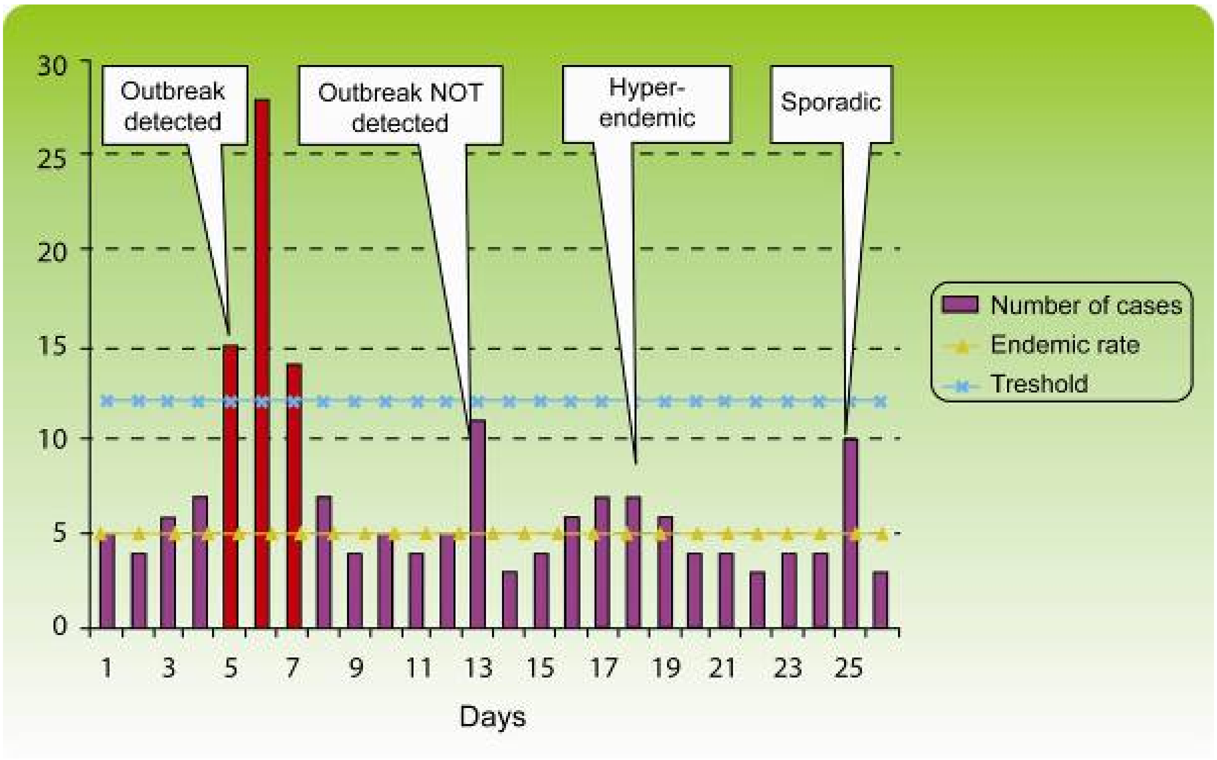
[6] For further information on the 2005 Iinternational Health Regulations, visit the WHO web site (http://www.who.int/csr/ihr/wha_58_3/en/, accessed 23 December 2010).

A passive surveillance system is usually too slow and insensitive to detect an outbreak at the time at which the outbreak occurs. However, some outbreaks may be identified retrospectively, when the data is analysed. Fig. 6.2 illustrates how a surveillance system can provide information on endemic illness rates and has a sensitivity threshold for detecting outbreaks once they exceed a certain number of cases.

Fig. 6.2. Epidemic to endemic illness as detected by surveillance systems



Source: adapted from Frost, Craun & Calderon, 1996.

Surveillance systems typically collect more information than just the occurrence of a case of disease. Depending on the type of surveillance system, information is often collected on:

- date of onset of illness;
- symptoms;
- etiology (diagnosis, laboratory confirmation);
- geographic location;
- age;
- sex;
- risk factors, such as other ill household members, source of drinking-water, exposure to animals, travel, exposure to recreational water;
- underlying health problems.

Although all of this information could be useful for learning about susceptible populations and important risk factors for disease, the information in a surveillance system needs to be limited to the most essential information for public health planning and intervention. The more information that is requested on a report form, the more personnel time is involved, and it then becomes less likely that the case will be reported. Health authorities would benefit from realizing that some of this information collection might be better suited for a specific epidemiologic research study of a target population and disease, rather than including it in a surveillance system. Conducting surveillance in specific sentinel populations is another surveillance approach that could be useful (discussed in more detail later in this chapter).

Passive surveillance for cases of acute gastroenteritis or specific diseases has strengths and limitations. This type of surveillance can provide useful information on changes in disease incidence over time. Passive surveillance may also allow retrospective identification of outbreaks when the data are compiled and analysed. However, it is important to use these data. For example, peaks in disease incidence should be investigated, even retrospectively, to determine if a failure in water treatment occurred or if other risk factors were involved. The limitations of passive surveillance include those listed here.

- Passive case surveillance has low sensitivity because only a small percentage of cases provide stool specimens and are diagnosed and reported.
- Some waterborne diseases, such as viral gastroenteritis, may not be included on the list of notifiable diseases.
- There is usually a significant time lag between the time of disease occurrence and the time that a case report is received.

6.1.2.3. Surveillance for waterborne disease outbreaks

Another approach to waterborne disease surveillance is passive surveillance for outbreaks. This is practised by several countries in the EU (Kramer et al., 2001), the United Kingdom and the United States (Lee et al., 2002).

In the United Kingdom, reports of waterborne disease outbreaks date back to the 1850s. However, a formal surveillance system for waterborne disease was not instituted until the 1990s (Stanwell-Smith, Andersson & Levy, 2003). This system receives information from four main sources: (1) reports of suspected outbreaks from local health officers and microbiologists in the Public Health Laboratory Service; (2) laboratory-based surveillance of notifiable diseases; (3) surveys of water quality and environmental sampling reports; and (4) reports from drinking-water authorities on suspected or confirmed incidents of water contamination. Information on reported outbreaks is compiled and published every six months in *Communicable Disease Weekly*. These reports include information on the number of outbreaks, number of cases, etiologic agents of the outbreaks, and whether the water supply involved was public or private.

Sweden has a multipart surveillance system for infectious diseases (Stanwell-Smith, Andersson & Levy, 2003), which requires reporting of notifiable diseases by health care providers and laboratories. This includes amoebiasis, campylobacteriois, cholera, infection with EHEC 0157, giardiasis, HAV, typhoid and paratyphoid fever, salmonellosis, shigellosis, and yersiniosis. In addition, laboratories voluntarily report on norovirus infections, cyclospora, cryptosporidiosis, other pathogenic *E. coli* and rotavirus strains. Waterborne disease outbreaks in Sweden are seldom detected by this surveillance system at the time at which they occur. Some outbreaks are detected by vigilant medical officers, who notice a cluster of cases and start investigations.

In the United States, passive voluntary surveillance for waterborne disease outbreaks started in 1971 and comprises collaboration between the Centers for Disease Control and Prevention

(CDC), the United States Environmental Protection Agency (USEPA) and state and regional epidemiologists. This surveillance system includes outbreaks associated with drinking-water as well as outbreaks associated with recreational water. The objectives of this surveillance system are to: (a) characterize the epidemiology of waterborne disease outbreaks; (b) identify the etiologic agents that cause the outbreaks; (c) determine the risk factors that contributed to the outbreak; (e) inform and train public health personnel to detect and investigate waterborne disease outbreaks; and (f) collaborate with local, regional, national and international agencies on strategies to prevent waterborne diseases (Stanwell-Smith, Andersson & Levy, 2003).

From 1971 to 2000, 731 drinking-water outbreaks were reported through this surveillance system. Although this is believed to be an underestimate of the true number of waterborne disease outbreaks that occurred during this period, the information collected in this surveillance system has been extremely valuable for improving our understanding of the pathogens that cause waterborne disease and the risk factors involved in waterborne disease outbreaks. The data collected in this surveillance system include:

- type of exposure (drinking-water or recreational water)
- location and date of outbreak
- actual or estimated number of individuals exposed/ill/hospitalized, deaths
- symptoms, incubation period, duration of illness
- etiologic agent
- epidemiologic data (attack rate, RR or OT)
- clinical laboratory data (results of faecal and serology tests)
- type of water system (community, non-community or individual drinking-water supply)
- swimming pool, hot tub, water park or lake for recreational water
- environmental data (results of water analyses, sanitary survey, water plant inspection)
- factors contributing to contamination of water.

These data are summarized in biannual reports (*Morbidity and Mortality Weekly Report* Surveillance Summaries) that CDC publishes and distributes to public health authorities and practitioners throughout the country.[7] Table 6.2 shows an example of the summary data on waterborne disease outbreaks associated with drinking-water for one year (1998).

Analyses of these surveillance data over time have provided insight into trends in waterborne disease in the United States. For example, the data show that the overall number of reported outbreaks associated with drinking-water has been steadily declining since the mid-1980s. However, the number of outbreaks associated with recreational water has been gradually increasing since 1978, when the surveillance system started to include recreational water outbreaks. For the majority of outbreaks, the pathogen is not identified. *Giardia* and *Cryptosporidium* are the most commonly reported etiologic agents of waterborne disease. Finally, most of the outbreaks involve (in particular, small) groundwater systems.

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[7] The information is also available on the Internet at the CDC web site (www.cdc.gov/mmwr, accessed 23 December 2010).

Table 6.2. Waterborne disease outbreaks associated with drinking-water, United States, 1998[a]

State	Month	Class[b]	Etiological agent	No of cases	Type of system[g]	Deficiency[h]	Source	Setting
Florida	May	III	*Giardia intestinalis*	7	Com	2	Well	Community
Florida	Sept.	III	Copper poisoning	35	Com	3	Well	Community
Florida	Dec.	III	*Giardia intestinalis*	2	Ind	2	Well	House
Illinois	May	III	*E. coli* O157:H7	3	Ind	2	Well	House
Minnesota	Aug.	I	*Shigella sonnei*	83	Com	4	Well	Fairground
Montana	Jul.	III	AGI[c]	5	Ind	3	Well	Home
New Mexico	Jul.	I	*Cryptosporidium parvum*[d]	32	Ind	5	Well	Group housing
Ohio	Oct.	III	AGI[e]	10	Com	4	Surface[i]	Treatment
Texas	Jul.	I	*Cryptosporidium parvum*[f]	1400	Com	3	Well	Subdivision
Wyoming	Jun.	I	*E. coli* O157:H7	157	Com	2	Well/ spring	Community

Note. n = 10.

[a] An outbreak is defined as (a) at least two individuals experiencing a similar illness after ingestion of drinking-water and (b) epidemiological evidence that implicates water as the probable source of the illness.

[b] Based on the epidemiological and water quality data provided on CDC form 52.12.

[c] Acute gastrointestinal illness of unknown etiology.

[d] Nine individuals had stool specimens that tested positive only for *Cryptosporidium*, and one person had a specimen that was positive for *Blastocystis hominis*.

[e] One person had a stool sample that was positive for *B. hominis*.

[f] Eighty-nine individuals had stool specimens that tested positive only for *Cryptosporidium*, and one person had a specimen that tested positive only for *Giardia*. None of the specimens were positive for both organisms.

[g] Com = community, Ind = individual. A community water system is a public water system that serves year-round residents of a community, subdivision, or mobile home part with ≥ 15 service connections or an average of ≥ 25 residents for ≥ 60 days per year. Individual systems are small systems that are not owned or operated by a water utility and that serve <15 connections or <persons.

[h] 1 = untreated water, 2 = untreated groundwater, 3 = treatment deficiency (e.g. temporary interruption or disinfection, occasionally inadequate disinfection, and inadequate or no filtration), 4 = distribution system deficiency (e.g. cross-connection, contamination of water mains during construction or repair, and contamination of a storage facility) and 5 = unknown or miscellaneous deficiency (e.g. contaminated bottled water).

