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Bucharest, 23–25 November 2010
Item 5 (b) of the provisional agenda
Work of the Task Forces: surveillance and early-warning systems, contingency plans and response capacities

Draft technical guidance for setting up, implementing and assessing surveillance systems of water-related disease*

Submitted by the Chair of the Task Force on Surveillance

Summary

The present document includes, in an annex, draft technical guidance on water-related disease surveillance which is being submitted to the second session of the Meeting of the Parties to the Protocol on Water and Health for consideration and adoption. The technical guidance is intended to assist the Parties 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 The draft guidance reviews the main threats to health related to water services, recalls basic concepts of epidemiology and disease surveillance and provides guidance on data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).

* This document was submitted for publication without formal editing.

Background and proposed action by the Meeting of the Parties

1. This document was prepared pursuant to the decision of the first session of the Meeting of the Parties to the Protocol on Water and Health entrusting the Task Force on Surveillance, led by the Government of Italy, with the preparation of guidelines for setting up, implementing and assessing surveillance systems for water-related diseases (programme of work for 2007–2009, ECE/MP.WH/2/Add.5–EUR/06/5069385/1/Add.5, paras. 12–18).

2. Following the request from the Meeting of the Parties, the Task Force identified the need for the preparation of the following guidance material:

(a) Technical guidance on setting up, implementing and assessing surveillance systems of water-related disease (contained in the annex to this document); and

(b) Policy guidance on setting up, implementing and assessing a surveillance system on water-related disease (ECE/MP.WH/2010/L.2–EUDHP/1003944/4.2/1/4).

3. The draft technical guidance for setting up, implementing and assessing surveillance systems of water-related disease is the product of a long participatory process through which the draft was consulted and commented on at the second and third meetings of the Task Force on Surveillance (held, respectively, on 28–29 April 2009 in Rome and on 11–12 February 2010 in Durres, Albania) and at the second and third meetings of the Working Group on Water and Health (2–3 July 2009 and 27–28 May 2010, Geneva). The drafting process was chaired by Italy and supported by the World Health Organization Regional Office for Europe (WHO/EURO).

4. The Meeting of the Parties may wish:

(a) To adopt the technical guidance for setting up, implementing and assessing surveillance systems of water-related disease, as contained in the annex to this document, recognizing its strategic importance for the implementation of the Protocol, in particular article 8, and to request the joint secretariat to print, publish and distribute it widely through different means, as appropriate;

(b) To invite Parties and non-Parties to the Protocol to implement the technical guidance in the framework of their activities on water-related disease surveillance;

(c) To request the Working Group on Water and Health and the Task Force on Surveillance to promote the implementation of the technical guidance, including through the development of capacity-building and awareness-raising activities;

(d) To review, at its third session, experience with the implementation of the technical guidance and decide, if need be, to update it in the light of practice and lessons learned;

(e) To thank Italy for its leadership in the development of the technical guidance, and those Parties and non-Parties that strongly supported it;

(f) To express its appreciation to the Chair of the Task Force on Surveillance, the WHO/EURO secretariat and all the experts who contributed to the development of this guidance document.

Annex

Draft technical guidance for setting up, implementing and assessing surveillance systems of water-related disease

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Preface

1. The importance of water-related diseases on human health has been recognized as a major threat to sustainable human development in a number of international forums, including the Millennium Development Goals, the World Summit on Sustainable Development, the 3rd World Water Forum, the Environment for Europe Conference, the Dushanbe Freshwater Forum and others. Within the European region, the majority of WHO Member States committed themselves to a co-ordinated 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.

2. 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 taken to focus on two groups of water-related diseases: those with a high epidemic potential including cholera, enterohaemorrhagic E. 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.

3. In line with the holistic approach between water services and health, the present guidance document 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.

4. The current document 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 Tallin Charter on Health Systems (Tallin, Estonia, 25 – 27 June 2008) particularly the ensurance of “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 2003 guidance concerning the use of integrated risk assessment/ risk management approach, termed a water safety plan, as a basis for the continued provision of safe water

5. 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.

6. The work was done by the Task Force on Water-related Disease Surveillance, chaired by the Italian Higher Institute of Public Health and supported by the joint Secretariat.

Acknowledgements

7. This technical report is the result of a compilation of official data and reports published by official sources. The preparation of this guide would not have been possible without the support of the WHO Collaborating Centre for Health Promoting Water Management and Risk Communication at the University of Bonn, Germany, in particular its efforts during the WHO public health initiative on surveillance of water-related diseases in central Asia and the subsequent drafting work. The following contributors participated:

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8. Finally, the work could not have been possible without the financial support of the WHO Division for Country Support.

9. K. Pond at the Robens Centre for Public and Environmental Health, University of Surrey provided English-language editing and Ana Isabel Guerreiro provided technical editing. Andrea Rechenburg of the WHO Collaborating Centre for Health Promoting Water Management and Risk Communication provided invaluable bibliographic support, as did Bruce Gordon of WHO Geneva.

10. Several scientists provided critical review and made valuable comments. At the risk for forgetting many, the following need special mention: Dr Sébastien Fierens of the

Scientific Institute of Public Health of the Belgian federal government, Belgium, Dr Susanne Herbst Dr Andrea Rechenburg, Yvonne Walz and Prof Thomas Kistemann of the WHO Collaborating Centre for Health Promoting Water Management and Risk Communication, University of Bonn, Germany; Dr Frantisek Kozisek of the National Institute of Public Health, Czech Republic; Dr Mihaly Kadar of the National Institute of Environmental Health, Hungary and Dr Enzo Funari of the Higher Institute of Public Health, Italy.

Acronyms

AIDS	Acquired Immuno-deficiency Syndrome
CCP	Critical control point
CDC	Centres for Disease Control and Prevention
CTC	Concentration-Time-Concept
CDC	Centres for Disease Control and Prevention (of the USA)
EC	European Commission
EHEC	Enterohaemorrhagic E. coli
EIEC	Entroinvasive E. Coli
ELISA	Enzyme-linked immunosorbent assay
EOHSP	European Observatory on Health System and Policy
EPEC	Enteropathogenic E. coli
ETEC	Enterotoxic E. Coli
GDWQ	Guidelines for drinking-water quality
GIS	Geographic Information System
GP	General Practitioner
HACCP	Hazard analysis and critical control points
GV	Guideline value
HAV	Hepatitis A virus
HEV	Hepatitis E virus
HuCVs	Human calicivirus
HUS	Haemolytic – uremic syndrome
IARC	International Association for Research on Cancer
OD	Odds ratio
OMT	Outbreak management team
MMWR	Morbidity and Mortality Weekly Report
NOEL	No observed effect level
NHMRC	National Health and Medical Research

	Countil
NTU	Nephelometric turbidity units
SRSV	Small round-structured viruses
TDI	Tolerable daily intake
VHH	Volatile halogenated hydrocarbons
WBD	Waterborne disease
WRD	Water-related disease
WSP	Water safety plan
WSS	Water supply service

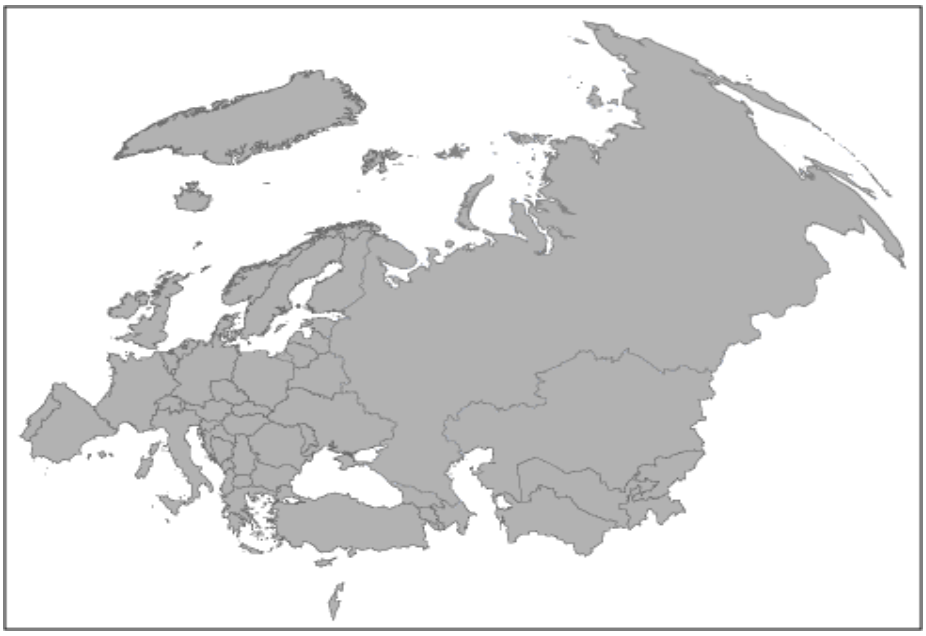
I. Introduction

Lead Author: Martin Exner

1. 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).

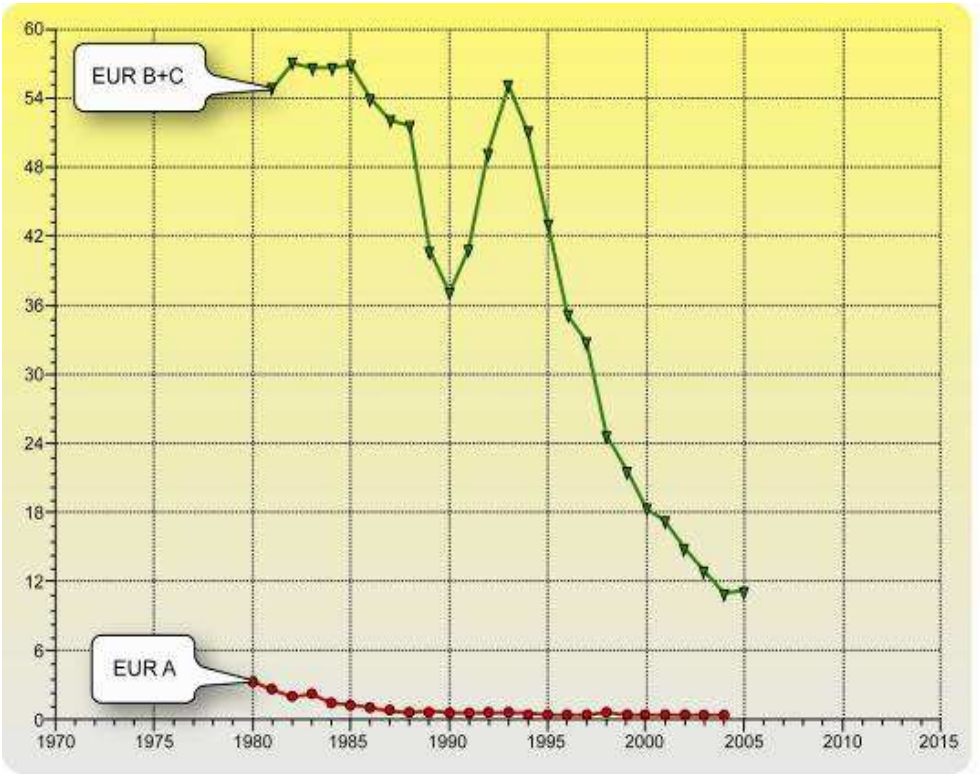
2. Gastrointestinal infections are one of the principal causes of morbidity and mortality among children. For children, under 5 years of age, in developing countries, it is estimated that a median of 3.2 episodes of diarrhoea occur per child per year (Kosek M et al, 2003). Estimates of mortality revealed that 4.9 children per 1,000 die each year as a result of diarrhoeal illnesses in the first 5 years of life. In the WHO European Region (**Figure 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]. **Figure 2** below shows the standard death rate from diarrhoeal diseases in the below five year age group in the EUR-A and the EUR-B+C region respectively (green) and the EUR-B+C region respectively (red).

Figure 1 WHO European Region



[1] The WHO defines its subregions as follows:
EUR-A: Andorra, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxemburg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom.
EUR-B: Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Poland, Romania, Serbia and Montenegro, 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

Figure 2 SDR diarrhoeal disease below 5 years of age (Source: WHO Health for all)



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

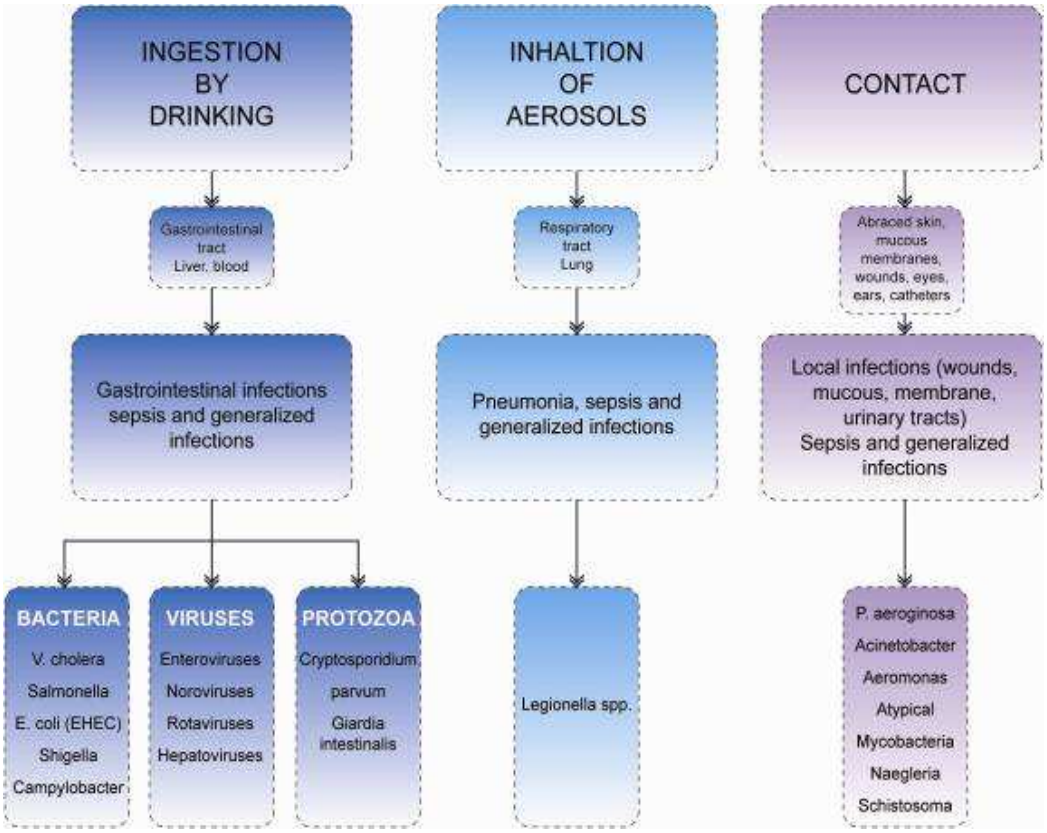
4. Waterborne diseases with high potential for developing into epidemics, such as cholera, were brought under control through the work of John Snow (1854), Filippo Pacini (1854) and Robert Koch (1883) and others. Diseases such as hepatitis A, typhoid and paratyphoid, bacillary dysentery and infections by E. coli are still important health concerns in many countries of the region while endemic or imported cholera cases demand constant vigilance.

5. Emerging pathogens in drinking-water have become increasingly important during the last 20 years. The newly-identified and re-emerging water-related pathogens include *Campylobacter* spp., human-pathogenic enterohaemorrhagic *E. coli*-strains (EHEC), *Yersinia enterocolitica*, enteric viruses such as rotavirus and noroviruses, 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 in the last twenty years.

6. 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. A typical example of the use aerosol as exposure route is infection by Legionella spp. An overview of transmission pathways for some pathogens is given in

Figure 3. It is important to distinguish between infections transmitted via ingestion and those transmitted via inhalation.

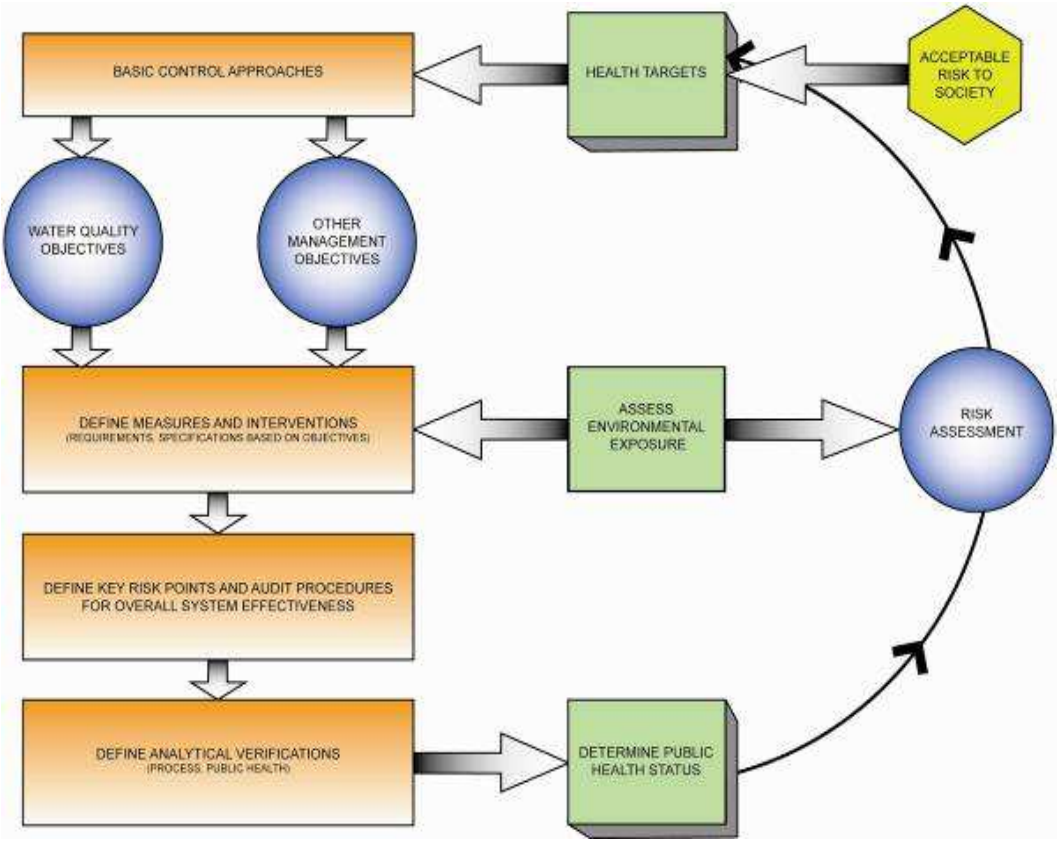
Figure 3 Transmission pathways (WHO, 2004)



7. Public health systems throughout the European region are therefore faced with important challenges: they are in 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 especially great in the eastern part of the region where strengthening of primary health is a priority.

8. 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 link between the two is found in the Framework for Safe Drinking-water as summarized in **Figure 4**.

Figure 4 Expanded health framework (Bartram et al, 2001)



9. Primary health care promotes a holistic approach to health that makes prevention equally 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 the understanding by primary health services of the approach followed by water utilities in their efforts to ensure safe water, and by the water utilities and other stakeholders in the techniques and approaches followed by (primary) health care services.

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

11. The second section introduces the different risk factors that affect drinking-water quality from resource over treatment and distribution to the ultimate consumer and on 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 as recommended in the 3rd edition of the WHO drinking-water quality guidelines are recalled as a holistic framework for risk assessment risk management. This section should allow health services to gain a fundamental insight in 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 not statutorily defined) and to interact in a meaningful way with water utilities and other stakeholders, particularly those tasked with environmental management.

12. The third section of the guidelines then focus on the specific management of health concerns of surveillance of water-related diseases. The surveillance of drinking-waterborne

infectious diseases basically distinguishes from conventional surveillance systems by the integration of data from the drinking-water supply in the surveillance of infectious diseases. The surveillance authority must have the power to determine 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 diseases outbreaks within the service area. The surveillance of drinking-waterborne infectious diseases is distinguished from conventional surveillance systems by the integration of data from the drinking-water supply in the surveillance of infectious diseases. The surveillance authority must have the power to determine whether a water supplier is fulfilling its obligations thereby again strengthening the multi-sectoral approach (WHO, 2006).

13. In order to promote a multi-sectoral 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 data and information management. Guidance will also be provided on evaluating existing surveillance systems and on how such systems could be improved.

14. Primary health care systems in the European region face different challenges and have different capacities. These differences have been taken into account as far as possible, and more detailed literature is identified in Annex. It is hoped that this guidance document will assist all stakeholders, policy makers, health professionals, water utility managers and other stakeholders in developing a common course of action to reduce the level of water related diseases in the 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.

II. Health Risks From Microbial Pathogens

Lead author: Friederike Dangendorf, Dirk Schoenen

A. Definitions

Legal definitions

15. 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.

16. “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”.

17. “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”

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

19. “ ‘Collective system’ means:

A system for the supply of drinking-water to a number of households or undertakings and/or

[…]

20. " '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"

B. Epidemiological definitions

21. Water-associated diseases are classified into five main groups (after Bradley 1974):

(a) Waterborne diseases: This group of infections is 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.

(b) Water-washed (water-hygiene) diseases: These illnesses 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.

(c) Water-scarce diseases: These illnesses 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 are spread by the faecal-oral route. In particular, eye (trachoma) and skin infections (scabies), diarrhoeal diseases occur under those conditions.

(d) Water-based diseases: Those diseases are caused by organisms, in particular by different species of worms that spend a part of their life cycle in different habitats. They spent one development cycle in aquatic molluscs, another one as fully-grown parasites in other animal or human hosts. Because stagnating surface waters, like reservoirs, are the preferred habitat of parasitic worms, the occurrence of water-based diseases like dracunculiasis and schistosomiasis can be heavily influenced by anthropogenic activities.

(e) Vector-borne diseases: These infections are caused by bites of insects breeding in water. Insect-vectors such as mosquitoes transmit diseases like malaria, chikungunya and other diseases.

Table 1 Waterborne pathogens and their significance in water supplies (WHO, 2004)

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
Escherichia 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	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	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
Rotavirus	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 Guidelines for drinking-water quality, 3rd ed., pp 122

22. In order to evaluate the health risks of water-associated human-pathogenic micro-organisms 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 important water-related infectious diseases.

C. Diarrhoeal Diseases

23. Diarrhoea occurs world-wide and causes 4% of all deaths and 5% of health loss due to disability[2]. Diarrhoea is the passage 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 European region the cause of diarrhoeal 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.

24. Diarrhoea due to infection may last a few days, or several weeks, as in 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 amongst children, especially in developing countries.

25. 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.

26. Diarrhoea is also associated with other infections such as malaria. Chemical irritation (e.g. magnesium sulphate or copper) of the gut or non-infectious bowel disease can also result in diarrhoea.

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

28. 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.

D. Bacteriological Pathogens

A brief historical note

29. The first hygienic-microbiological requirements for drinking-water were set by Fraenkel (1887) on the basis of colony count studies in wells in the Berlin area. His investigations revealed colony count in the groundwater of 0/ml, exceptionally 10/ml. This groundwater did not present any infection risk. Fraenkel 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

[2] WHO Factsheet at http://www.who.int/water_sanitation_health/diseases/diarrhoea/en/ accessed 11 November 2008

dead and 16956 diseased persons (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 available process in order to improve the water quality.

30. 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 at 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, has to be appropriately treated, and (ii) the colony count after the treatment should not exceed 100/ml. The colony count below 10/ml, which was required by Fraenkel (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 above given requirements by Robert Koch were published in 1894, and became a legal rule in Germany in 1899.

31. 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 a too restrictive 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.

Cholera

32. Faecal contamination of drinking-water is still the most important 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).

33. 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 Vibrio 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 2 years the cholera spread from Peru to Mexico. These cholera epidemics show the potential for modern societies to disseminate an epidemic pathogen globally.