[i] Surface water from an unknown source.

Source: adapted from Centers for Disease Control and Prevention, 2002.

The strengths of this waterborne disease outbreak surveillance system are that it has provided useful information on changing trends in waterborne disease outbreaks in the United States and it is flexible. It includes both drinking-water and recreational water, captures outbreaks of unknown etiology and those associated with both infectious and chemical agents, captures outbreaks associated with gastroenteritis and those associated with respiratory disease and dermatitis, and captures outbreaks of various sizes. The limitations of this surveillance system are: (a) it has low sensitivity (it is estimated that only one in every 25 waterborne disease outbreaks is reported); (b) it does not capture sporadic cases of waterborne disease; (c) there is a lack of uniformity between states and outbreak investigation (some are well investigated including clinical and environmental samples; others only to a minimal extent); (d) inconsistent quality and completeness of data collected by different states; and (e) data analysis usually occurs at federal and not at the local level. The overall problem is that many waterborne disease outbreaks are never recognized by local health authorities. Even if recognized, they may not be investigated or reported because of a shortage of trained health personnel available to work on waterborne diseases within local health departments.

All surveillance systems for waterborne disease outbreaks need to include a method for evaluating the evidence that an outbreak is indeed the result of contaminated water or whether it may be due to another transmission route. Table 6.3 shows the criteria used by the national surveillance system for water-related diseases in England and Wales. Table 6.4 shows the criteria used to classify waterborne disease outbreaks in the surveillance system in the United States (Stanwell-Smith, Andersson & Levy, 2003). Both sets of criteria combine and evaluate the evidence from the epidemiologic investigation, the water quality data and information on the performance of the water treatment plant.

Table 6.3. Criteria for strength of association of water with human infectious disease

Event	Strength of association
(a) Pathogen found in human case samples was also found in water samples	- Strong association if: a + c, a + d or b + c
(b) Documented water quality failure or water treatment failure	- Probable association if: b + d, only c or only a
(c) Significant result from analytical epidemiological study (case-control or cohort)	- Possible association if: b + d
(d) Suggestive evidence of association from a descriptive epidemiological study	

Source: compiled from Department of Health survey data relating to national surveillance for water-related diseases in England and Wales.

Table 6.4. Classification of investigations of waterborne disease outbreaks in the United States

Class	Epidemiological data	Water quality data
I	Adequate data to implicate water as a source of outbreak; data were provided about exposed and unexposed individuals, and the RR or OR was ≥ 2 or the p-value was <0.05	Provided and adequate: could be historical information or lab data (e.g. history that the chlorinator malfunctioned, or water main broke, or no chlorine residual, or positive coliform detections in water)
II	Adequate	Neither provided nor inadequate (e.g. stating that a lake was overcrowded)
III	Provided by limited epidemiologic data that did not meet the criteria for Class I, or claim made that ill individuals had no exposures in common, besides water, but no data provided	Provided and adequate
IV	Provided but limited	Neither provided nor inadequate

Source: Centers for Disease Control and Prevention, 2008.

6.1.2.4. Alternative surveillance approaches for water-related diseases

Another approach to surveillance is “active surveillance” which means that the surveillance authority contacts health workers or laboratories on a routine basis to ask if they have identified any infections, cases or events. Generally, active surveillance systems are more sensitive and rapid in collecting information than those that rely on passive surveillance. Active surveillance for cases of specific diseases may involve telephoning sentinel health care providers and/or laboratories on a routine basis (such as weekly) to determine how many cases of a specific disease they diagnosed in the past week. This approach results in more cases being reported, and it cuts down on the time lag between diagnosis of an infection and reporting an infection. However, cases that do not seek medical care or do not provide clinical specimens for diagnosis are still not detected by active surveillance systems. Also, active surveillance is more costly than passive surveillance because it requires more personnel time and resources for communication.

Table 6.1 lists some active surveillance approaches for collecting data on specific health outcomes, ranging from mild to severe illness, in a community. Some of these approaches have been called "enhanced surveillance" because they may be carried out in addition to traditional passive surveillance for notifiable diseases (Frost, Craun & Calderon, 1996). Some of these approaches can be useful for rapidly identifying outbreaks of disease within a community. Each approach and its strengths and limitations, as described in the following subsections.

6.1.2.4.1. Surveys

Surveys are a flexible and often low-cost approach to collecting information on a specific infection or health outcome. Seroprevalence surveys that collect and test sera from a specific population can indicate symptomatic and asymptomatic infections from specific pathogens. Stool surveys of schoolchildren can indicate the presence of helminth infections, such as ascaris. Sometimes these activities may be considered research rather than surveillance. However, the results of such activities could indicate the success or failure of specific public health programmes, such as vaccine campaigns or school-based anti-helminth treatment interventions. The limitations of some surveys may include difficulty in obtaining subject compliance for providing specimens and the cost of laboratory assays. Also, there is evidence that community surveys of self-reported diarrhoea can overestimate the size of an outbreak (Hunter & Syed, 2001).

6.1.2.4.2. Monitoring absenteeism

Often the first consequence of an infection is that the infected subject will stay home from school or work. Large numbers of absent schoolchildren is often an indication of an outbreak of disease within a community. Telephone or computer-based systems can be set up to monitor absenteeism in schools and sentinel workplaces (factories or government offices with large numbers of employees who must check in and check out on a daily basis). The strengths of this type of system are that it is relatively easy and inexpensive, has the potential to be set up as an electronic reporting system and may allow early detection of outbreaks. However, even if an outbreak is detected, this type of system does not provide any indication of whether the outbreak is waterborne. With this surveillance approach, it is possible to examine whether a peak of absenteeism at one institution also occurs simultaneously at other institutions in different areas using the same water supply. If so, the outbreak is more likely to be waterborne. A critical aspect of this approach is that it requires the cooperation of participating institutions that are able to accurately track absenteeism in a stable population of students or workers.

6.1.2.4.3. Monitoring inquiries to community health workers or nurse hotlines

Mild cases of illness may lead to seeking advice from a community health worker or nurse via telephone or in person, instead of physically visiting a clinic or private health care provider. This behaviour may be to avoid the expense of a doctor's visit, or simply to determine if the symptoms justify seeking medical attention. Some health care providers have "nurse hotlines", where a patient first speaks to a nurse on the telephone to describe his or her illness, and the nurse decides whether the patient needs to be seen by a physician.

For some health care systems, it may be possible to monitor these types of inquiries and use this as an inexpensive and timely method of disease surveillance. Community health workers could be instructed to keep records of inquiries or visits related to gastrointestinal illness. Nurses are usually required to keep records of all telephone inquiries, including information on the patient and the symptoms. This type of surveillance approach clearly requires time and cooperation of community health workers and nurses at health care facilities. An advantage of this approach is that it can collect information on specific symptoms and may capture mild illnesses that would not be seen at a medical facility. Limitations of this approach are that it is based on self-reported symptoms, and there is no indication of whether the symptoms are associated with water quality.

6.1.2.4.4. Monitoring sales of anti-diarrhoeal medications

Increased sales of anti-diarrhoeal medications have been observed to be an early indication of outbreaks of diarrhoeal disease (Sacks et al., 1986). Monitoring sales of anti-diarrhoeal medications has also been used as an indicator of community gastrointestinal illness in studies of water quality and disease (Beaudeau et al., 1999). This surveillance approach involves developing a network of pharmacies that agree to keep records on the sale of anti-diarrhoeal medications and then setting up a system to routinely collect this information from the pharmacies. Again, this is a relatively easy and inexpensive method to collect information on incidence of gastroenteritis in the community and could be set up as an electronic reporting system. This approach also captures mild cases of illness in individuals that may not seek medical care and could be designed to collect information on a frequent (weekly) basis in order to rapidly detect rises in gastroenteritis incidence. However, this surveillance system requires the cooperation of a large number of pharmacies and those participating must have accurate bookkeeping of sales of specific medications. It is important to note that some peaks in sales may not be associated with illness but may be due to discount prices or new advertisements.

6.1.2.4.5. Monitoring illness in sentinel families or institutions

Another surveillance approach is to routinely collect illness/symptom data from houses of sentinel families who agree to record episodes of gastrointestinal illness. Data can be collected in health diaries followed by periodic household interviews by community health workers or telephone interviews. This system can also be used to routinely collect illness/symptom data from institutions (such as nursing homes, residences for the elderly, residences for students, or prisons) that agree to record episodes of gastrointestinal illness. This surveillance approach can detect mild illnesses, could be designed to collect information on a frequent basis and could possibly be set up as an electronic reporting system. Clearly, this system requires cooperation and time from a large number of families and institutions to record data. The data is based on self-reported illness/symptoms and thus may have low accuracy. Also, some institutions (for example, nursing homes) may have high background illness rates because of susceptible populations and multiple disease transmission routes within the institutions. However, if disease peaks are detected, it would be possible to examine whether a peak of illness at one institution also occurs simultaneously at other institutions in different areas using the same water supply. If so, then the outbreak is more likely to be waterborne.

6.1.2.4.6. Monitoring visits to health care providers for gastrointestinal illness

Depending on the health care system in the region, it may be possible to design surveillance systems that routinely collect information from patient records at various medical providers (including community clinics, hospital emergency rooms, and hospital admissions) for patients with gastrointestinal illness. This surveillance approach should capture moderate to severe cases of illness and could be set up as an electronic reporting system. However, this system again requires the cooperation and time of a large number of health care providers and does not indicate whether the gastrointestinal illness is waterborne. This is similar to the notifiable disease surveillance approach, except that it could target sentinel health care providers who are interested in providing surveillance data and health providers with automated patient visit records.

6.1.2.4.7. Monitoring laboratory activity and results

Clinical laboratories can provide much valuable information for surveillance purposes. For tracking diarrhoea rates in a community, information can be collected on the total numbers of stool samples submitted for microbial analyses on a weekly or monthly basis. This data should be stratified by inpatients and outpatients with gastrointestinal illness in order to roughly differentiate between nosocomial infections and community-acquired diarrhoea. Even without the etiologic results, information on the number of stool samples submitted for microbial analyses could be useful to detect sudden changes in incidence of gastrointestinal illness. In addition, laboratory-confirmed infections of enteric pathogens can be routinely monitored. In many regions, hospital and clinic laboratories, private medical laboratories, and government public health labs are already required to record and report the detection of specific enteric pathogens (*Giardia, Entamoeba histolytica, V. cholerae*, etc.). Laboratory-based active surveillance and electronic reporting offers a rapid method to detect confirmed infections that cause moderate to severe symptoms and that prompt the subject to seek medical care. This surveillance approach is very specific for target infections. However, the sensitivity of this type of surveillance may be poor if care providers do not request stool specimens or individuals do not provide specimens.

6.1.2.4.8. Monitoring death certificates

Death certificates are an important source of information for surveillance of many diseases. Information from death certificates is also fundamental source for official mortality statistics which are used to support epidemiological and statistical research other than to better define the mortality impact for particular events. Death certificate data are generally analysed by examining the “underlying cause of death”: the disease or injury that initiated the events resulting in death. For each death the underlying cause is selected from an array of conditions reported in the medical certification section on the death certificate. This section provides a format for entering the cause of death sequentially.

For waterborne disease surveillance, it is possible to set up a system to routinely check death certificates for deaths associated with enteric pathogens. However, the data in death certificates are of variable quality, and some death certificates might only record immediate cause of death and not underlying causes of death. Other limitations of this approach are that many enteric infections may be undiagnosed and not recorded in death certificates, and there is usually no evidence relating to whether mortality from an enteric infection was linked to waterborne transmission. Another consideration is that for some regions, mortality from waterborne disease is an infrequent event and it is not worthwhile setting up a surveillance system for such a rare event.