34. Travel-associated, imported cases were reported in the United States, Japan and Europe (Chin, J 2000). Also in the European region, cholera cases are frequently being reported from all countries; importation by returning tourists is the main cause.

35. The organism enters the gut via ingestion, colonises 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.

36. 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 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.

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

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

Typhoid fever

39. The causative agent of typhoid fever is Salmonella typhi, which is an enteropathogenic organism amongst 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 S I and Pegues D, 2000; Chin J, 2000).

40. Symptoms of infection can be mild or severe and include sustained high fever (as high as 39°C - 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 J, 2000).

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

42. 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 J, 2000).

43. S. typhi has been isolated from water and sewage. The persistence in water supplies is moderate; the survival time of salmonellae 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).

44. 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 approximately 2000 cases registered during a 2-week period. The outbreak occurred due to the contamination of the municipal water supply (MMWR, 1998).

45. Children in endemic areas are at highest risk for S. typhii 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.

Shigella

46. Shigellosis or bacillary dysentery is an acute bacterial disease characterised by bloody diarrhoea. Shigella spp. are small gram-negative bacteria that belong to the family of Enterobacteriaceae. 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 between 4 to 7 days. The incubation time is between 1 to 7 days for all Shigella spp. infectious diseases (Dupont H L, 2000; Gleeson C and Gray N, 1997).

47. The severity of the infections depends on the species and of 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 hemolytic-uremic-syndrome (HUS) (Chin J, 2000). S. sonnei causes a milder variant.

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

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

50. 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. So far the disease was not known to be often spread by waterborne transmission, but waterborne outbreaks are occurring more frequently due to faecally contaminated drinking-water. Epidemics of waterborne shigellosis generally appear in the context of wells contaminated with faecal material or sewage discharge close to water intakes or bathing areas. Chlorination of water is an effective prevention measure [WHO, 2004; Dupont HL, 2000).

Campylobacter

51. 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 C. coli are of human pathogenic importance.

52. 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.

53. 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, and in pets including cats and dogs. The animals themselves may not have symptoms. Therefore, raw milk, undercooked poultry and beef are important sources of infection. Excretion of Campylobacter by domestic and wild animals and sewage discharge may lead to contamination of surface water (Medema, 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, 2000).

54. 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, 1998). The survival of Campylobacter during drinking-water purification was examined by Feuerpfeil et al. (1997). Even after generally effective purification technologies (flocculation, filtration) Campylobacter could still be detected. Campylobacter are sensitive to chlorine and are in general inactivated by disinfection during drinking-water purification (Lund, 1996).

55. 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.

Pathogenic Escherischia coli strains

56. *Escherichia coli* 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 C and Gray N, 1997).

57. 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 PS and Griffin PM, 1998).

58. The enterohemorrhagic E. coli 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 a haemolytical uraemic syndrome (HUS) was established. The HUS complex of symptoms includes, among others, bloody diarrhoea and acute renal failure, in particular in children.

59. The infectious dose is low with about bout 102 EHEC bacteria. In about 80% of the illnesses watery diarrhoea and in 20% additionally symptoms of HUS occur [Mead P.S. and Griffin P.M., 1998; Doyle M.P., 1990).

60. 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 (Söderströmet 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.

61. 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. There is a high risk to fall ill for infants and old people (Doyle, M.P. 1990).

62. EHEC infections have been reported from more than 30 countries worldwide. In some countries they are nowadays already regarded as the third most frequent cause of bacterial intestinal infections after salmonella and campylobacter. In Canada, the USA and some areas of Scotland, the annual incidence rates amount to 8 per 100,000 inhabitants (Mead, P.S. and Griffin, P.M., 1998).

Legionellosis

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

64. Legionella species can cause two different types of disease: (1) Legionnaires' disease which is a pneumonia and (2) Pontiac fever, a milder, flu-like form.

65. So far 50 species with about 70 serogroups have been identified in the Legionnellaceae family of which Legionella pneumophila is responsible for 90 percent 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).

66. Legionellosis is not characterised by distinct symptoms, but non-specific signs such as anorexia, malaise, headache, and rapidly raising fever. Cough, abdominal pain and diarrhoea often occur. The incubation period lasts between 2-10 days, mostly 5 - 6 days and rarely up to 20 days. Pontiac fever is a flu-like Legionellosis without pneumonic illness (Bartram J., 2007; Yu, V.L., 2000; Chin J, 2000).

67. 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 from France (Nguyen et al. 2006). Transmission can also be categorised according to the place of infection into community-acquired pneumonia and nosocomial infections (Bartram J, 2007). Person-to-person transmission does not occur.

68. 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 different industrial settings especially when such water systems are not properly maintained. Also water systems in domestic houses may cause infection.

69. 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 50ºC (Szewzyk U, 2000). Different biocides, UV irradiation and point-of-use filtration are other methods used against legionella.

E. Viral Diseases – Viral Hepatitis A

70. 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.

71. HAV is relatively stable in the environment after it is excreted with the faeces. The infectivity retains several weeks at room temperature. It is stable after incubation at 56°C but boiling destroys the virus after 5 minutes.

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

73. 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 101 viruses (Feinstone S.M. and Gust I., 2000).

74. 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. The HAV comprises only a single serotype. People, who were infected, acquire a life-long immunity with strains from any part of the world.

75. 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 is 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 the HAV (Feinstone S.M. and Gust I.D., 2000).

76. 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. The virus can persist in waste water, seawater, soils, surface waters and water supplies for days to months. It is also quite resistant to free chlorine, particularly when the water contains organic matter (WHO, 2003; Feinstone S.M. and Gust I.D., 2000).

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

78. 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) have 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, rotaviruses also have high health significance and hih relative infectivity, moderate resistance to chlorine and high relative infectivity (Guillot, 2010)

79. However, diagnosis of viruses, using such relatively advanced techniques as electron microscopy and ELISA, is still often beyond the routine capabilities of surveillance systems.

F. Protozoan Diseases

Cryptosporidiosis

80. Cryptosporidium spp. are protozoan parasites. Several different species are recognised of which Cryptosporidium parvum is primarily responsible for clinical illnesses.

81. 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 could also be observed. It is possible that the disease can occur without the parasite detected. Even when the parasite remains undetected, the infected human being 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 C.N., 1999).

82. 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 etc.) 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.

83. The infectious dose is recognised 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 recognised to be very different (Gibson et al. 1998).

84. The infectious oocysts come from the faeces of infected human beings and warm-blooded animals. Approximately 40 species of mammals are known as a reservoir of pathogens, amongst which are domestic (cattle, pigs, dogs, cats) and wild animals. Particularly calves play an important role as an animal reservoirs of pathogens. They can excrete 7 x 106 oocysts per gram faeces.

85. According to studies, the pathogens can be found in approx. 65 - 97% of the surface waters. Also high numbers were found in surface water receiving untreated or treated wastewater, while the parasites occur much less frequently in groundwater. Significantly high numbers of Cryptosporidium parvum are found during extreme rain falls (Kistemann T., 1998; Karanis P. and Seitz, H.M., 1996; Juranek D.D., 1995; Teunis P.F., 1997).

86. 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 characterised by a high tenacity, a low infection dose and a high resistance to disinfectants (Exner, M. 1996).

87. The importance 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 UK and the USA. Until now outbreaks were frequently reported with partly very high numbers of illnesses (Hunter P., 1997).

Giardiasis

88. Giardia spp. are flagellate protozoan parasites of the genus Giardia. Giardia lamblia (also called G. duodenalis or G. intestinalis) is believed to be the most frequent cause of diarrhoea disease and the most frequent intestinal parasite in humans worldwide. Clinical symptoms after infection with cysts includes asymptomatic cyst passages, acute, usually self-limited diarrhoeas, and chronic syndromes of diarrhoea. Further symptoms may be abdominal cramps, malabsorption and weight loss.

89. The infectious dose is very low. The incubation period is usually about one to two weeks. Generally, the acute illness heals after 10 days, but can last for 4-12 weeks. (Hunter P, 1997).

90. In developing countries Giardia is one of the first enteric pathogens to infect children with prevalence of 15-20 percent occurring in children less than 10 years old.

91. 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, storm water discharge or droppings of infected animals. The cysts are able to survive in the

aquatic environment for long periods of time without losing their infectiousness (Gibson, C.J., 1998; Gleeson, C. and Gray N., 1997).

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

93. In a number of studies it was shown that 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 T.B., 1998; Kistemann T., 2002; Ong C., 1996; Payment P., 2000; Robertson LJ, 2001).

G. Diseases of High Local Importance

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

Helminthic diseases

95. Although not retained 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. They 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.

96. 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 and malnutrition.

97. 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 A.A.F, 2000). A problem is the use of inadequately treated wastewater in irrigation and faecal sludge in soil fertilisation. This practice is often associated with an elevated prevalence of intestinal helminth infections and diarrhoeal diseases in workers, farmers and consumers (Mara D. and Cairncross S., 1989).

98. 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 A.A.F, 2000). 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 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 A.A.F., 2000).

99. 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 A.A.F., 2000).

100. 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 can also show abdominal discomfort (King C., 2000).

101. 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.

Cyanobacteria in drinking-water

102. Cyanobacteria are ubiquitous procariotic microorganisms that occurr especially 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 et al., 2005) into:

(a) hepatotoxins (microcystins and nodularines);

(b) neurotoxins (saxitoxins, anatoxin-a, homoanatoxin-a, anatoxin-a(s));

(c) cytotoxins (cylindrospermopsin);

(d) irritants and gastrointestinal toxins: aplysiatoxin, debromoaplysiatoxin, lyngbyatoxin (produced by marine cyanobacteria);

(e) lipopolisaccharidic (LPS) endotoxins;

(f) other cyanotoxins whose toxicological or ecotoxicological profile is still only partially known, as microviridin J and β-N-methylamino-L-alanine (BMAA).

103. 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, 2007). In favourable conditions for their growth (i.e nutrient availability, temperature, light), 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 microcystins production 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, microcystin concentrations in water bodies are influenced by some environmental parameters, like nutrient availability, temperature, pH, light, etc. (Sivonen and Jones, 1999). Cyanotoxins may be localized both within the cyanobacterial cells and dissolved in the water, depending on both the nature of the toxin and the growth stage (Chorus and 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/L have been reported in surface waters for microcystins

(MCs), cylindrospermin (CYN) and anatoxin-a(s), respectively (Sivonen and 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 and Chorus, 2007) but on the contrary, higher CYN levels are reported in dissolved form than within cells (Rücker et al., 2007). Scarce information is available on the proportion of dissolved form with respect 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 and Orr, 1994).

Risk associated to cyanotoxin exposure

104. Humans may be exposed to cyanotoxins through several routes: the oral one is by far the most important, occurring by 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, sport and professional activities (i.e. fishery) in infested waters, or to the domestic use of cyanotoxin-containing water, as in the case of 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 route of exposure to cyanotoxins has been assessed and reviewed in several publications (Chorus and Bartram, 1999; Funari and Testai, 2008; van Apeldoorn et al., 2007; Ibeling and Chorus, 2007).

Episodes of human intoxication attributed to drinking water contamination by cyanobacteria

105. Human exposure to cyanotoxins has been associated with several episodes of diseases. The most important one has been reported in Brazil, where 56 patients out of 130 in hemodialysis treatment died after receiving water, which subsequently turned out to be contaminated by MCs (Jochimsen et al., 1998, Azevedo et al., 2002). Indeed, the parental route of exposure considerably increases the internal dose of toxins, directly entering the bloodstream; therefore, it represents an extremely relevant route of exposure, with respect to the risk evaluation for human health (Funari and Testai, 2008). Taking into account the particular exposure together with the pathological conditions of patients, the water used for hemodialysis 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 exposures coincides with the use of unfiltered/ untreated surface waters. Depending on cyanotoxin levels in drinking water, both acute/short-term and chronic effects in humans may occur (Chorus and Bartram, 1999; Funari and Testai, 2008). Acute/short-term effects are associated either with the consumption of raw waters infested by cyanobacteria or with high cyanotoxin dissolved concentrations 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.