6.1.2.4.9. Monitoring water customer complaints

A final approach that could be relevant for waterborne disease surveillance is to monitor complaints from water customers about water quality and aesthetics. In some countries, water treatment plants keep records of customer complaints about water and collect information on the type of complaint (taste, odour, turbidity) and the location of the customer filing the complaint. Whenever possible, water utilities should try to send a team to collect water samples from the household with the complaint and analyse the water for chlorine residual, turbidity and coliforms. Customer complaints can provide an early indication of significant problems with water quality. One of the first indications of the 1993 outbreak of cryptosporidiosis in Milwaukee, Wisconsin was customer complaints about water turbidity (MacKenzie et al., 1994). Customer complaint records can provide useful geographic information about sources of water quality problems, although they usually do not provide information about water-related illness. It is also possible to add GIS information to a database for tracking customer complaints.

6.1.2.4.10. Summary of general strengths and limitations of enhanced surveillance

These alternative surveillance approaches can provide valuable information on changes in disease rates over time. Some of the more sensitive methods may be able to show the effect of new water quality regulations or implementation of new treatment processes. Some of these systems can provide real-time information to alert health authorities to the occurrence of a waterborne disease outbreak and enable rapid investigation and control. More detailed information on the application of many of these methods and their evaluation is provided in a 2001 report from the American Water Works Association Research Foundation on waterborne gastrointestinal disease outbreak detection (Emde et al., 2001). It is important to remember that most of these approaches relate to surveillance for enteric illness rather than waterborne disease and many enteric pathogens can be transmitted via food or person-to-person contact as well as water. In order to determine the proportion of enteric illness in a community that is due to water contamination, it is necessary to conduct epidemiologic studies or evaluations of water supply interventions.

6.1.2.5. Surveillance approaches for regions with limited resources

When resources are limited, innovative surveillance approaches are needed. In these situations, it is critical that surveillance activities are linked to specific health goals. For example, if a regional health goal is to reduce diarrhoea morbidity and malnutrition in young children by 25% in two years, then the regional health authorities need reliable data on diarrhoea morbidity and nutritional status. The data users need to be involved in the design of the information collection system – especially in the definition of the data to be collected and the format in which the resulting information will be presented. This way, the data users can be assured of having the type of data that meets their needs. Several surveillance approaches that have proven useful in regions with limited resources (White & McDonnell, 2000) are described in the following subsections.

6.1.2.5.1. Sentinel clinics and laboratories

One approach that works well in areas in which there is a wide range in the quality of health clinics and laboratories is to establish a network of sentinel sites. These should be clinics and/or laboratories that have more resources and more experienced and dedicated personnel that can be used to collect information on more diseases, including detailed information on each case. These clinics and laboratories may receive additional support from the national government and/or international agencies, allowing them to perform more diagnostic tests and to record more accurately patient visits and laboratory results in computer databases. Data collected at sentinel sites may not be representative of the population. Typically these sentinel clinic and laboratories are concentrated in urban areas and the surveillance system may need to make special arrangements to set up small, rural sentinel clinics with additional resources for better diagnoses and data collection. Such a network of sentinel clinics can be useful for collecting more detailed and accurate information on specific risk factors, susceptible populations, the presence of antibiotic-resistant strains of organisms, and so on.

6.1.2.5.2. Focused surveys

Another useful approach is to conduct intermittent targeted surveys for a specific purpose on an ad-hoc basis as needed (White et al., 2001). Such surveys can collect information on a variety of health outcomes and provide population-based information. Examples of this approach are school surveys of children with anaemia due to worm infections and household surveys of diarrhoeal disease in young children. Surveys in elementary schools that include stool collection and testing can indicate the need for anti-helminthic medication interventions for a high-risk subpopulation, or can be used to measure the success of such interventions. Household diarrhoea surveys can be linked to education interventions and the use of oral rehydration therapy.

6.1.2.5.3. Sharing resources

Waterborne disease surveillance systems should also explore the possibility of integrating with other existing surveillance systems, such as those for polio eradication, child survival, malaria, and so on. Some surveillance programmes already sponsored by national or international agencies may be willing to share assets that would also be relevant for waterborne disease surveillance, such as information, personnel, transportation, computers, reference laboratories and so on.

6.1.2.5.4. Training and staff incentives

Successful surveillance programmes everywhere require competent and dedicated staff, high-quality and ongoing training, supervision and career paths, with rewards for advancement for surveillance system staff. In regions with limited resources, it is particularly important for surveillance programmes to include appropriate training for designated data collectors because their educational backgrounds may be inadequate for this role. Methods to check data quality and ensure quality control should be included in the training programme. The completion of surveillance activities should be part of routine formal performance evaluations of health workers responsible for data reporting. Feedback from higher levels of the surveillance system on how the surveillance data are used can provide an additional incentive for high-quality data collection and analyses.

6.1.2.5.5. Infrastructure needs

Public health authorities responsible for surveillance need to carefully consider the goals of the surveillance system, choose an appropriate approach to meet those goals and then identify the critical resources needed to collect and analyse the data. Some transportation and communication infrastructures are necessary for all surveillance systems. One barrier to surveillance systems in rural areas or areas with limited resources is lack of transportation for health staff to investigate cases, collect specimens and transport specimens to the laboratory. As already mentioned, sharing transportation and communication resources with other government or international programmes may help to overcome this barrier. Data-collection forms and communication systems (telephones, internet or reliable mail service) are also needed for data transfer from the data collectors to the data compilers and analysts. In some regions, computers may not be available or may be too old or in need of repair to be useful. Manual transfer and tabulation of data on handwritten forms takes time and can introduce errors. If manual data collection and transfer is the only feasible option, then forms should be designed to include check lists that are easy to complete. Data transfer and entry should include practices to reduce error, such as double data entry and comparing duplicate databases for discrepancies.

6.2. Setting up a national surveillance system

6.2.1. Introduction

The success of any surveillance system starts with the commitment and quality of the staff that collect data at local level. Health practitioners who have contact with patients, who notice clusters of cases, and who initiate investigations of outbreaks need to have a good understanding of the goals of the surveillance system, how it works and what pattern the disease rates take in their region. These are the people who act as the first point of contact for data that are eventually included in national and international surveillance systems (Stanwell-Smith, Andersson & Levy, 2003; Hunter, 2003).

Usually, outbreaks are first recognized and investigated at the local level. Later, national experts may assist with the outbreak investigation, but the most critical period in an outbreak investigation is often at the beginning when it is possible to collect the best clinical and environmental specimens for determining the aetiology of the outbreak. Interventions to stop or prevent disease outbreaks also usually occur at the local level. However, it must be recognized that local health providers and public health authorities have many critical responsibilities, and it may be difficult for them to commit sufficient time to surveillance activities. Therefore, it is important when setting up a surveillance system to consider at what levels specific actions occur. If public health action and problem solving related to water and sanitation occurs at a local level, then local surveillance for waterborne disease is critical and must be supported by adequate personnel and resources (White & McDonnell, 2000). National surveillance may be less important or unnecessary if the appropriate response is more likely to involve local health, water and sanitation authorities.

Whether establishing a surveillance system at local level or on a national scale, similar decisions relating to the basic operation of the system must be made. These can be summarized as a series of questions.

- Who is responsible for reporting a case?
- To whom are the cases reported?
- What information is collected?
- Who collects the information?
- How are data transferred among administrative levels?
- How is information stored?
- Who analyses the data?
- How are the data analysed?
- How often are the data analysed?
- What types of reports are prepared?
- How often are the reports disseminated?
- To whom are the reports disseminated?
- Through what mechanisms are the reports distributed?
- Are there any automatic responses to case reports?

6.2.2. Data collection

The method of data collection and data transfer depends on the available technology in the region. Data collection can be carried out using handwritten forms or directly into a database via a laptop computer taken into the field for investigation. Laboratories may report their results directly into an electronic web site that is set up for local hospital laboratories or national reference laboratories. Data storage can be in paper form, in notebooks and filing cabinets, or on computer databases that are backed up on a routine basis. Whatever system is used, the priorities should be to: (a) maintain confidentiality of personal patient information; (b) minimize data loss during storage and transfer; (c) minimize inaccurate data entry; (d) minimize inaccurate data transfer; and (e) keep multiple backups of the data, for both the electronic and paper versions.

6.2.3. Data management and analysis

Free epidemiology software (such as “Epi Info”) can be used to assist with surveillance data management and analyses. Epi Info is available on the Internet[8] in seven languages (Arabic, Chinese, English, French, Russian, Serbo-Croatian and Spanish) and manuals are also available in Czech, German, Hungarian, Italian, Norwegian, Polish, Portuguese and Rumanian. Complicated analyses of surveillance data are usually not necessary. For outbreak surveillance systems, the number of outbreaks and the number of cases are usually reported by month, by geographical region, by type of water supply, by etiologic agent and sometimes by risk factor or deficiency. For surveillance systems that report the number of cases of specific diseases, calculations of disease incidence by season, geographical region, age group and sex are useful for showing temporal and geographical patterns of disease occurrence, as well as what population groups are most affected. Perhaps the most challenging analytical aspect is determining the denominator when calculating standardized disease rates for specific populations. For example, when comparing diarrhoeal disease rates in an urban area to a rural area, hospital records may be used to provide data on the number of cases. In order to calculate disease rates (incidence or prevalence), it is necessary to have information on the size of the population served by a particular hospital or health facility during the time period in which the cases were reported.

6.2.4. Information flow

In most surveillance systems, information is collected at a local level and sent to regional and national health authorities that then compile and analyse the data. The results of the data analyses are then summarized in reports that are provided to national and perhaps local health authorities. The general pattern of information flow in a disease surveillance system is illustrated in Fig. 6.3. In some countries, these reports are also made available to the public and to international agencies, such as WHO and various nongovernmental organizations. It is critical that the surveillance reports reach the health policy-makers who can use these results to guide decisions relating to water and sanitation interventions, vaccine strategies, primary health care, and so on. It is also vital that surveillance results and analyses are disseminated to the local level in order to maintain the interest and cooperation of the data collectors and data providers. In most countries, surveillance data collectors (health care providers and laboratories) rarely face consequences for failure to report cases. Therefore, data collectors must understand the purpose of the surveillance system, be committed to its goals, and see evidence that the information is used to improve public health.

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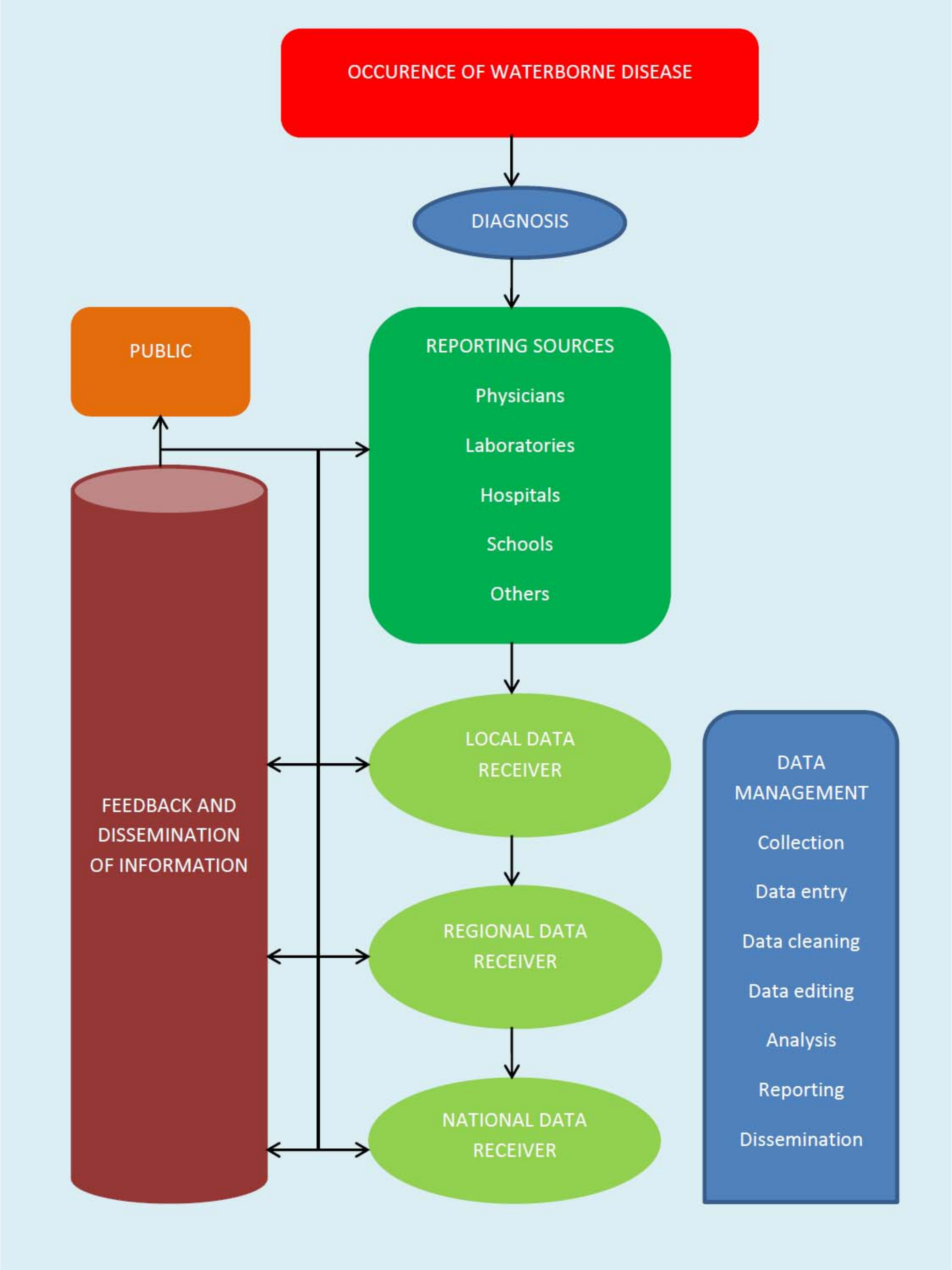
[8] See the CDC web site (http://www.cdc.gov/epiinfo/, accessed 23 December 2010).

Fig. 6. 3. Flow of surveillance information between local, regional and national levels



Source: adapted from Klaucke, 1992.

6.2.5. Information use

The final step in a surveillance system is how the information collected from the surveillance system is used to protect public health. For waterborne disease surveillance, action may occur at the national level through the implementation of appropriate guidelines for water treatment and water quality and by allocating necessary resources for improving water supply and sanitation systems in areas with higher rates of enteric illness. At the regional level, information from surveillance may prompt local health and water authorities to inspect and maintain water supply systems to ensure proper treatment and delivery of safe water. It is important to build links between water supply authorities and public health authorities in order to be able to work quickly to recognize and control waterborne disease outbreaks. Ultimately, the success of a waterborne disease surveillance system depends on whether it provides the type of data that public health authorities and water authorities can use to address causes of waterborne disease.

6.3. Evaluating a surveillance system

Any public health programme should be periodically evaluated to determine if it is meeting its objectives. Evaluation is particularly important for surveillance systems because they can become routine data-collection activities that are simply continued for their own sake and lose track of the purposes for which they were intended. This section describes criteria that are usually used to evaluate a surveillance system and how these criteria can be applied to waterborne disease surveillance systems.

6.3.1. Evaluation criteria

When evaluating a waterborne disease surveillance system, it is important to refer back to the purpose of the surveillance system and to ask the following questions.

- Should there be a surveillance system for waterborne diseases?
- Is the surveillance system useful? Does the information from this surveillance help with policy decisions relating to water supply and sanitation interventions?
- Does waterborne disease surveillance lead to improved public health?

For the first question, regarding whether there should be a surveillance system for waterborne disease, one should consider whether waterborne disease is an important public health problem. If data are available, one can consider:

- the magnitude of waterborne disease
- the level of morbidity associated with waterborne disease
- the severity of disease
- premature mortality associated with waterborne disease
- economic costs (including medical costs, absenteeism and lost productivity)
- whether waterborne disease is preventable.

Usually, some type of surveillance system is necessary to provide information on whether waterborne disease is an important public health problem. In the absence of such information, public health authorities may mistakenly conclude that waterborne disease is not a problem in their country because they were not looking for waterborne disease. On a global basis, the importance of waterborne disease is well documented. It is estimated that 4% of all deaths and 5.7% of the total disease burden worldwide is associated with lack of access to safe drinking-water, inadequate sanitation and poor hygiene (Pruss et al., 2002). However, the burden from waterborne disease can vary dramatically by region. Many countries throughout the world have some type of waterborne disease surveillance system, regardless of whether they are high-, middle- or low-income countries, and waterborne disease outbreaks have been documented even in countries that have advanced technology for water treatment. Finally, there is evidence from numerous studies conducted in a variety of settings indicating that waterborne disease morbidity and mortality can be reduced by improvements in water and sanitation (Esrey et al., 1991). The challenge of an effective waterborne disease surveillance system is to provide information to guide effective water and sanitation interventions that result in improved health.

Evaluating the usefulness of a waterborne disease surveillance system depends on the objectives of the system. Typically, one should expect that an effective system can detect trends in the occurrence of waterborne disease and outbreaks of waterborne disease. The surveillance system should also be able to provide accurate information on the magnitude of morbidity and mortality associated with waterborne disease. Ideally, the system should also be able to identify risk factors for waterborne disease (both endemic and epidemic) and stimulate implementation and/or research on control and prevention strategies. Finally, the surveillance system should permit assessment of the effectiveness of control and prevention measures for reducing waterborne disease.

6.3.1.1. Output evaluation criteria

The output of a surveillance system can be evaluated by considering five criteria: sensitivity, predictive value positive, timeliness, representativeness and data quality.

6.3.1.1.1. Sensitivity

The sensitivity of a system is its ability to detect the events under surveillance. Using the example of cases of shigellosis, sensitivity can be expressed as A/(A+C), which is the proportion of all the true cases in the population (A+C) that are reported to the surveillance system (Table 6.5).

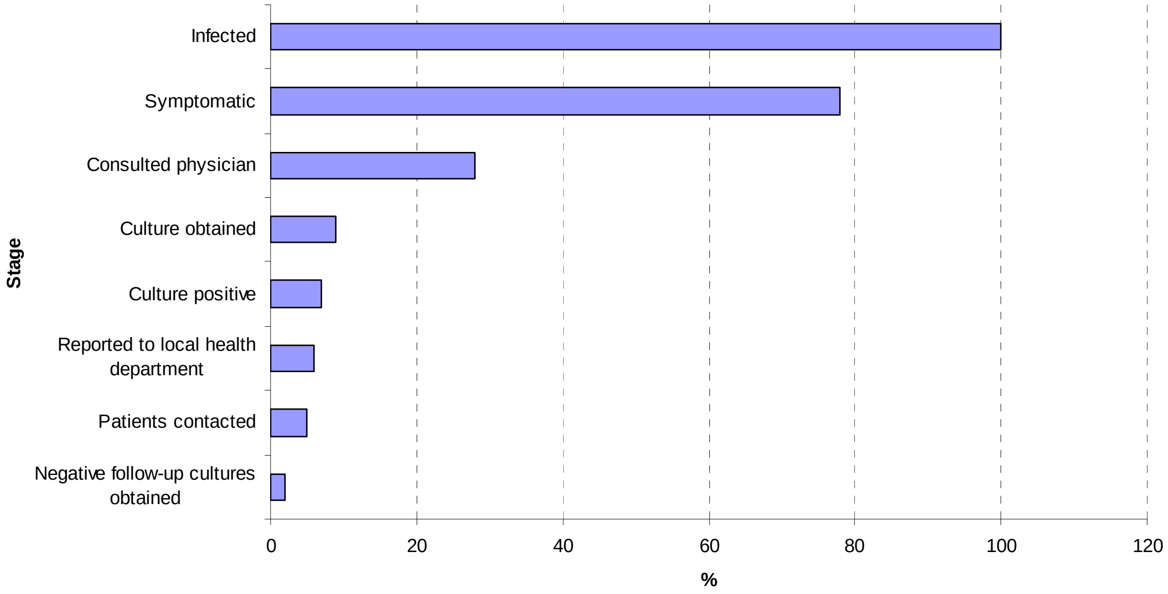
Table 6.5. Detection of a health condition with a surveillance system

		Conditions present		
		Yes	No	
Detected by surveillance	Yes	True positive (A)	False positive (B)	A+B
	No	False negative (C)	True negative (D)	C+D
		A+C	B+D	Total

The sensitivity of a system is affected by the number of steps in the reporting process and the level of compliance at each step. The greater the number of steps in the reporting process, the more likely it is that information will be lost in the process. Most surveillance systems are not sensitive enough to estimate the true disease burden. For example, it is inevitable that some cases of shigellosis will not be recognized or reported (Fig. 6.4).

Sensitivities of surveillance vary from system to system and between countries and geographic regions, and it can be difficult to compare or combine data from different surveillance systems. A recent review of waterborne disease surveillance systems in Europe concluded that the data were not comparable among countries because of differences in reporting methods, case definitions, the structures of the surveillance system and quality of the data (Kramer et al., 2001).

Fig. 6.4. Stages of identification, reporting and investigation of shigellosis



6.3.1.1.2. Predictive value positive

"Predictive value positive" is a measure of the accuracy of a surveillance system and is defined as the proportion of cases included in the surveillance data set that actually have the disease of all the cases reported to the surveillance system. In Table 6.6 the predictive value positive is shown as A/A+B, where:

- A equals the number of true positive cases that were detected by surveillance;
- B equals the number of false-positive cases detected by the surveillance; and
- (A+B) = all the cases reported to the surveillance system.

Some false-positive cases (B) may be included in the surveillance system because of misdiagnosis or because the condition that is being detected is not well defined. For example, monitoring the sales of anti-diarrhoeal medication has a low predictive value positive for cases of waterborne disease because some peaks of increased sales may be due to a discounted price or a new advertisement campaign. Therefore, it is important to compare the results of a system that monitors the sale of anti-diarrhoeal medications with another surveillance system for waterborne disease.