106. Many episodes of human intoxications have been reported so far, some of which are indicated in the following **Table 2**.

Table 2 Episodes of human intoxication from cyanobacteria

Etiological agent	*Place*	*Outbreak*	*Effects*	*Reference*
Blooms of Anabaena & Microcystis spp	Brazil	2000 cases of gastro-enteritis and 88 deaths in a period of 42 days		Teixera et al, 1993
Treatment with copper sulphate used of a Cylindrospermopsis raciborskii bloom	Australia	140 children and 10 adults required hospitalization for liver and kidney damage within a week	Total recovery of all patients	Byth, 1980 Hawkins and Griffiths, 1993
Different cyanobacteria blooms	Australia, Austria	Gastro-enteritis and liver damages	???	Botes et al, 1985 Fawell at al, 1993 Zilberg, 1996 El Saadi et al, 1995 Falconer. 1989, 1994

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

108. For poor countries, recommendations can be made not to use surface waters infested by cyanobacterial blooms without filtering to remove cells (i.e. 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 and 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 in demonstrating that cyanotoxin exposure is the actual cause of the observed effects (i.e. hepatic and colorectal tumours), but gave just an indication that they are simply among the most likely one. The poor quality of the available epidemiological data, due to the study design and/or to the presence of strong confounding factors, has lead the 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 MC. 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 to 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(A)EL=40 µg/kg bw/day (Fawell et al., 1994). The choice of this NO(A)EL 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 and 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 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/L for MC-LR in drinking water, considering a daily consumption of 2L 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).

109. Specific GV 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 default value for the total concentration of all MC variants has been suggested (Chorus and Bartram, 1999). WHO has not derived GV for any other cyanotoxins due to the lack of adequate toxicological data; however some considerations leading to provisional risk assessment can be done (Funari and Testai, 2008). Regarding anatoxin-a, an actual NO(A)EL has not been identified, since no effects were observed at the highest tested doses in a sub-chronic study (510 µg/kg bw/day) (Astrachan et al., 1980; Fawell et al., 1999). However, by using the highest value as a NO(A)EL, a provisional TDI= 0.51 µg/kg bw/day can be derived by applying an UF =1000, as for MC-LR, leading to a GV 1.2 µg/L (Duy et al., 2000). Based on these considerations, it has been proposed that a GV=1 µg/L for the total concentrations of anatoxins in drinking water could provide an adequate margin of safety to protect human health of potentially exposed populations (Fawell et al., 1999). The limit = 6 µg/l established by New Zealand for total anatoxins content in drinking water and the one adopted by Australia equal to 3µg/l for anatoxin-a (Chorus, 2005) are in agreement with these consideration.

110. Concerning CYN, starting from the subchronic NO(A)EL= 30 µg/kg bw/day (Humpage and Falconer, 2003) and dividing it for an UF =1000, as previously done 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 life span. Since CYN metabolites have been suspected of genotoxic potential, this TDI should be updated, once more data will be available. A GV= 0.81 µg/L (rounded to 1 µg/L) can be derived (Humpage and Falconer, 2003; Codd et al., 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 (LOAEL= 500 µg/kg bw); however, some i.p. 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).

111. Considering that MC-LR is 30-100 fold 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 = 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 i.p. studies is very steep, special attention should be exercised, 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, also considering that the evaluation has been based on data on MC-LR, which is among the most toxic variants. Although no evidence of human intoxication from drinking water contaminated by STX has been reported so far, they could also represent a source of concern for acute effects due to their occurrence in freshwaters up to 2700 µg/L (Batorèu et al., 2005). For this reason, some countries proposed GV or adopted mandatory regulatory requirements: a guideline concentration of 3 µg/L STX equivalents in drinking water has been adopted in Australia (NHMRC, 2001) and 1µg/L in New Zealand (Orr et al., 2004). Considering a daily intake of 2L drinking water, these regulatory limits correspond to 2-6 µg STX /person,which is only a small fraction of the limit established by the European Union (EU) for bivalve mollusks (80 µg STX eq/100 g of meat, see below), in order to protect consumers from acute effects (EU Directive

91/492/EEC of 15 July 1991 laying down the health conditions for the production and the placing on the market of live bivalve molluscs).

H. Monitoring

112. The discovery of pathogenic organisms in the second half of the 19th century quickly clear 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 being also transmitted by water. **Table 2** informs on water-transmissible pathogens that can occur in aquatic resources. This 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 recognized as being transmitted by drinking-water. The following period witnessed the recognition of many other pathogens as being also transmitted by water. **Table 3** below lists pathogens that can occur in source water in health-endangering concentrations (Schoenen, D, 1996).

Table 3 Water-transmissible pathogens

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

113. In the following text, no attention is paid to pathogens which are found in water in amounts insignificant to health, but which can reproduce in the water-distribution networks (see **Table 4**); the minimization of the health risk posed by these pathogens requires special preventive measures.

Table 4 Pathogens that can reproduce in the water distribution system (Adapted from: Ainsworth R, 2004,p 5-8)

Pathogens that can reproduce in the water distribution system
Pseudomonas aeruginosa
Legionella spp.
Aeromonas hydrophila
Flavobacterium spp.
Acinetobacter spp.
Amoebae (Acanthamoebae, Naeglerias)
Atypical mycobacteria

114. With the exception of leptospira, the pathogens listed in **Table 3** Water-transmissible pathogens are transmitted by the faecal/oral route, i.e. these pathogens are excreted from the human or animal digestive tract and are ingested orally. The pathogens can be transmitted directly either from person to person, or from animal to person, or the transmission can take place via foods, drinking-water or other objects, since they are highly resistant to environmental damage. In contrast, leptospira arises as a rule via a contact of the skin with contaminated objects or, exceptionally, also via ingestion of contaminated water.

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

III. Health risks from chemicals

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A. Basic chemical considerations

116. 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:

(a) Naturally occurring chemicals (for example carbonate, calcium, magnesium, chloride, sodium, potassium, but also arsenic, fluoride and radio-active substances)

(b) Chemicals from drinking-water treatment and reaction products (aluminum, chlorine, phosphate, trihalomethanes)

(c) Chemicals which enter the drinking-water through contact with materials of the drinking-water distribution network (iron, lead, copper)

(d) Chemicals which enter the drinking-water resource through anthropogenic activities (pesticides, antibiotics, estrogenic substances)

Organoleptic assessment

117. 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 instinct of smell may provide a warning mechanism for the presence of toxic substances or microbiological pollution, e.g. by gas producing pathogens. Smell can be categorised as metallic, earthy, aromatic, putrid etc. 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 can not be regarded as the sole and sufficient assessment method.

118. 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 a microbiological contamination. Water quality assessment using appearance might warn the human being, as the smell does. Chemically reduced ground water can contain iron (II) and manganese (II) 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).

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

Undesired effect in drinking-water preparation

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

(a) the choice of the drinking-water resource

(b) the water treatment measures

(c) the choice of the materials of the drinking-water distribution system

121. For geological reasons, the drinking-water resource can contain undesirable substances as for example arsenic. Other contamination arises mostly from anthropogenic origin (nitrate, lead etc.).

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

(a) industrial products (for example heavy metals, solvents)

(b) products from extensive agriculture (for example pesticides, nitrates, nitrites, fattening aids such as antibiotics and estrogenic substances)

(c) products from accidents (for example oil, radioactive substances)

123. 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 step of the process, the materials used are not to release substances in toxic concentrations.

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

125. 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.

Basis for calculating the guideline values

126. Chemicals in drinking-water can have acute and chronic effects on human beings. WHO has established guidelines for several chemicals in drinking waters in order to protect human health from long-term exposures.

127. The threshold values are based on a tolerable daily intake (TDI):

TDI = (NOAEL or LOAEL) / UF

Whereby NOAEL = no-observed-adverse-effect level LOAEL = lowest observed adverse effect level UF = uncertainty factor

128. For the chemicals in the drinking-water the Guideline Value (GV) is valid:

GV = (TDI x BW x P) / C

Whereby BW = body weight P = fraction of the TDI allocated to drinking-water

C = daily drinking-water consumption

B. Selected Parameters

129. In the following section, some chemicals are described which have toxic or possibly toxic effects on human beings. A comprehensive review of guideline values (GV) may be found in (WHO, 2004) while detailed descriptions on 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].

Inorganics

Arsenic

130. 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.

131. The provisional GV is 0.01 mg/l .

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

Fluoride

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

134. The GV is 1.5 mg/l. Where the intake from other sources are 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.

135. A concentration of 1 mg/l should be achievable using activated alumina (not a conventional treatment process, but relatively simple to install filters. However, in areas

[3] The index is available from URL http://www.who.int/water_sanitation_health/dwq/chemicals/en/index.html accessed 17 November 2008

with high natural fluoride levels in drinking-water, the GV may be difficult to achieve, in some circumstances, with the treatment technologies available.

Cadmium

136. Occurrence of cadmium in drinking-water sources is mainly from 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.

137. The GV for cadmium is 0.003 mg/l. Treatment achievability is 0.002 mg/l using coagulation or precipitation softening.

Aluminium

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

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

140. 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/l, and 0.1 mg/l should be achievable in well-run large treatment works.

Nitrates and nitrites

141. Nitrates can be detected in nearly all waters in low quantities. High concentrations can be caused by leachates from saltpetre stocks, agricultural fertilisers 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.

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

143. The GV / provisional GV for nitrite stands at 3 mg/l for methaemoglobinaemia in infants (short-term exposure), 0.2 mg/l (provisional) (long-term exposure)

144. 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.

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

Lead

146. 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 case of a longer stagnation period. 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 minimise plumbosolvency.

147. The GV for lead is 0.01 mg/l.

Pesticides

148. 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.

149. Indeed, after agricultural application, pesticides can leach into ground water or be transported to surface water through run off or drainage. Often a very small fraction, if any, of the amount applied reach 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, hence they are endowed of a scarce mobility.

150. The environmental fate of pesticides is controlled by their physico-chemical properties (Gustafson, 1988; Singh et al., 2002; Dagnac et al., 2002; Turusov et al., 2002). Beyond their intrinsic properties, other factors play a role in the contamination process of water bodies, like the type of cultivation/treatment, the rate and frequency of application and total use, the nature of soil (texture and organic matter content), the hydro geological features and climate conditions (Giuliano, 1995; FOCUS, 2000; Worrall and Kolpin, 2004).

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

152. A high number of monitoring studies are available on this issue (Senseman et al., 1997; Garmouma et al., 1997; Thurman et al., 1998; Funari et al., 1995, 1998; Kreuger 1998; Spliid and Koppen, 1998; EEA 1999; Tuxen et al., 2000; Scribner et al., 2000; Younes, 2000; Barbash et al., 2001; Van Maanen et al., 2001; Squillace et al., 2002; Cerejeira et al., 2003; Papadopoulou et al., 2004; Lapworth et al., 2006; Comoretto et al., 2007). 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; atrazine, desethylatrazine, bentazone, diuron, MCPA, metolachlor, molinate, oxadiazon, terbuthylatrazine and desethylterbuthylatrazine in surface water.

153. Lipophilic compounds like dioxins and DDT strongly interact with soil particles, are substantially immobile and are not considered water contaminants.

Disinfection by-products (DBPs)

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

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

(a) Changing process conditions (including removal of precursor compounds prior to application).

(b) Using a different chemical disinfectant with a lower propensity to produce by-products with the source water

(c) Using non-chemical disinfection and/or

(d) Removing DBPs prior to distribution.

156. 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.

Radio-activity

157. WHO calculates guidance levels for radio-nuclides in drinking-water by the following equation:

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

Where:

GL = guidance level of radionucleide in drinking-water (Bq/l)

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

158. Guidance levels for selected radionucleides in drinking-water are as follows

^{210}Pb 0.1 Bq/l

^{224}Ra, ^{225}Ra and ^{226}Ra 1 Bq/l

^{228}Ra 0.1 Bq/l

^{210}Po 0.1 Bq/l

^{235}U and ^{236}U 1 Bq/l

^{237}U 100 Bq/l

^{238}U 10 Bq/l (The provisional GV for uranium in drinking-water is 15µg/l based on its chemical toxicity for the kidney)

^{229}Th 0.1 Bq/l

159. Detailed analysis of individual radioactive species and determination of their concentration is usually not justified. A more practical approach is a screening procedure, where 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/l for gross alpha activity and 1 Bq for gross beta activity.