6.3.1.1.3. Timeliness

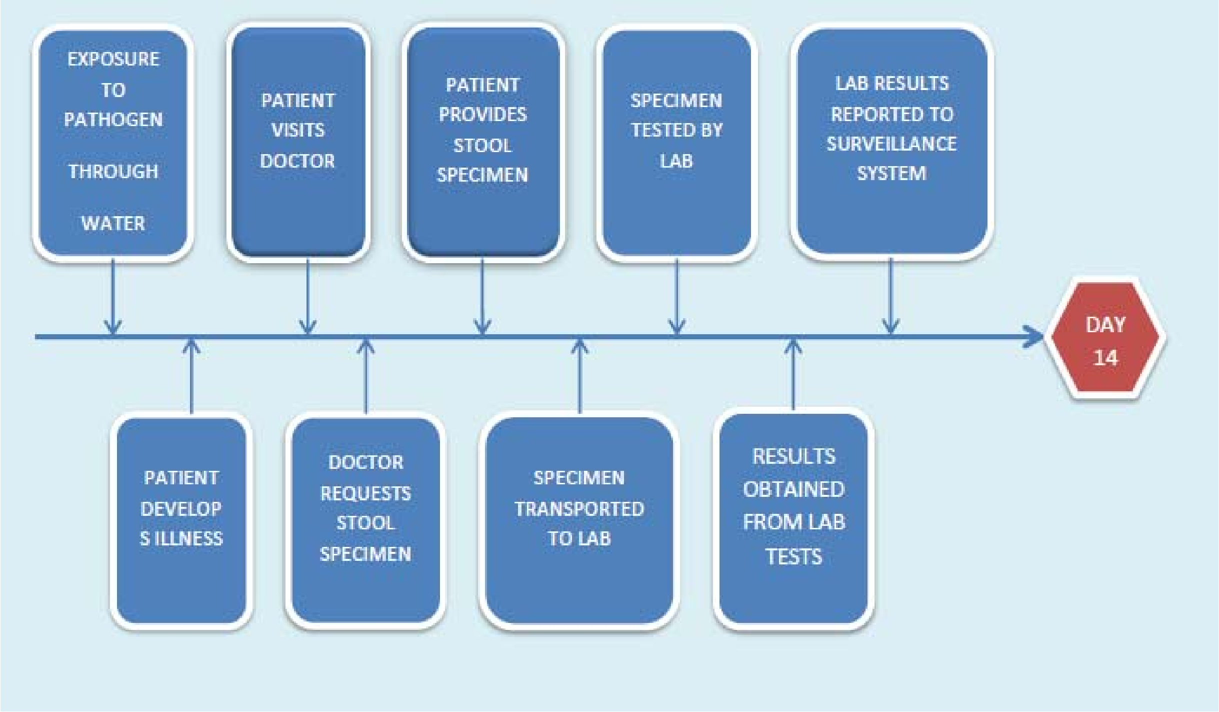
The timeliness of a waterborne disease surveillance system can be assessed by measuring how long it takes for a case of waterborne disease or an outbreak of waterborne disease to be recognized and reported to the system. As with sensitivity, the timeliness of a surveillance system may be related to the number of steps involved in the reporting process. The greater the number of steps, the longer the reporting process will take. For example, laboratory-based surveillance systems can have a long lag time between the point at which a patient is exposed to a pathogen and the point at which the laboratory-confirmed infection is reported to the surveillance system (Fig. 6.5). If the lag time in a surveillance system for *Shigella* infections is 11–14 days, this is enough time for secondary and tertiary transmission of infection, and the timeliness of the system may not be sufficient for effective disease control. The lag time in a surveillance system may also depend on the technology that is involved in the process. Systems in which the data are collected in person, transcribed manually on paper and then entered into a database will be slower than systems that are automated and use a telephone or internet reporting system.

Table 6.6. Number of waterborne disease outbreaks by year, Germany, 1946 - 2000

Year	Location	Disease / Pathogen	Cases
1946	Neu-Oetting	Typhoid	≈ 400
1948	Neu-Oetting	Typhoid	≈ 600
1956	Hagen	Typhoid/paratyphoid	≈ 500
1971	Heidenau	Dysentery	482
1972	Worbis	Dysentery	≈ 1 400
1972	Dingelstedt	Hepatitis A	≈ 40
1978	Muenchen-Ismaning	Dysentery	2 450
1980	Jena	Typhoid	69
1981	Halle	Rotavirus	11 600
2000	Regensdorf	Giardiasis	10

Note. n = 10.
Source: adapted from Thofern, 1990.

Fig. 6.5. Lag time in laboratory-based surveillance



Finally, the type of surveillance system (passive versus active) will affect the speed with which events are reported. Whether the timeliness of a surveillance system is adequate depends on the objectives of the system. Does the surveillance system provide information early enough to allow appropriate public health action to prevent and control disease transmission? Most passive surveillance systems are not rapid enough to detect waterborne disease outbreaks at the time at which they occur. Outbreaks of waterborne disease are usually detected after the primary contamination event has passed. If rapid detection of waterborne disease outbreaks is a goal of the surveillance system, then the enhanced, active surveillance methods described earlier must be used. If the goals of the surveillance system are to monitor long-term trends in waterborne disease or to evaluate the impact of improved water and sanitation interventions or stricter water quality regulations, then the longer reporting times that are characteristic of passive surveillance systems may be acceptable.

6.3.1.1.4. Representativeness

The data collected in a surveillance system should be representative of the true situation in the population covered by the surveillance system. Are the cases of disease that are reported to the surveillance system typical of the cases that occur in the population? Often, severe individual cases of illness are more likely to be reported than mild cases because the individuals affected are more likely to seek medical care and to be diagnosed. Waterborne outbreaks of more severe illness, such as typhoid, cholera or *E. coli* O157:H7 are also more likely to be recognized and reported because mortality may be involved. Surveillance systems should also assess whether there is overreporting or underreporting of cases in certain economic classes or regions resulting from differences in access to medical care. Individuals from rural areas and poorer groups in the population are often less likely to be included in a surveillance system because of limited access to medical care. Sometimes alternative active surveillance approaches must be used to capture the true disease burden within these populations. Surveillance systems for waterborne disease outbreaks are more likely to detect larger outbreaks that occur in large municipal water systems because more people are likely to be affected by the outbreak and there is better access to medical care and diagnostic laboratories that can detect and report the illness.

Of course, if ill people in a big city visit more general practitioners (GPs), information on unusually high incidence may be "diluted" and last longer. For example, the "famous" outbreak of crytposporidiosis in Milwaukee, Wisconsin in 1993 was recognized as outbreak only when about 200 000 people (about half of the affected population) became ill.

Smaller water utilities may be at greater risk of problems relating to waterborne disease because water quality at these facilities may be monitored less frequently, the facilities may have fewer treatment processes, and the operators may have less training and may only work part time. However, it is more difficult to detect waterborne disease outbreaks associated with small water utilities because fewer people may be affected and there may be limited access to medical care or limited communication with regional and/or national health authorities.

6.3.1.1.5. Data quality

The final area of output that should be evaluated is the quality of the data collected by the surveillance system. Assessments of data quality can be carried out simply by inspection of the data forms and the database. Are the data collected in the system complete? Are the data forms filled out completely or are there many blank or unknown responses? Is the database complete or are there many fields with missing data? Assessing the accuracy of the data collected in the surveillance system requires a confirmation system. In some systems, a portion of the data is reviewed and checked with follow-up investigations to confirm that the cases or outbreaks reported to the surveillance system are real events.

6.3.2. Process evaluation criteria

The surveillance system process can be evaluated by studying four criteria: acceptability, simplicity, flexibility and cost.

6.3.2.1. Acceptability

Acceptability depends on making the surveillance system easy for the user – especially for those who are responsible for the initial reporting of the cases or outbreaks. Surveillance forms should be concise, have clear instructions, be easy to fill out and minimize the amount of time required to fill them out.

A surveillance system must also be acceptable to the population under surveillance. Health surveillance sometimes involved collecting information about sensitive, painful or embarrassing risk factors for disease, such as HIV status or sexually transmitted infections. Surveillance systems must be committed to protecting the privacy of the cases that are reported.

6.3.2.2. Simplicity

Simple surveillance systems are less costly and are more likely to be successful and sustainable. Case definitions and outbreak definitions need to be clear. Reporting information should be limited to the most critical information that is required. Data transfer from local to regional and national levels should be as simple as possible – especially in low and middle-income areas with limited communication resources. Much valuable information can be obtained from simple, straightforward data analyses that calculate disease incidence by season, geographic region, age group and sex.

6.3.2.3. Flexibility

Sustainable surveillance systems need to be flexible and adapt to changes in health, politics and technology. There may be changes in the epidemiology of certain waterborne diseases because of the introduction of new sensitive populations or new strains of pathogens into a geographic area due to population movement, war, severe weather events or other new risk factors. Changes in government may result in changes in political priorities, public health information needs and reporting regulations. Changes in communication technology may lead to changes in the technology used for reporting and data transfer. Flexible surveillance systems will be easier to modify in order to accommodate future changes.

6.3.2.4. Cost

Cost is often a major factor in the evaluation of a surveillance system and usually determines whether a system will be implemented and sustained. Surveillance systems can be very costly in terms of both financial and human resources. Public health authorities need to weigh the costs of the system against the public health benefits in order to decide whether the costs are acceptable and if the critical surveillance information is being collected in the most economical way. Table 6.7 compares the estimated costs of active versus passive surveillance at a local health department in the United States (Vogt et al., 1983). In this situation, the active surveillance system reported 60 cases and the passive surveillance system reported 37 cases. The active surveillance reports were more complete; the physicians commented that they liked the active surveillance system because it relieved them of the responsibility of remembering to report notifiable diseases; and the active surveillance system improved communications between physicians and public health authorities. However, the cost of each additional case reported by the surveillance system in this specific situation was US$ 861 (Vogt et al., 1983).

6.3.2.5. Evaluation of staff capability

Finally, the ability of local health staff and clinics to effectively run and sustain a local surveillance system can be evaluated by means of several basic indicators. The staff should be: (a) reporting data regularly, (b) displaying the pooled data they have collected, (c) able to explain the meaning of the data, (d) able to use the data to suggest solutions to local health problems, and

(e) able to use the data to evaluate interventions targeted at specific water and sanitation problems. If the local public staff are carrying out these activities, they are likely to understand the usefulness of the surveillance information for planning public health interventions and can sustain the surveillance system (White & McDonnell, 2000).

Table 6.7. Comparing estimated costs[a] for active and passive surveillance systems

Type of surveillance system	Cost (US$)	
	Active[b]	Passive[c]
Paper	114	80
E-mail	185	48
Telephone	1 947	175
Personnel (secretary)	3 000	2 000
Personnel (public health nurse)	14 025	0
Total	19 271	2 303

Notes: [a]Vermont Health Department costs (1 June 1980 to 31 May 1981); [b] Active: weekly calls from health department to request reports; [c] Passive: provider-initiated reporting.
Source: Vogt et al., 1983.

6.4. Summary

A good surveillance system should be useful. The goals of a waterborne disease case or outbreak surveillance system should be linked to specific and achievable public health objectives, such as eliminating waterborne typhoid fever or reducing the incidence of paediatric gastroenteritis. Surveillance systems should be designed to provide reliable data that is relevant to the waterborne disease concerns of the region.

Good waterborne disease and outbreak surveillance systems can provide important information for designing and implementing water and sanitation interventions to improve public health. Surveillance can also be used to determine the effectiveness of an intervention by comparing disease rates before and after the intervention. The costs and benefits of waterborne disease and outbreak surveillance depend on the problem addressed, the context and the priorities of the society. If surveillance data are only being collected and not being analysed and used, then the system is a failure. Dissemination of waterborne disease surveillance reports needs to occur at several levels. For the system to be effective, the results of the analyses must reach public health authorities that will use the results to take appropriate action – including health, water and sanitation authorities at local, regional and national levels. Dissemination of the surveillance results to the local data collectors is also critical – otherwise data-collection activities become meaningless requirements with little incentive for compliance. There is no incentive for busy, overburdened clinical or public health staff to collect surveillance information unless they can see that this information is used to make significant improvements in public health.

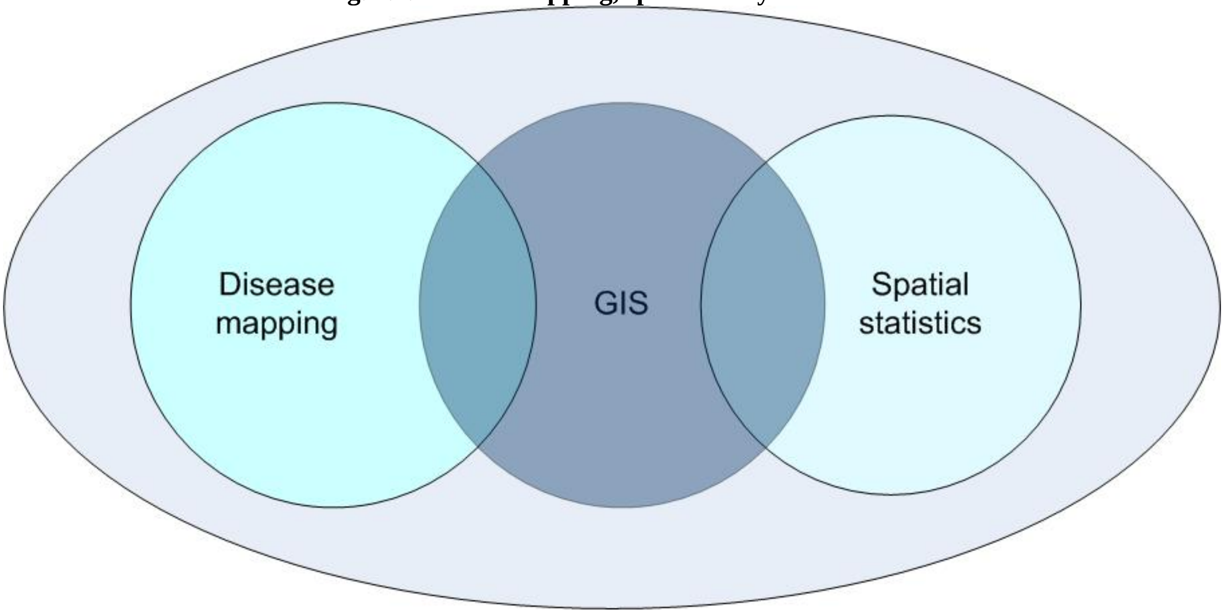
7. Data management and analysis using GIS

Lead authors: Thomas Kistemann, Angela Queste, Ina Wienand and Thomas Classen

7.1. Introduction to GIS

A GIS is a computing technology for the capture, storage, manipulation, analysis and display of spatially referenced data (Clarke, McLafferty & Tempalski, 1996; Croner, Sperling & Broome, 1996; Moore & Carpenter, 1999; WHO, 1999). Mostly, GIS is used to combine mapping facilities and spatial statistical methods (see Fig. 7.1).

Fig. 7.1. Disease mapping, spatial analysis and GIS



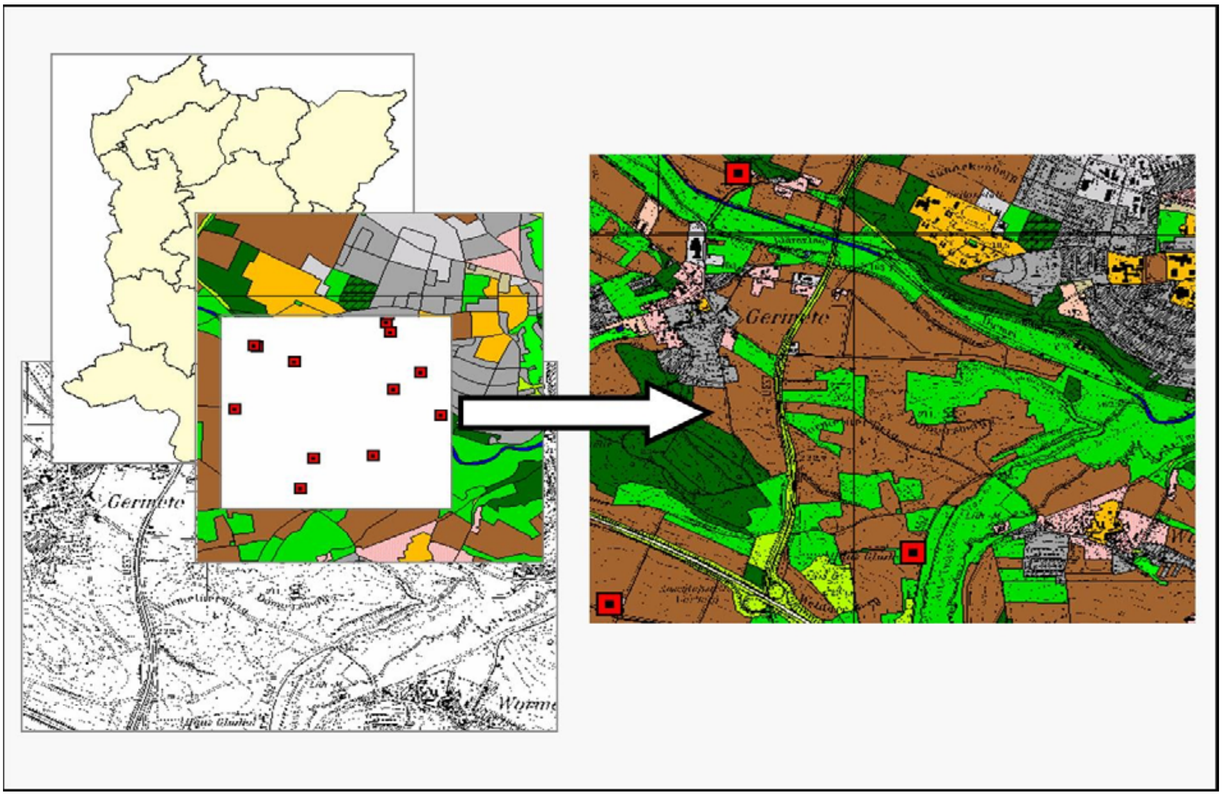
A GIS can be used to define the condition and location of disease events, to analyse time trends, to investigate spatial patterns and to carry out modelling of disease developments. The functions of a GIS are to generate thematic maps, to allow overlaying of different pieces of information, and to create buffer areas around selected features. It can be used to carry out specific calculations, such as the calculation of distances.

A GIS works with dynamic databases, which permit a dynamic link between spatially related data and maps. In this way, data updates are automatically reflected on the map.

One of the most important features in a GIS is the layer structure, which allows a combination of disease data with influencing factors. Layers can be districts, topographical maps, land-use patterns, the place of residence of diseased individuals, the water distribution system, or the incidence of gastrointestinal infections, for example. Fig. 7.2 demonstrates the different layers “districts”, “topographical map”, “land use” and “location of drinking-water wells”. The link between these different kinds of data enables the generation of new information as well as the retrieval and analysis of existing data.

GIS applications can be of high value for hazard identification and exposure assessment, as well as preventive, control and surveillance measures.

Fig. 7.2. Layered structure of a GIS



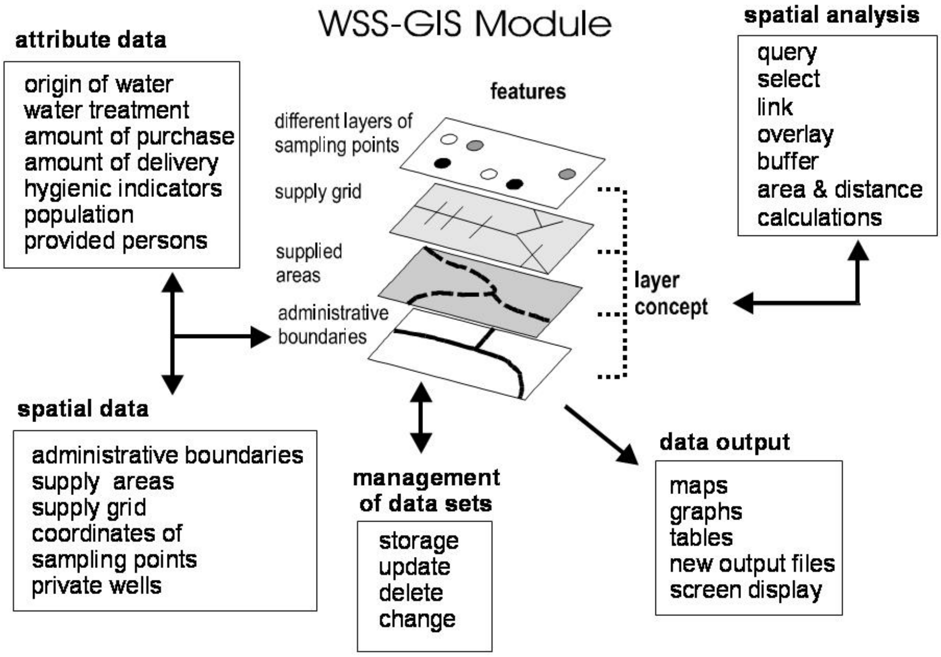
Source: Institute for Hygiene and Public Health, University of Bonn, Germany.

7.2. Application of GISs to waterborne disease epidemiology

After explaining the basics of GISs, the next step is to show some examples of how a GIS can be used in waterborne disease epidemiology. GIS application is beneficial for risk assessment, outbreak management, cause identification or risk communication for health authorities, water supplies and other public institutions.

In outbreak situations, urgent public health action is needed. In such situations it is important to understand spatial relations, which are a condition for successful prevention, control and surveillance of diseases. A GIS is an ideal tool for monitoring waterborne disease interventions over time. It helps to determine the geographical distribution and variation of diseases, presenting simply the results of analysing spatial and longitudinal trends, mapping populations at risk and assessing resource allocations. Much of the relevant information is space related, presenting, for example, distribution of cases, along with patterns of risk factors, health services, infrastructure and emergency medical services. An important condition of an incident plan or outbreak management approach is to prepare GIS facilities before the outbreak. With enormous volumes of data on land-use patterns in catchment areas, water quality, pipe materials, customer complaints and so on, the capacity of a water supply structure GIS (WSS GIS) combines these large volumes of data from widely different sources, making it an ideal tool for storing, analysing and displaying data concerning WSSs (Kistemann, 2001b). The Institute for Hygiene and Public Health in Bonn, Germany designed a so-called WSS GIS module to handle the referring data. The principle of the module is shown in Fig. 7.3.

Fig. 7.3. Elements of a WSS GIS



Source: Kistemann et al., 2001b.

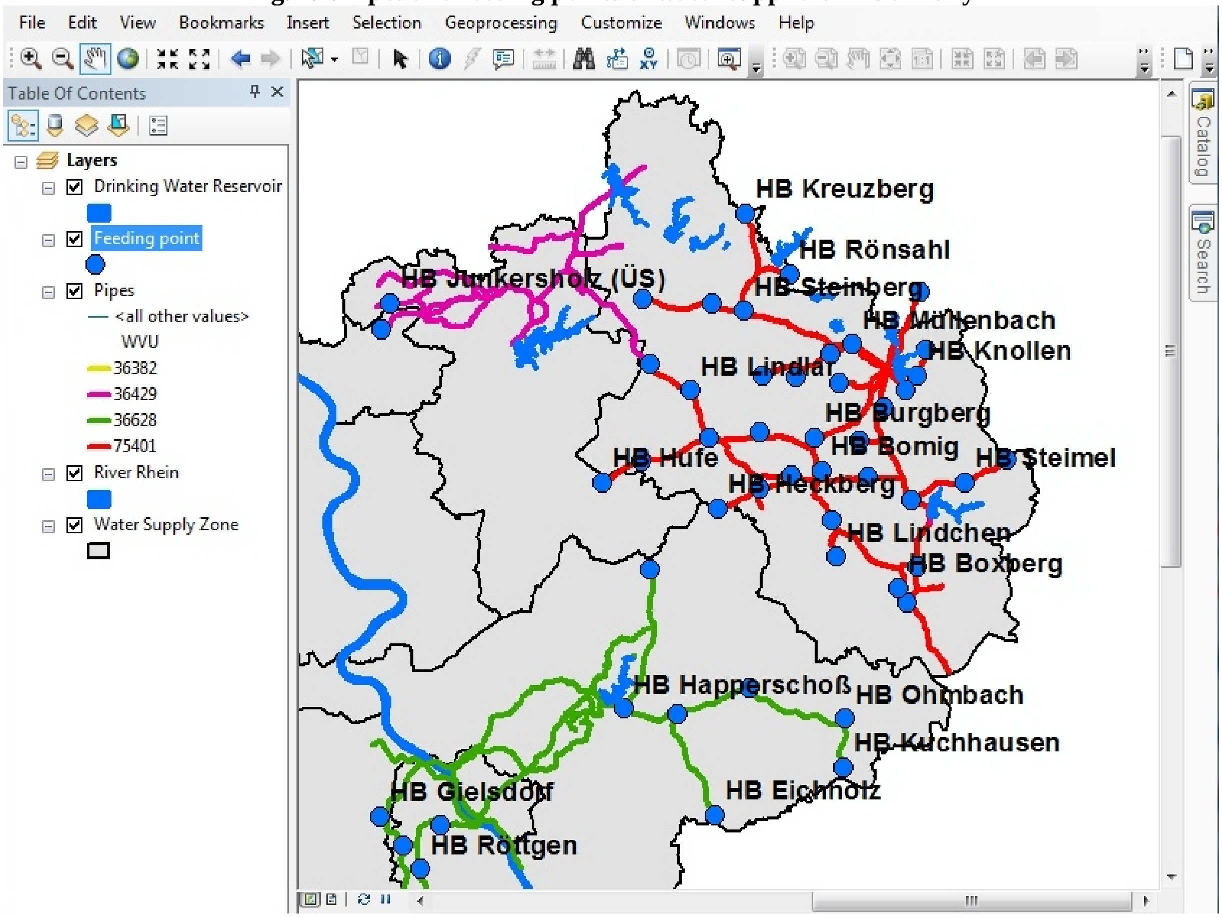
As with all databases, a GIS is only as powerful as the raw data allows. It is therefore essential that the data are of the highest quality. Although some datasets can be purchased, such as some digitized maps, data requirements are often designed to be specific to the task.