IV. Health Risks in the Water System

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160. The great majority of health-related water-quality problems are 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.

161. Securing safety of dinking-water supplies is based on the use of multiple barriers, operating from the water resources in the catchment to consumer, to prevent contamination

of drinking-water, 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.

162. The holistic risk assessment risk management that characterizes successful water services is termed a “water safety plan”, and is at the core of a well-managed water service.

A. Vulnerability of the resource

General considerations

163. In general, raw water quality is influenced by both natural and human-use factors. Important natural factors which may affect the quality include wildlife, climate, topography, geology and vegetation. Human-use factors include point sources (e.g., municipal wastewater and industrial wastewater discharges) and non-point sources (e.g., urban and agricultural runoff including agrochemicals, livestock or recreational use) of contamination. For example, discharges of municipal wastewater can be a major source of microbial pathogens; urban runoff 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.

164. It is important that the characteristics of the local catchment or aquifer be well understood, and that hazards that could lead to water pollution be identified and managed. The extent to which potentially polluting activities in the catchment can be reduced may appear to be limited. However, introducing good practice 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).

New water services

165. 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 increase certain industrial activities.

166. 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.

167. 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 may 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 (WHO seminar packs for drinking-

water quality available on-line http://www.who.int/water_sanitation_health/dwq/dwqtraining/en/).

Groundwaters

168. Rain water 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 micro-organisms, 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 micro-organisms. Such sources meet the most stringent hygienic and microbiological requirements for an optimal drinking-water supply.

169. Groundwater is vulnerable to pollution though 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 long-reaching consequences. As regards the maintenance of groundwater quality, as with many other things, prevention is better than cure.

170. 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 5**

Table 5 Examples of hazards to resource water (WHO, 2004)

Catchments	Geology
	Rapid variations in raw water quality
	Sewage and septic system discharges
	Industrial discharges
	Chemical use in catchment areas (e.g use of fertilisers 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

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

(a) the contaminant load that is, or might be, applied to the subsurface environment as a result of human activity, and

(b) the pollution vulnerability, which is determined by the characteristics of the strata separating the aquifer from the land surface (WHO, 2003a)

172. 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.

173. 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 who prepare 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.

174. 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 law relating to groundwater protection can only be effective when the socio-economic conditions permit their implementation without incurring undue costs to communities and societies.

175. The development and application of groundwater protection zones forms a key component of water safety plans for groundwater supplies. Protection zones, in which land-use and pollutant discharges are controlled, represent a commonly used approach to manage 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 6** below, whilst **Table 7 Supporting programmes for groundwater protection (WHO, 2006)Table 7** Supporting programmes for groundwater protection (WHO, 2006) Table 7 provides an indication of the additional supporting programmes that may be required to maintain effective control of groundwater quality.

176. The control of agricultural practices can lead to a minimisation of pollution of groundwater from these activities and are also important to consider in the implementation of protection zones. For example, correct application of fertilisers 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 water, 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 optimised to minimise pollution, this is particularly important where intensive facilities occur. These are all-important factors to consider in the protection of groundwater resources and quality.

Table 6 Control measures for groundwater protection zones, options for monitoring and verification (WHO, 2006)

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.

Table 7 Supporting programmes for groundwater protection (WHO, 2006)

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
Prioritisation 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

Sources and springs

177. 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 of 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.

178. 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.

Surface water

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

180. Protection of open surface water is problematic in the absence of proper management (WHO, under preparation). 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 localised 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.

181. Effective resource and source protection include the following elements:

(a) developing and implementing a catchment management plan, which includes control measures to protect surface and groundwater sources;

(b) ensuring that planning regulations include the protection of water resources from potentially polluting activities and are enforced; and

(c) promoting awareness in the community of the impact of human activity on water quality.

182. Where surface water is used as a source of drinking-water, then land use within the catchment must be controlled and preferably limited to activities, which 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.

183. 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 utilises fertilisers, and pesticides which may pollute the water body.

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

185. Where a number of 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 (e.g. 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.

B. Water treatment

186. After source water protection, the next barrier to the prevention of contamination of the 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, which affect the acceptability or promote the survival of micro-organisms. Treatment processes usually function either through the physical removal of contaminants through filtration, settling or biological removal of micro-organisms. There are a number of 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 be in a number of stages, with initial pre-treatment by settling or pre-filtration through course media, flocculation and sedimentation, 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 a breakdown of a single process.

Basic local water treatment

187. 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 Vol. 3 of the WHO Guidelines on Drinking Water Quality (2rd ed). Today's national and international policy frameworks recognize that further attention to this neglected topic is needed urgently if the water and sanitation targets known as the Millennium Development Goals are to be met.

188. 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 geographic and cultural context. Further information on the Network is available from http://www.who.int/water_sanitation_health/dwq/smallcommunity/en/index.html

189. In small communities in rural areas, protection of the source of water (see sections 4.1.2 and 4.1.3) 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 a safe and palatable drinking-water.

190. 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 make long-term commitment. 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 under-estimated. If this is not done 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.

191. There are a number of types of water sources, which may be available to rural communities:

(a) Protected springs Although protected springs require very little maintenance, the following basic checks should be made every 1 -3 months:

(i) Does the water change colour after rain?

(ii) Has a water-quality test been carried out recently?

(iii) Did the community receive the results of the test?

(iv) Is the area behind the retaining wall losing the grass cover?

(v) Does the retaining wall show signs of damage?

(vi) Can this be repaired locally?

(vii) Does the uphill ditch need clearing?

(viii) Does the downhill ditch need clearing?

(ix) Does the fence need repairing?

(x) Does the grass behind the retaining wall need cutting?

(xi) Do the outlets leak?

(b) Ponds and lakes Ponds and lakes have traditionally been used as sources of drinking-water. Although they are easily contaminated, the water quality can be improved by 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 micro-organisms through settling and inactivation, including solar (ultraviolet) disinfection. Most pathogenic micro-

organisms 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 disinfection by-products. During impoundment in lakes or reservoirs reductions of faecal indicator bacteria, salmonella, and enteroviruses are about 99%, being greatest during the summer and with residence periods of approximately 3-4 weeks.

(c) Groundwater: Though groundwater is often seen as a pure and safe resource, any new well should have a comprehensive suite of chemical and microbial parameters tested for 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 though may not be suitable for small rural systems as it must be generated on-site as required. This is also the problem if chlorine dioxide is to be considered.

The most common problems with quality in rural groundwater and possible treatment solutions are outlined in Table 8 below.

Table 8 Contaminants associated with rural groundwaters, and possible treatment (Adopted from WHO, 2006)

Contaminant	*Sources*	*Treatment*
Nitrate	Natural, fertilisers, 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 (GAC)

Centralized water treatment

192. There are many different water treatment processes available. The following section gives an outline of the main processes involved in 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 decided before consideration is given to the best way of providing it. It is imperative that the selection of technology for treatment plants is done 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. There are many texts providing detailed descriptions of the engineering processes involved in water treatment which is beyond the scope of these guidelines.

193. Water treatment consists of a range of steps operated in sequence (Gray, 1996). These are listed below. 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.

(a) Pre-treatment

(b) Coagulation

(c) Flocculation

(d) Clarification

(e) Filtration

(f) Adjustment of the pH

(g) Disinfection

(h) Softening

(i) Sludge removal

Pre-treatment

194. Pre-treatment can broadly be defined as any process used to modify water quality prior to 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.

Coagulation, flocculation, sedimentation and filtration

195. Coagulation, flocculation, sedimentation (or flotation) and filtration are unit operations used to remove particles, including micro-organisms (bacteria, viruses and protozoa) from the water. It is important that operations are optimised 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.

Coagulation

196. After fine screening, most of the remaining suspended solids will be very small. Coagulation removes particles (including micro-organisms) 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 et al, 2002 for a review).

197. 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 accident in Camelford, UK (David and 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.

Sedimentation

198. 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.

199. 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.

Filtration

200. 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 (microfiltration, ultrafiltration, nanofiltration and reverse osmosis) filtration. 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).

Rapid and slow sand filtration

201. 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 micro-organisms. 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.

202. 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.

203. 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 98-99.5% or more, *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.

204. The operation of filters, 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.

Disinfection

205. 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.

206. 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 sterilise 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.

207. 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. Micro-organisms that are aggregated or are adsorbed to particulate matter will also be partly protected from disinfection, and there are 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 be 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 property managed plant.

208. An example of the difference between baseline removal of waterborne diseases and maximum removal rate is shown in Table 9 below.

Table 9 Removal rates of unit processes

Treatment process	*Enteric pathogen group*	*Baseline removal*	*Maximum removal possible*
Pretreatment			
Roughing filters	Bacteria	50%	Upto 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 casue deterioration in quality	Avoiding intake at periods of peak turbdity 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 m 99.99% after 4m (minimum based on virus removal	
	Viruses	99.9% after 2 m 99.99% after 4m	
	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	
	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 avilable	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%	
	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	Ct99:0.08 mg.min/litre at 1-2°C, pH 7; 3.3 mg.min/litre at 1-2 °C, pH 8.5
	Viruses	Ct99:12mg.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	Ct99: 94mg.min/litre at 1-2°C, pH 7; 278 mg.min/litre at 1-2 °C, pH 8.5
	Viruses	Ct99:1240mg.min/litre at 1°C; 430 mg.min/litre at 15 °C, both at pH 6 - 9
	Protozoa	Giardia
		Ct99 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	Ct99: 0.13mg.min/litre at 1-2°C, pH 7; 0.19 mg.min/litre at 1-2 °C, pH 8.5

	Viruses	Ct99: 8.4mg.min/litre at 1°C; 2.8 mg.min/litre at 15 °C, both at pH 6 - 9
	Protozoa	Giardia
		Ct99 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 Ct99: 40 mg.min/litre at 22°C, pH 8
Ozone	Bacteria	Ct99: 0.02mg.min/litre at 5°C, pH 6-7
	Viruses	Ct99: 0.9mg.min/litre at 1°C; 0.3 mg.min/litre at 15 °C
	Protozoa	Giardia
		Ct99 1.9 mg.min/litre at 1°C; 0.63 mg.min.litre at 15°C pH 6 - 9
		Cryptosporidium Ct99: 40 mg.min/litre at 1°C; 4.4 mg.min/litre at 22°C
UV irradiation	Bacteria	99% inactivation: 7mJ/cm2
	Viruses	99% inactivation: 59 mJ/cm2
		Giardia: 99% inactivation: 5 mJ/cm2
		Cryptosporidium
		99.9% inactivation: 10 mJ/cm2

209. 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 inside the production plant, and will become one of the key components of a water safety plan (WSP).

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

211. The importance of plant maintenance is obvious, yet maintenance may be often poor so that continued emphasis on operation and management from the side of management is required to make the importance of this accepted by the workers. The subject is large and covering it in depth is beyond the scope of this manual. 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 stated which cover the broad maintenance picture:

(a) Provide good housekeeping - everything clean, orderly, and organised.

(b) Develop a plan of daily operation and follow it.

(c) Modify the daily plan as experience and conditions indicate.

(d) Follow manufacturers' recommendations for operation and maintenance of equipment.

(e) Establish and follow an inspection and lubrication routine for each piece of equipment.

(f) Keep records of maintenance and repair for each piece of equipment.

(g) Establish a plan for maintenance of the plant structures. Most of 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.

(h) Maintain a well-equipped workshop with a competent electromechanic, having a reasonable stock of pipes, electrical wire and essential repair parts.

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

(a) Electrical and mechanical hazards

(b) Water treatment chemical hazards

(c) Chemical storage and handling hazards

(d) Flammable situations

(e) Chlorine toxicity and handling

(f) Traffic control in work areas

(g) On-site construction work and/or trenching hazards

(h) Working in confined and/or poorly ventilated spaces

(i) Hearing and vision hazards

(j) First aid

C. Vulnerability in the distribution system

213. 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 they can pose a significant health risk. Yet such deterioration can occur because of failure of the integrity of the network, or because of chemical and microbial changes in the water during transport

Compromised network integrity

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

215. 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.