The water supply infrastructure strongly influences the spatial pattern of drinking-water-related ill health. Therefore, and in particular if applying the hazard analysis and critical control points (HACCP) concept of quality management, it is of huge importance to have detailed information on water purification facilities, disinfection points, feeding points, and water distribution. One of the most immediately obvious benefits of a GIS is the way in which data can be presented. Maps are able to display and convey complex ranges of different data types which allow patterns and relationships to be quickly and easily identified among the mass of information. In Fig. 7.4, feeding points and digitized pipes are shown. The points show different health authorities responsible for the surveillance in those regions.

It is very helpful to use such a spatial tool, as water supply infrastructure – at least in densely populated areas – is often very complicated, including confusing relationships between different waterworks. By using spatial analysis tools in a GIS, it is possible to describe spatial patterns, calculate distances of selected features or predict values for unmeasured locations. Fig. 7.5 shows the application of a buffer tool for a small creek in Germany in order to calculate areas within a specific distance of the creek that are influenced by agricultural activities, such as live stock farming, for example.

A more sophisticated approach to spatial analysis using a GIS is the use of interpolation techniques. One example is kriging interpolation – assuming that things that are close to one another are more alike than other farther away. Fig. 7.6 shows the spread of chemical contamination with volatile halogenated hydrocarbons (VHH) in a groundwater abstraction catchment area in Germany.

Fig. 7.4. Pipes and feeding points of water suppliers in Germany



Source: Institute for Hygiene and Public Health, University of Bonn, Germany.

With the interpolation technique, contamination is calculated for non-measured areas. It weights the surrounding measured values to derive a prediction for each location. As a result, the contamination could be displayed in series of maps. In this example, spatial analysis showed that concentrations decreased downstream, but this decrease was greater for highly chlorinated pollutants. The GIS enabled the calculation of the total VHH load of the groundwater, and it was clear that contamination considerably endangered the waterworks.

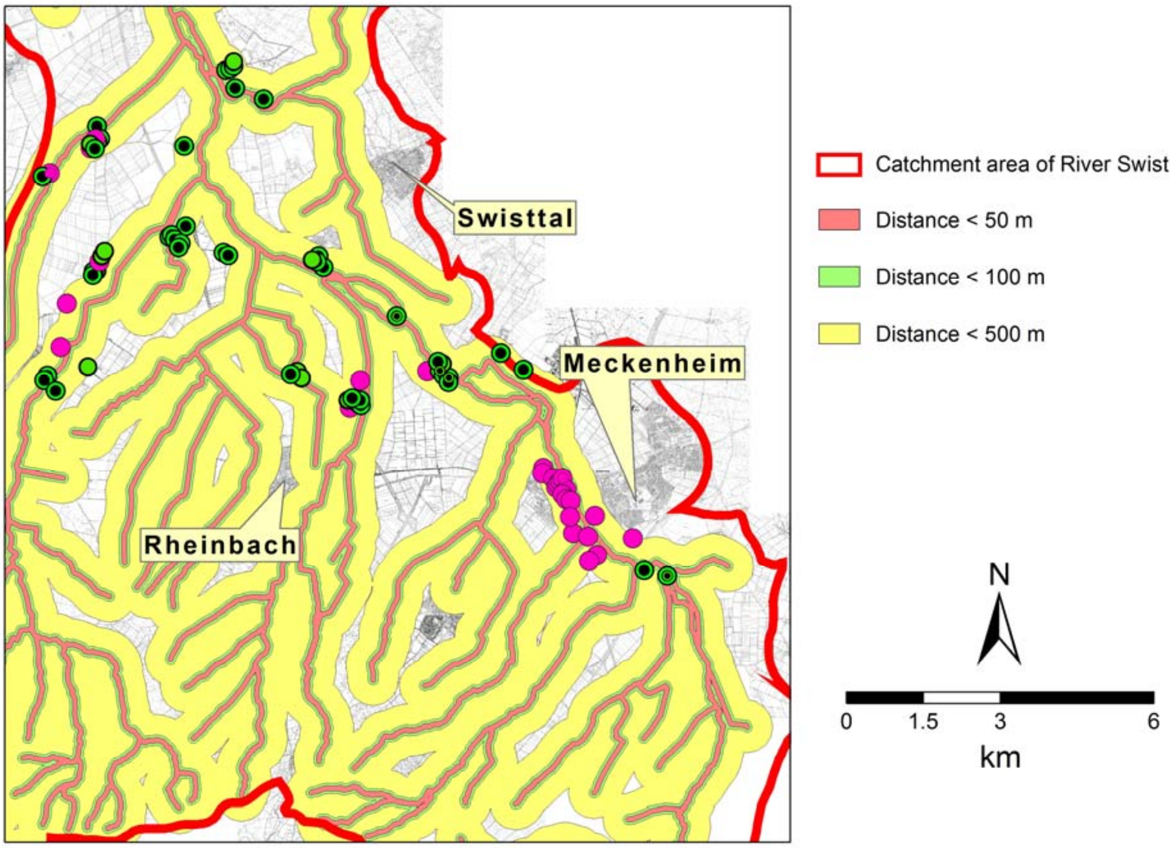
Combining high-quality spatial information on catchment areas, water supply infrastructure and epidemiology of water-related diseases allows the assessment of the burden of water-related disease caused by specific conditions. This is a precondition for logically defining relevant priorities in water-related disease management. It is clear that high-quality map outputs may be useful in helping to generate results, especially to those from outside the field.

7.3. Example: GIS-supported epidemiological confirmation of the first waterborne giardiasis outbreak in Germany

The aim of the previous section was to give an impression of the numerous opportunities for epidemiology offered by GISs. In an investigation carried out in 2000/2001, a giardiasis outbreak could be identified as (drinking-)waterborne by a GIS-supported epidemiological study (Kistemann, Classen & Exner, 2003; Gornik et al., 2001; Atherholt et al., 1998; Ong et al., 1996;

Craun & Frost, 2002; Howe et al., 2002; Hunter & Quigley, 1998; Kramer et al., 2001; Steiner, Thielman & Guerrant, 1997; States et al., 1997; Kistemann, 2001a).

Fig. 7.5. Creating buffer areas in GIS

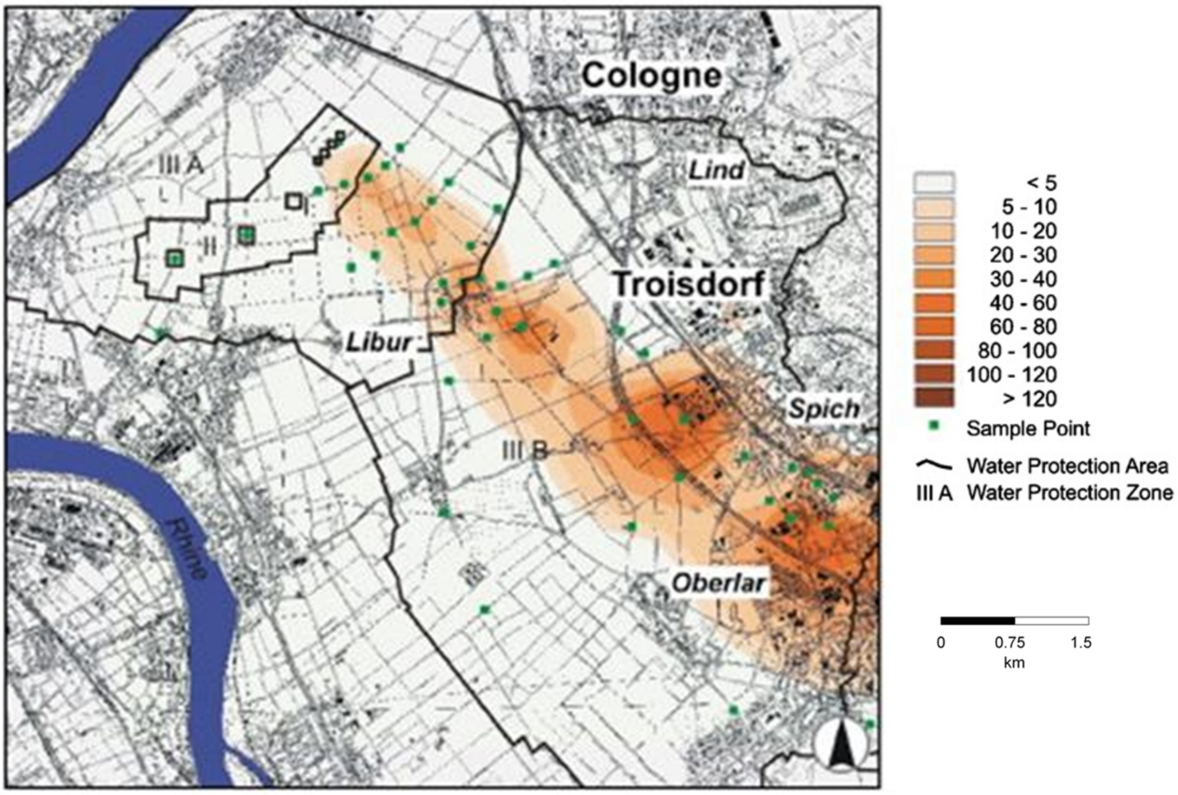


Source: Institute for Hygiene and Public Health, University of Bonn, Germany.

Since May 2000 a GP within a small municipality in Germany (Rengsdorf) had noticed an increasing number of diarrhoeal diseases within her patients. This was not uncommon for Rengsdorf, as in 1990, 1996 and 1999 there had been several sporadic cases of giardiasis in patients presenting with diarrhoea. However, the GP had the stools of all of her patients with diarrhoea tested for *G. lamblia*. The samples of 8 out of a total of 43 patients tested positive for a *Giardia* cyst, which indicates a prevalence of 18.6%. The GP suspected the cases to be interrelated and reported all infections to the district health authority, as the Federal Epidemic Act requires every infection to be reported. The Public Health Officer knew about water being a possible transmission route for *Giardia* infections and asked the Institute for Hygiene and Public Health in Bonn to support the carrying out of parasitological and epidemiological investigations to determine whether the Rengsdorf *Giardia* cases were related to water.

With the interpolation technique, contamination is calculated for non-measured areas. It weights the surrounding measured values to derive a prediction for each location. As a result, the contamination could be displayed in series of maps. In this example, spatial analysis showed that concentrations decreased downstream, but this decrease was greater for highly chlorinated pollutants. The GIS enabled the calculation of the total VHH load of the groundwater, and it was clear that contamination considerably endangered the waterworks.