216. Water distribution systems should be fully enclosed and storages 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 and/or interference with water storages.

217. Contamination can occur in the distribution system through:

(a) Infiltration. Contaminated sub-surface water is drawn into the distribution system when contaminated water in the sub-surface material surrounding the distribution system enters a low-pressure zone in an inadequately protected section of the distribution network. Pressure waves in the distribution system may cause such changes in pressure within the network facilitating ingress.

(b) Back siphonage. Faecally contaminated water is drawn into the distribution system or storage reservoir through a back-flow mechanism resulting from a reduction in line pressure and a physical link between contaminated water and the storage or distribution system.

(c) Open drinking-water storage reservoirs. Microbial contamination can also be introduced into the distribution system through open reservoirs for the storage of drinking-water.

(d) 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.

(e) Cross-connection. Human error resulting in the unintentional cross-connection of wastewater or storm water to the distribution system, or through illegal or unauthorised connections.

(f) Direct connection. Physical link between the piping of a potable and a non-potable system.

(g) Indirect connection. When water makes the connection, e.g. a hose connecting the drinking-water supply to contaminated water or sewer leakage entering the drinking-water pipes.

218. 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.

219. 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.

220. 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 satisfactory.

221. 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.

222. 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, inclusive the modest storage areas at the household level are essential to protect human health.

223. Intermittent supplies, either because of planned discontinuation of supplies at certain points of the day 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.

224. 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 intrusion of contaminated water into the pipelines through faulty joints, cracks, etc. In addition, the pipelines are subject to additional stress caused by transient flows, affecting the durability of the system and weakening pipes and joints (Global Water Supply and Sanitation Assessment Report, 2000).

225. 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 (avoid stagnation in storage tanks and looping dead-end sections), undertaking a program of pipe replacement, flushing and relining, and maintaining positive pressures in the distribution system.

226. The monitoring most often used to determine if a distribution system has delivered water of an acceptable quality is 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.

Deterioration of the microbial water quality

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

228. 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 micro-organisms and the number 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 such as Legionella, spp (Steinert, et at., 2002). The development of non-pathogenic coliforms is possible in biofilms but the operator should not dismiss a non-faecal cause.

229. Drinking-water entering the distribution system may contain free-living amoebae and environmental strains of various bacterial species, often referred to as heterotrophic bacteria. Under favourable conditions (see section 4.3) amoebae and heterotrophs will colonise a distribution system and form biofilms. Many environmental strains of bacteria such as *Citrobacter*, *Enterobacter* and *Klebsiella* may also colonise distribution systems (van der Kooij, 2003). There is no evidence at present to implicate the occurrence of these micro-organisms from biofilms (excepting for example, *Legionella* or *Mycobacterium*) with adverse health effects in the general population with the possible exception of immuno-compromised population groups.

230. 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 interfere with the methods used to monitor parameters of health significance.

231. 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.

232. A number of 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 micro-organisms. Where a disinfectant residual is used within a distribution system minimisation of the production of disinfection by-products which are 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.

233. 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 micro-organisms. Where the water contains appreciable assimilable organic carbon and where the

water temperature exceeds 20°C, a chlorine residual of 0.25 mg/l may be required to prevent the growth of Aeromonas and other nuisance bacteria.

234. 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.

D. Water safety plans WSP

235. Water Safety Plans (WSPs) were introduced in the 3rd edition of the Guidelines for Drinking-water Quality WHO,2008) 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 deal with the changes in quantity and quality expected to result from extreme weather events. In the following paragraphs, the key steps of a water safety plan are reviewed on the basis of the official WHO manual. Special manuals were released shortly thereafter (Bartram et al, 2009)

WSP Team creation

236. Technical expertise for the development of a WSP needs to be brought together as the first step towards the development of a water safety plan. Team members are usually sourced from within the utility, but may also include members from a wider group of stakeholders, with the 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 WSP approach and have the visible support of senior management.

237. 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.

Description of the water supply system

238. 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 and towards new developments in the resource capture area. Also existing and potential connections between one system and other systems need to be taken up in the descriptive process. Basically, two types of connections need to be considered:

(a) Those from which the water utility concerned would receive support in case of accident, disturbance of other emergency

(b) Those to which the water utility concerned would need to provide support in case of emergency conditions prevailing in that (foreign) service area. The latter should include not only service areas reachable through cross-connections of the different

distribution systems, but also need to take into account the potential to come to the aid of populations in areas which can not be reached by piped connections.

239. The objective is to ensure that subsequent documentation of the nature of the raw, interim, and finished water quality, and of the system used to produce the water of that quality is accurate 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.

Identification of hazards and hazardous events and risks

240. In this step:

(a) All potential biological, physical and chemical hazards associated with each step in the drinking-water supply need to be identified

(b) All hazards and hazardous events that could result in the water supply being, or becoming, contaminated, compromised or interrupted need to be identified

(c) Risks identified at each point of the flow diagram need to be evaluated and ranked

Determine and validate control measures, reassess and prioritise risks

241. The WSP team should document existing and potential control measures, and consider whether existing controls are effective. Depending on the type of control, this could be done 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 which the WSP team considers unacceptable, should be investigated in terms of additional corrective action.

Develop, implement and maintain an improvement / upgrade plan

242. Improvement plans address controls that were found to be inexistent or faulty in the previous step. 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 etc. Significant resources may be needed, and therefore a detailed analysis and careful prioritization should be made 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.

Operational monitoring

243. 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. Defining the monitoring of the control measures also requires inclusion of the corrective actions necessary when operational targets are not met.

Verify the effectiveness of the WSP

244. 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:

(a) Compliance monitoring

(b) Internal and external auditing of operational activities

(c) Consumer satisfaction

245. 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.

Prepare management procedures

246. Two types of documentations 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 the improvement / upgrade plan 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

Develop supporting programmes

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

Period review

248. 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.

Revision after incident

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

Typical challenges

250. The following **Table 10** summarizes the challenges and expected outputs of each step in the WSP process

Table 10 Challenges and outputs of the different steps in a WSP (WHO, 2009)

WSP Step	*Challenges*	*Outputs*
1. Assemble the WSP team	▪ Finding skilled personnel ▪ Organize 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	Establishment of 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. Description of 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 ▪ Finding 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. Identification of the users and uses of the water
3. Hazard identification and risk assessment	▪ The 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 unavailability 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. Description of what could go wrong and where in terms of hazards and hazardous events. 2. Assessment of risks expressed in an interpretable and comparable manner, such that more significant risks are clearly distinguished from less significant risks.
4. Risk assessment	▪ Identify staff responsibilities in terms of who will undertake the field work to identify the hazards and determine the control measures	1. Identification of the controls 2. Validation of the effectiveness of the controls

	▪ Ensure appropriate controls are identified that are cost-effective and sustainable ▪ Uncertainty in prioritizing the risks due to unavailability 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 events	3. Identification and prioritization of insufficiently controlled risks
5. Develop, implement and maintain an improvement / upgrade plan	▪ Ensure that the WSP is kept up to date ▪ Secure 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. Development of a prioritized upgrade / improvement plan for each significant uncontrolled risk. 2. Implementation of 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 ways of monitoring ▪ 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. An assessment of the performance of control measures at appropriate time intervals 2. Establishment of 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 working effectively 3. Confirmation that the water quality meets define targets
8. 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. Supporting 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. 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. Incidents	▪ An open and honest appraisal of causes, chain of events, and factors influencing the emergency, incident or near-miss situation ▪ Focussing 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

E. Point of use treatment

251. Point-of-Use treatment (POU) 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 to where people can rely only on their own initiative to ensure microbial safety, but also in locations where the quality of piped water has been compromised. Point-of-use treatment also needs to be accompanied by safe storage. (Arnold and Colford, 2007; Fewtrell, Kaufmann et al 2005; Clasen et al 2007; Clasen et al 2006; Clasen et al 2005; Clasen and Bastable 2003; Trevett and Carter 2005). A variety of technologies for treatment of household water have been described, and many are widely used in different parts of the world.

252. 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:

(a) 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.

(b) Candle filters. These are commercially produced. Contaminated water is allowed to filter slowly through a porous ceramic material. Larger micro-organisms - 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 micro-organisms - such as viruses that cause hepatitis A, may not be removed by candle filters.

(c) Stone or ceramic filters. These 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 though to test water with a representative sample to determine the efficiency of removal of faecal contamination.

(d) Slow sand filter. Although slow sand filters are very efficient at removing micro-organisms from contaminated water, they require a continuous flow of water to function effectively. They are the least likely to be implemented and sustainable at the household level. This is because the preferred filter designs and installations often are larger and capable of treating more water than needed by individual households and because they require technical skills for maintenance and operation that may not be practical for individual users.

(i). Once particulate matter has been removed, several POU treatment techniques exists. The most common are:

(e) Boiling. Although some authorities recommend that water be brought to a rolling boil for 1 to 5 minutes, the WHO GDWQ 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 1000m above sea level, 1 minute of extra boiling time should be added. The disadvantages 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; 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.

(f) Solar disinfection by the combined action of heat and UV radiation - this method has been shown to effectively treat water, but can take longer than chlorine disinfection.

(g) Solar disinfection by heat alone ("solar cooking").

(h) UV disinfection with lamps

(i) Chlorination 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 would 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.

(j) Combined systems of chemical coagulation-filtration and chlorine disinfection 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 responsible for much of its disinfection activity.

253. As a final step in POU, the safety of the final product needs to be guaranteed. Water treated at the POU, if not consumed immediately, should be safety stored independently from the treatment method.

V. Essential Epidemiology

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A. Basic Definitions

254. 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, and the eradication of these diseases. Knowledge about the burden of waterborne diseases in populations is essential for action by health authorities, to use the limited resources most effectively for prevention and care.

255. There are some fundamental epidemiological terms that are also important for waterborne disease epidemiology.

Surveillance

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

Mortality

257. The death rate (or crude mortality rate) for all deaths or a specific cause of death is calculated as follows (Bonita R et al, 2006):

$$Crudemortalityrate = \frac{Numberofdeathsduringaspecifiedperiod}{Numberofpersonsatriskofdyingduringthesameperiod} . *10^{n}$$

258. The main disadvantage of the crude mortality rate is that it does not take into account issues like age, sex, socio-economic class etc. so that further refinements are usually required such as the calculation of the age-specific death rate, the infant mortality or child mortality rate etc.

259. 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 of death rates of children under the age of five with the percentage of the population that has access to safe drinking-water would be made.

Morbidity

260. Morbidity describes any departure from a state of well-being (Last, 2001). Morbidity 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 in a population, usually expressed as cases per 100,000 or per million in one year. This includes all cases, which means also fatal and non-fatal cases. An example would be the morbidity due to hepatitis A infections, including all diseased and dead persons. For diseases with a low case fatality, like self-limiting diarrhoea, data on morbidity are more useful than mortality rates. In many countries, some morbidity data is collected to meet legal requirements, e.g. in respect of notifiable waterborne diseases.

Prevalence and incidence

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

262. 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 to the provision of services needed in a community. An example for the prevalence would be the occurrence of bladder cancer on the 1st January 2003 in a country that chlorines the drinking-water.

Prevalence per 1,000 =

$$\frac{No\ of\ cases\ of\ a\ disease\ present\ \text{int}\ he\ population\ at\ a\ specified\ time}{No\ of\ \ persons\ present\ at\ that\ specified\ time} X 1{,}000$$

263. 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.

$$\textit{Incidence per 1,000} = \frac{\textit{No of new cases of a disease occurring in the population during a specified period of time}}{\textit{No of persons at risk of developing the disease during that period of time}} X\ 1{,}000$$

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

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

Endemic, epidemic and pandemic disease distribution

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

267. An ***endemic*** disease is a disease constantly present in a given population, e.g. hepatitis A in several Eastern European regions.

268. A disease that occurs epidemically shows an abnormally high local incidence, i.e. 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 a sewage contamination of the drinking-water source, as happened in southern Kyrgyzstan at the end of 2003.

269. A ***pandemic*** is a disease that has an abnormally high incidence over a large geographic area. Cholera pandemics are the most famous 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 pandemic, the eighth one, has begun in 1992 in India and Bangladesh and is caused by Vibrio cholerae non-01 - 0139 Bengal.

270. 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.

Outbreak

271. An outbreak is a short-term local increase in a disease (Last, 2001). The WHO definition of an outbreak comprises two or more cases of illness arising from the same source (Andersson Y and Bohan P, 2001). A possible source for 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 (Hunter P, 2002); however, it may prove to be even more difficult to detect outbreaks affecting a bigger number of people but occurring in a larger population such as a metropolitan areas (Kožišek, 2010).

Population at risk

272. In waterborne disease epidemiology, the population at risk has to 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 R, 1993).

B. Basic Study Designs

273. 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.

Descriptive studies

274. 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.

275. Mostly data from routine surveillance such as death reports, notifications of infectious diseases, laboratory reports, or case finding exercises are used as data source. For case finding exercises, information is searched about the temporal, geographic and demographic distribution of the disease (time, place, person). Thus, within these studies, data on the date-of-onset, place of residence, travel history, age, sex as well as food and water consumption of those affected is collected (Hunter PR, 1997).

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

277. One of the most important variants of descriptive studies is the so-called ***ecological study***. This study design is based on conclusions on disease causation that are drawn by correlating incidence or prevalence rates for population groups (e.g. communities) with possible risk factors, such as the proportion of people drinking well water or the proportion of unemployed people (Hunter P, 1997). Though they have the advantage to be simple to conduct, to be economical, and that population data with widely differing characteristics can be used, they have some major disadvantages. The most important factor is that no individual link between exposure and effect can be made. 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 them either way (Beaglehole R, 1993 and, Hunter P, 1997).

278. 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 for an ecological study is this of Munger et al. (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.

279. 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 (e.g. well water) (Hunter PR, 1997). That 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 study design is that they are relatively easy and economical to conduct (Beaglehole R, 1993). When using this study design, the problem of bias should be taken into account, in particular selection bias, e.g. 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 P, 1997). In an outbreak situation, a cross-sectional survey

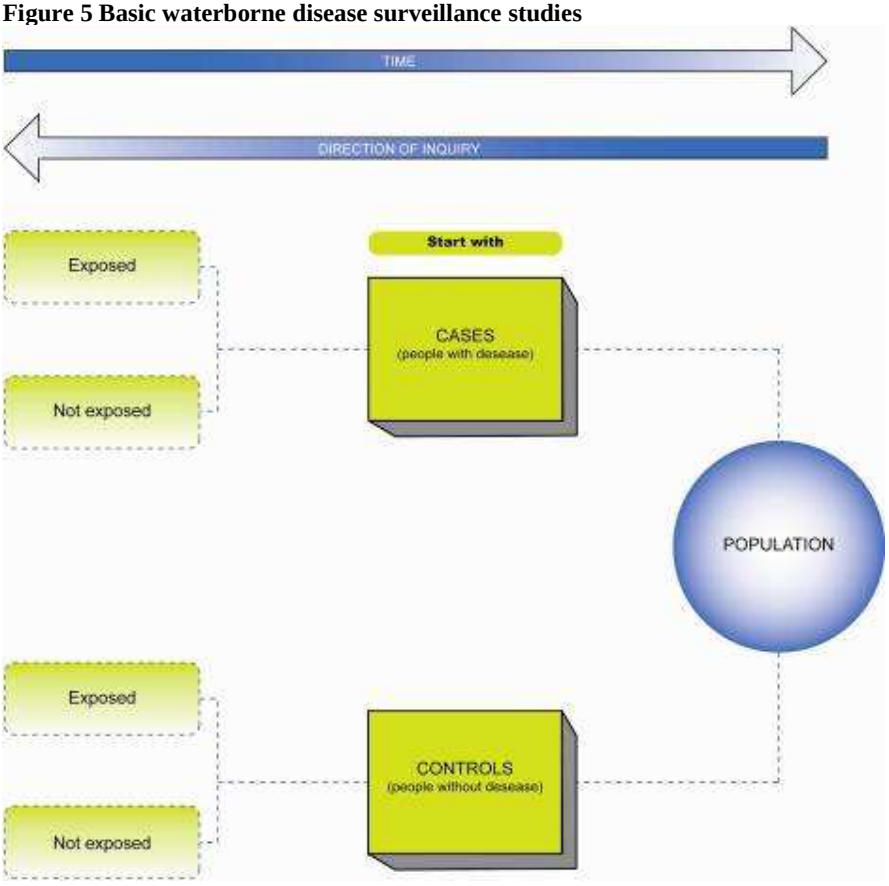
involving the measurement of multiple exposures is often the first step in an investigation to unveil the cause (for example contaminated drinking-water)

Analytical studies

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

281. 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 persons with disease (cases) with those persons in a group of individuals unaffected by the disease (controls) (Hunter P, 1997). The advantage of case-control studies is 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 the one time so that the relative contribution of each can be estimated (e.g. food, water etc.). **Figure 1**demonstrates the procedure for conducting case-control studies. Case control studies are retrospective, which means that the direction of the inquiry is going into the past.

Figure 5 Basic waterborne disease surveillance studies



282. 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, i.e. free of symptoms like diarrhoea or vomiting. The methods that can be used for selecting the cases may include telephone recruitment or the usage of administrative registers (Beaglehole, 1993).

283. After identifying cases and controls, a matching of controls to cases has to be performed. 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 is to be analysed by, for example, age group or social class (Beaglehole, 1993). The proportions of cases and controls that for example are exposed to drinking-water are then compared and deductions can be made about 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.

284. The measured value in a case-control study is the Odds Ratio (OR). An example for calculating an OR is given in **Table 11**. The Odds Ratio 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 it is tested, whether people with Cholera were exposed to a specific risk factor, e.g. consumed seafood, or not. In Table 51 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, 1993). In case-control studies, a relative risk (RR), which is the measured value of cohort studies which will be explained below, cannot be calculated, because cases and controls are not random samples of the entire population.

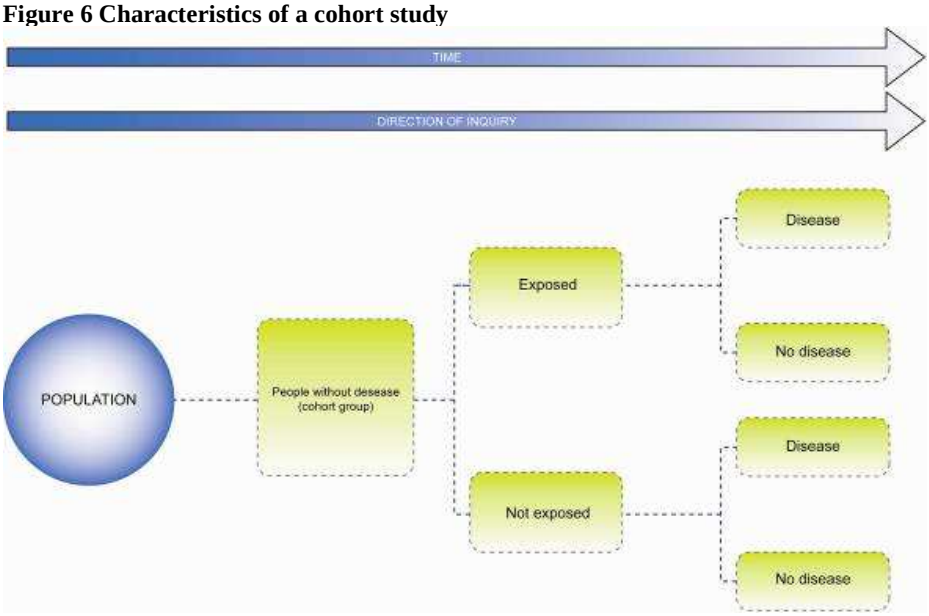
Table 11 Calculation of the Odds Ratio (OR)

	Exposure: consumption of seafood		
Disease (cholera)	Yes	No	Total
Yes	50_a	11_b	61
No	16_c	41_d	57
Total	66	52	118

OR = (a*d)/(b*c) = (50*41)/(11*16)=11.6

285. Contrary to case-control studies, cohort studies are studies of a group of individuals for whom exposure data is known. The direction of the inquiry is normally the future, and the level of risk is investigated with which the exposure leads to diseases.

Figure 6 Characteristics of a cohort study



286. 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, 1993). As example exposures can be named e.g. chemicals in water, like nitrate, arsenic, trihalomethanes or different kinds of water supplies (groundwater vs. bank filtrate).

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

288. The advantage of cohort studies is that they provide the best information about causation of disease and the best measurement of risk. The relative risk (RR) is used to compare the incidence of disease between those exposed and those not exposed to a potential causative agent (Hunter, 1997). Besides, cohort studies are conceptually simple. The basic disadvantage of cohort studies is that it is a major undertaking and that it requires long follow-up periods due to the disease often occurring long time after exposure. Retrospective cohort studies are one special kind of cohort studies which is typically used for outbreaks affecting water supplies of small communities.

289. Retrospective cohort studies are performed when all people are potentially exposed to a single risk factor (i.e. supplied by water from a single well) (Hunter, 1997). One example for the application of this kind of cohort study is described in detail in chapter 6 of this manual. As cohort group all primary school children of a small region in Germany were selected, where a Giardiasis outbreak occurred during May and August 2000. Questionnaires were used to investigate potential exposures like water and food consumption habits, contact to animals and bathing in recreational water. The Relative Risk 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.

C. Sources of errors in Epidemiological Studies

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

Random error

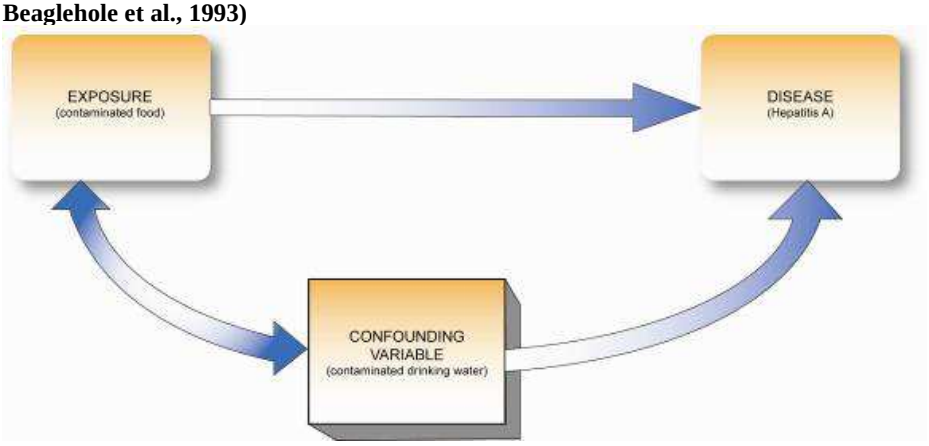
291. Random errors can occur due to individual biological variation, sampling errors and measurement errors. They can be reduced by careful measurement of exposure and outcome thus making individual measurements as precise as possible. But they can never be completely eliminated. This is due to the fact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

Systematic error

292. Systematic errors or biases can also occur and have to be always 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 are 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 means that e.g. different laboratories measure different concentrations of pathogens. And an example for a recall bias is the recall difference as regards food consumption between ill and healthy persons that participate in a case-control study.

293. 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 visualized in **Figure 7**. In investigating a hepatitis A outbreak contaminated drinking-water there could be a confounder for example if only contaminated food would be taken into account as exposure factor.

Figure 7 Confounding: contaminated food and water and hepatitis A (modified after Beaglehole et al., 1993)



D. Specific Methodological Challenges of Conducting Epidemiological Studies

294. 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 utilise 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 criticised 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 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.

Study Design

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

(a) The objectives of the study

(b) The nature of the exposure and illness under study

(c) Available epidemiological and biostatistical expertise, together with economic constraints

296. It is vital that these three 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 the use to which the data acquired can be put.