Fig. 7.6. Kringing interpolation in a GIS (Universal Kringing with linear drift, search distance 1500m)



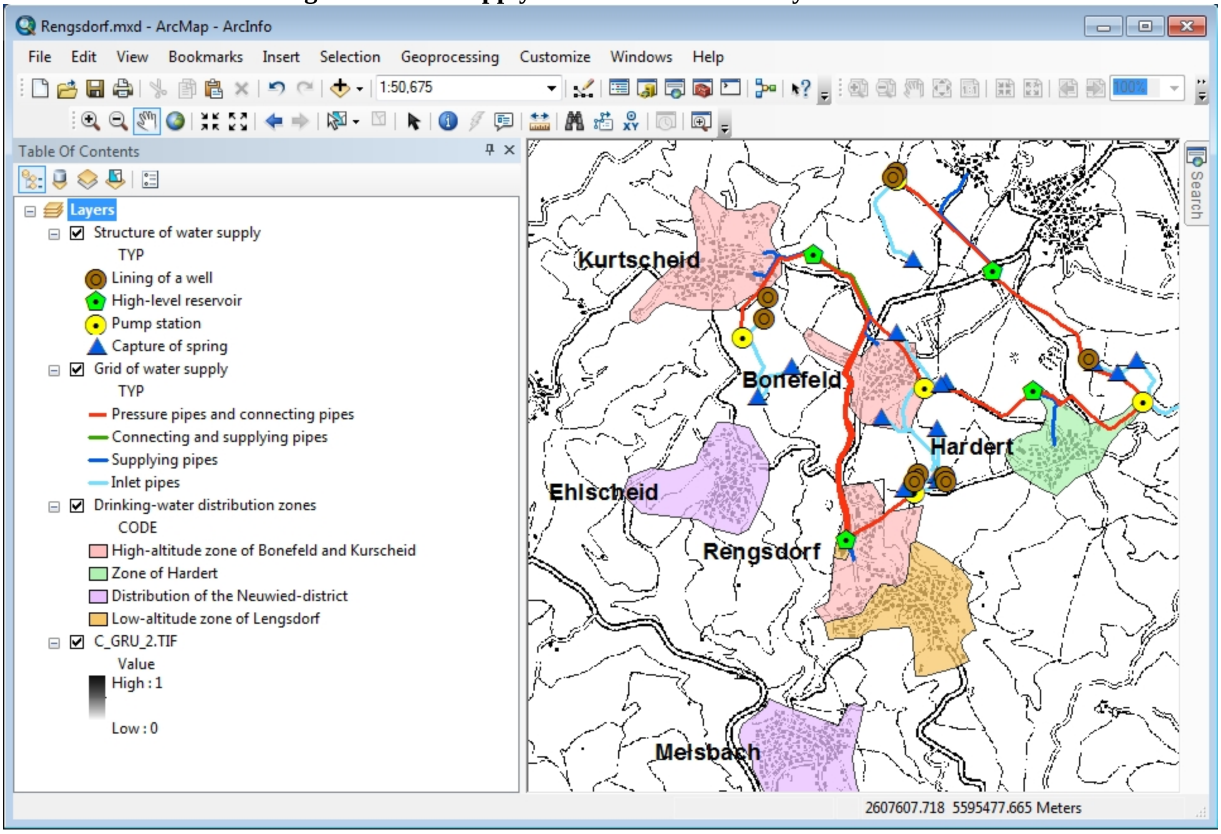
Source: Institute for Hygiene and Public Health, University of Bonn, Germany.

Combining high-quality spatial information on catchment areas, water supply infrastructure and epidemiology of water-related diseases allows the assessment of the burden of water-related disease caused by specific conditions. This is a precondition for logically defining relevant priorities in water-related disease management. It is clear that high-quality map outputs may be useful in helping to generate results, especially to those from outside the field.

A retrospective cohort study was conducted in November 2000, comprising the catchment area of the GP practice (Rengsdorf) as well as a control area (Melsbach). Both areas had one primary school and all primary school pupils were chosen as the investigation population (N = 418). A total of 383 pupils participated in the study: the response rate was 91.6% and the share of the total population was 4.1%.

At least two stool samples were taken from every participant, and their parents answered a questionnaire investigating potential risk factors for giardiasis infection. Furthermore, the origin of domestic tap water was traced for every pupil via place of residence. As a precondition, the drinking-water supply structures of the investigation area had to be investigated. All the data were stored in a database (MS-Access®) and analysed for statistics by means of a standard software package (Epilnfo2000®). Geo-referenced data were transferred to a GIS (ArcView®) via SQL-connections to support spatial analysis and communication of results. Fig. 7.7 shows the complex structure of water supply in the investigated area.

Fig. 7.7. Water supply structures shown as layers in a GIS

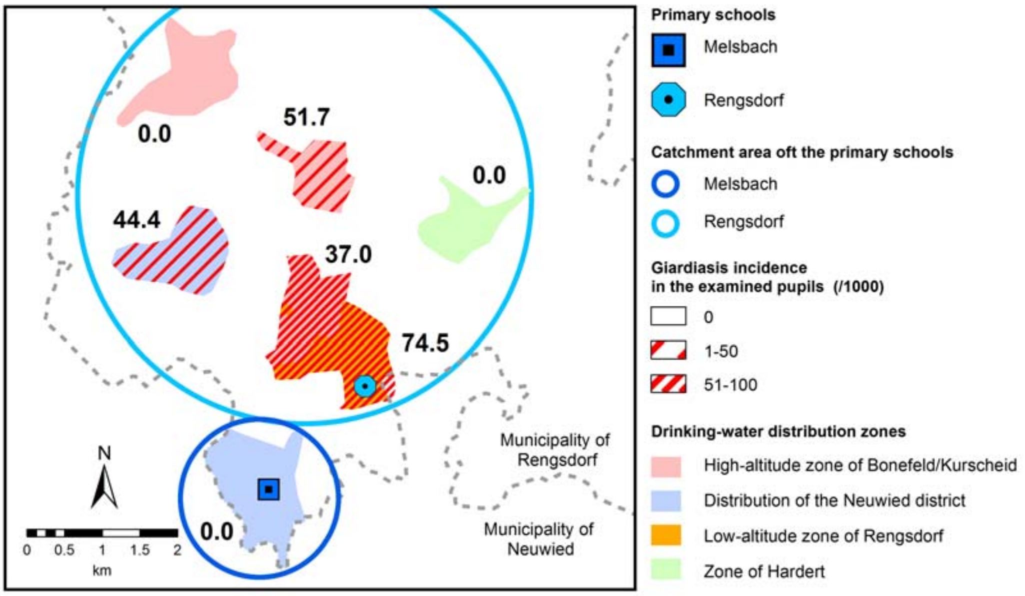


Source: Institute for Hygiene and Public Health, University of Bonn, Germany.

In the village of Rengsdorf, the water supply is divided into two zones. The low-altitude zone is provided by a high-level reservoir container, which is fed by four wells and five springs situated in the surrounding forests and farmland. The water is disinfected by use of chlorine-dioxide, but there is no further treatment. About 600 000 litres of drinking-water are fed into the net daily. The high-altitude zone receives drinking-water from another reservoir, which is fed by several wells and springs. In addition, about 10% of the water continuously comes from the low-altitude zone reservoir. About 700 000 litres of drinking-water are fed into the net, after chlorination, but without any other treatment. The village of Hardert has its own supply system, which is not connected to the Rengsdorf zones. The submunicipalities of Melsbach and Ehlscheid receive their drinking-water from the large district waterworks, which abstracts ground water from the well-protected, quaternary sediments of the Rhine valley. All the information can be obtained from the GIS simply by clicking the info button. Photos were also connected to the GIS via hot-links.

Among the 383 participants, 13 cases of giardiasis could be identified (six girls and seven boys). As the cases were asymptomatic, their infection had been unknown before entering the study group. The prevalence of the total study group was 33.9/1000. The next step was to link the cases to the villages and then to calculate prevalence for the water distribution zones (see Fig. 7.8 and 7.9).

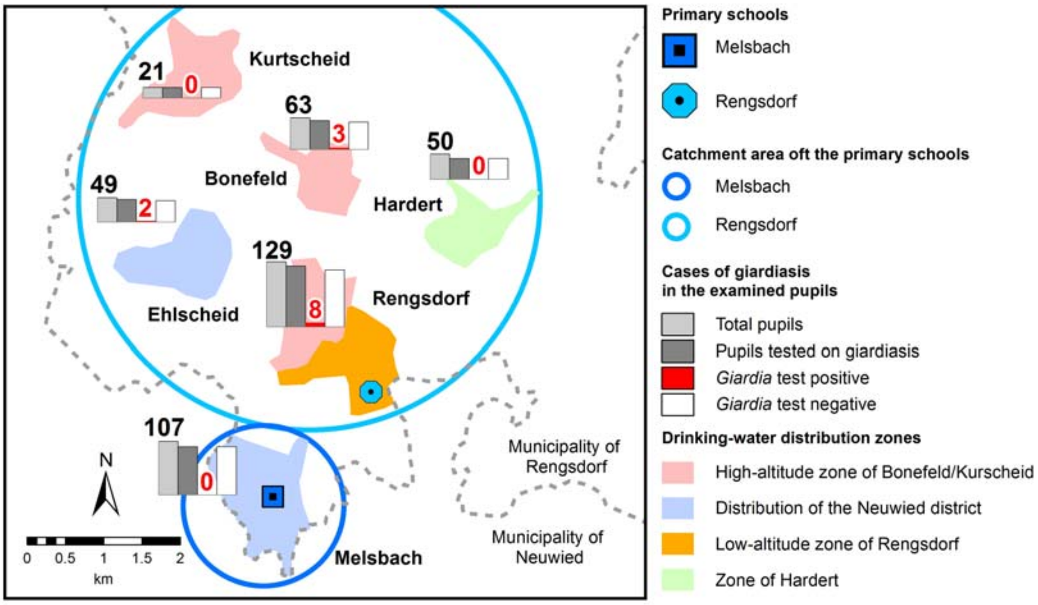
Fig. 7.8. Giardia prevalence throughout the examined pupils



Source: Institute for Hygiene and Public Health, University of Bonn, Germany.

To investigate the potential relationship between cases and water supply, those supply zones were combined which were not related to the Rengsdorf supply zones; for example, Hardert, Ehlscheid and Melsbach. The risk of infection was increased by 6.9 within the Rengsdorf low-altitude zone (p=0.008). For the Bonefeld supply zone, the risk was also significantly increased, by 3.5 (p=0.078). The combination of both zones showed an increase by 5.1 (p=0.009). The results relating to water consumption habits showed that the risk of *Giardia* infection is significantly increased if a carbonation system (such as a SodaStream) is used at home to prepare tap water for consumption. Other factors, such as nutritional habits, travelling, animal contact, and bathing in natural waters were not identified as significant for acquiring a *Giardia* infection.

Fig. 7. 9. Giardia incidence throughout the examined pupils



Note. [a] Differentiated for drinking-water distribution zones and individual villages.
Source: Institute for Hygiene and Public Health, University of Bonn, Germany.

Simultaneously with the epidemiological investigation, microbiological and parasitological investigations of the raw and drinking-water in Rengsdorf were conducted, along with a field investigation. They verified the suspicion, as *Giardia* cysts and *E. coli* were detected in raw and drinking-water samples. Additional field investigation (stored in the GIS as a shape and by means of hot-links) confirmed with high probability several environmental risk factors very close to a spring as having been responsible for contaminating raw water, such as a deer enclosure or the outlet of combined sewage overflow. However, it was impossible to positively identify the contamination source of the spring retrospectively.

The Rengsdorf case has revitalized discussion of water-related diseases in Germany. Politicians, authorities, the waterworks organization and researchers have been very interested in the casuistry. This GIS-supported epidemiological investigation has impressively demonstrated that waterborne outbreaks are not impossible in Germany and may occur more often than people realize.

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