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

298. Before beginning the study the following must be easily available to enable high quality epidemiological investigation of outbreaks of waterborne illness:

(a). Relevant information including maps of water distribution and supply zones (provided by water companies) and population data for the affected area.

(b). Staff with appropriate skills including epidemiological, statistical, data handling, interviewing, leadership and organisational skills.

(c). Facilities including an 'incident room' to co-ordinate the work of the investigations team and collect all the data. (Source: Hunter, 2003).

Which study design is most suitable?

299. Experimental or intervention studies are thought to provide the most accurate results, once the potential for selection bias and confounding has been minimised, 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 where attention is paid to measuring exposure and disease accurately and allowing for potential confounding factors (Blum and Feacham, 1985).

300. 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.

(a) *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.

(b) *Information bias* occurs when there are systematic differences in the way data on exposure or outcome are obtained from the different study groups.

(c) *Recall bias* occurs when the reporting of disease status is different depending on the exposure status.

(d) *Interview bias* occurs where interviewers are aware of the exposure status of individuals and may influence the answers on disease status.

(e) *Confounding* occurs when the relationship between the exposure and disease is attributable (partly or wholly) to the effect of another risk factor, i.e. the confounder (see below for examples of non-water related risk factors for gastroenteritis). It happens where 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.

Examples of non-water related risk factors for gastroenteritis

(i) Age

(ii) Gender

(iii) History of migraine headaches

(iv) History of stress or anxiety

(v) Frequency of diarrhoea (often, sometimes, rarely or never)

(vi) Current use of prescription drugs

(vii) Illnesses within 4 weeks prior to the trial day lasting more than 24 hours

(viii) Use of prescription drugs within 4 weeks prior to the trial day

(ix) Consumption of any of the following foods in the period from 3 days prior to 7 days after the trial day: mayonnaise, purchased sandwiches, chicken, eggs, hamburgers, hot dogs, raw milk, cold meat or seafood.

(x) Illness in the household within 3 weeks after the trial day

(xi) Alcohol consumption within the 7-day period after the trial

(xii) Frequency of usual alcohol consumption

(xiii) Taking of laxatives within 4 days of the trial day

(xiv) Taking of other stomach remedies within 4 days of the trial day

(xv) (Adapted from Kay and Dufour, 2000).

Exposure Assessment

301. 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 use of water supply 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 rely on information from questionnaires or interviews, because actual water use may differ from reported water use.

302. 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, often inadequate indicators of microbiological water quality and/or poor laboratory methods are 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 micro-organisms 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 micro-organisms 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 et al, 2003).

303. 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 events. 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, where 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 with 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 though costs may be high. Generally 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, and power outages that result in negative pressure and an influx of contaminated water or sewage.

304. 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 in the household.

305. Other household members may be exposed to these pathogens by other routes of transmission or may already have immunity.

Measurement of Health Outcomes

306. 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.

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

308. In the city of Cherepovets, in north-western Russia, a series of epidemiological studies on waterborne diseases have been out carried in recent years. Egorov et al. studied residual chlorine levels and gastrointestinal disease (2002), exposure to disinfection by-products (2003a), the relative frequency of Cryptosporidium infections (2004). Furthermore the association between drinking-water turbidity and diarrhoeal disease was assessed (2003b).

309. 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 practiced and many residents are regularly exposed to drinking-water with no free chlorine residual, 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.

310. Exposures of study participants were characterised with mean water quality parameters by 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.

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

312. The results demonstrated an association between decline in free residual chlorine concentrations in the distribution system and increase in the risk of GI illness in the city of Cherepovets, Russia. Re-chlorination 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.

Analysis

313. 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 strong evidence of causality.

314. 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 (e.g. 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 generalised estimating equations (Liang and Zeger, 1986).

315. 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. Children under five have higher rates of diarrhoeal disease and different environmental exposures than older children and adults.

316. 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.

Association

317. It is not possible to detail all the statistical methods and analysis available to undertake measures of association and potential impact in this manual and the reader is referred to the bibliography for further reading. A brief outline is provided below. 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'.

Absolute measure of association

Calculation of risk ratio

318. The risk ratio is the incidence proportion in the exposed group (P1) divided by the incidence proportion in the non-exposed group (Po): Risk ratio = P_1/ Po

319. 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.

Calculation of Odd Ratios

320. 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 odds ratio. 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

321. The odds ratio is

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

322. The final expression (A1*B0/A0*B1) is the cross product ratio in the 2-by-2 table shown below:

	Disease +	*Disease -*	
Exposure +	A1	B1	N1
Exposure -	A0	B0	N0

323. An odds ratio of 1 indicates no association between the exposure and disease. In addition, the odds ratio 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 odds ratio is approximately equal to the risk ratio.

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

(a) The design of the epidemiological study is critical because it affects every aspect of the study. It should address why the study is being done, and how it will be conducted.

(b) 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.

(c) 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.

(d) 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 infection that occurs 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.

(e) The approaches for collecting exposure and health effects data should be described in detail.

(f) Data analysis should include the steps taken to control selection, misclassification and confounding bias. The statistical evaluation procedures should be fully described.

(g) 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.

(h) The study plan should be submitted to the appropriate authorities to ensure that any regulatory limitations regarding human studies will be met especially confidentiality restrictions and informed consent procedures.

E. Detection, Investigation and Reporting of Water-Related Disease Outbreaks

325. A waterborne outbreak is given when two or more persons (better: more cases than would be expected (Quigley, 2003)) experience a similar illness after ingestion of water from the same source. Drinking-water-related outbreaks are both a demonstration of a breakdown or failure in the water supply system, and present an opportunity to provide new insights into disease transmission and improvements to the supply system (Andersson, 2001).

326. In this chapter, we will discuss the way how to adequately manage the event of a water-related disease outbreak. We will address both the pro active phase (see chapter 5.6.1: preparation) and the reactive phase (see chapter 5.6.2: response) of water-related disease outbreak management. First of all however, and to facilitate focusing on the major problems of outbreak management, we will have a brief look on

(a) (emerging) risk factors of water-related disease outbreaks, and

(b) major obstacles in detecting water-related disease outbreaks.

327. 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 different factors strongly varies due to both natural conditions and socio-economic development of countries, and is affected and triggered by different global change processes. However, from the experience of the last decades can be stated that until now no country has achieved the goal to minimise the risk of a water-related disease outbreak to zero.

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

329. Concerning sources of water supply:

(a) 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

(b) non-existence of legal catchment protection zones

(c) increasing variability of precipitation patterns both in time and space due to climate change

330. Concerning water processing:

(a) insufficient, over-used and/or inadequate water treatment facilities

(b) change of water pressure in water distribution systems causing mobilisation of micro-organisms and biofilms

(c) lack of education and training of water works personnel leading to insufficient planning, running and/or maintenance of facilities

331. Concerning water use and misuse:

(a) growing amount of people with reduced immuno-competence, due to age (demographic transition), drugs, and medical treatment

(b) new and complex technical applications of water, e.g. dental units, air conditioning, cooling towers, spas

(c) increasing awareness of possible misuse of vulnerable water supply systems for health threatening attacks

332. Despite this, the issue of emerging pathogens has become a major concern throughout the last decade (NAS, 1992). Emerging pathogens comprise different groups of micro-organisms which have newly been detected (e.g. for water-related pathogens: *Cryptosporidium parvum*, *Legionella pneumophila*), of which pathogenic mutants have newly been detected (*V. cholerae* 0 139), of which human-pathogenic aspects have newly been detected (*Campylobacter* spp.), 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*).

333. To detect and report 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. Especially doctors would rarely be consulted if patients have to pay for health services. Medical doctors only rarely let stool samples of their diarrhoea patients being examined, particularly if this would stretch their budget. If gastrointestinal symptoms dominate the patient's syndrome, a foodborne disease is often supposed even by specialists, and water as a potential source is not thoroughly taken into account.

334. Many health care systems, even under advanced socio-economic conditions, are lacking adequate capacities in more public health oriented skills such as epidemiology, microbiology, and toxicology. Another point is that communication 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 leads to the fact that the number of outbreaks is 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.

Preparation

335. The facts and obstacles mentioned above lead to the necessity that public health services have to be well prepared to be able to (i) detect water-related outbreaks, and (ii) adequately react if a water-related outbreak occurs (Exner M and Kistemann T, 2003).

336. The infrastructure and processes of a sufficient incident and/or outbreak management has to be prepared and trained before a water-related disease outbreak occurs. An outbreak management team (OMT) has to be installed, and the central task of this OMT is the preparation for an outbreak. The OMT should stand under the headship of the local Public Health Officer. Further, officially designated members of the OMT should be:

(a) a specialist for hygiene and environmental medicine from a regional centre, if available;

(b) leading representatives of the water utilities responsible for the water supply of the population;

(c) representatives from the water department of the regional environmental agency and from the agricultural and/or forest agencies, if necessary;

(d) representatives from the police, and the fire brigades should be in the team as well.

337. The OMT should meet regularly to build up trust and reduce communication barriers. Deputy regulations should be installed in advance to make sure that representatives

of each relevant institution are always available. If an outbreak is to be suspected, the terms of reference of an OMT comprise

(a) to review the evidence for an outbreak

(b) to identify the population at risk

(c) to decide on control measures

(d) to make arrangements for the commitment of personnel and resources

(e) to monitor the implementation and effectiveness of measures taken

(f) to decide on the end of an outbreak

(g) to prepare a report and make recommendations for future prevention.

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

339. A detailed outbreak plan has to be developed, and occasional exercises have to be performed. Site-specific risk factors have to be identified, and each of the above-mentioned general risk factors has to 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 basis of relevant information, which is quickly available for the OMT in case of an outbreak. The entire water supply system and the relevant processes, i.e. from the catchment to the consumers' tap, have to be characterised and documented thoroughly. This can very efficiently be done by use of a Geographical Information System (GIS), which is described with more detail in chapter 7. Key steps in the outbreak management have to be defined earlier.

340. Communication of information to the public is a key problem in emergency situations. Therefore, it has to 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.

Response

341. The response phase of an outbreak management can systematically be divided into different steps:

(a) Trigger event: outbreak detection and confirmation

(b) Acute reaction: outbreak declaration, quick and preliminary descriptive hazard investigation, initial and immediate control measures

(c) Analysis: in-depth analytical hazard investigation, continuous re-evaluation of control measures

(d) Normalisation: conclusion and declaration of normalisation

(e) End: evaluation, formal report, learning lessons for the future

342. 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 investigation should be circular in that lessons learned should feed into preparation and planning for the next outbreak (Quigley C and Hunter P, 2003).

Trigger Event

343. 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. Mostly, they are 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.

344. 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, e.g. a transport accident, extreme rainfall and runoff, flooding, sewage or liquid manure accidents, are trigger events which can be recognised 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 micro-organisms (particularly *Salmonella*, *Shigella dysenterica*, *E. coli* 0 157:H7, *Cryptosporidium parvum*) should prompt highest vigilance.

Acute Reaction

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

346. The major goal of this phase, however, is to reduce the risk by quickly implementing preliminary control measures. Treatment failures have to be corrected; eventually an additional disinfection step may help. Sometimes, if possible, an alternate water supply has to be activated. High-risk persons should be excluded from water consumption (it is good to identify those persons and institutions in advance!), and consumers may be advised to boil all water before consuming it.

347. Information has to be given to the public by only one person, who is authorised by the OMT, and it is without any doubt advantageous to have a professional in this position.

Analysis

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

(a) 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 sero-prevalence studies.

(b) 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.

(c) The hygienic investigation of raw water, treated water, disinfected water, and water at the consumers' tap is normally based on the interpretation of some microbiological, physical and chemical standard parameters.

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

350. During the analytical phase, the further development of the outbreak situation has to be checked critically: Do new cases occur? Does the incidence of cases increase or decrease? The immediate control measures have continuously to be revaluated. 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.

Normalisation

351. Before normalisation of the situation can be declared, the following questions have to be answered:

(a) Are the causes of the outbreak completely understood?

(b) Have efficient control measures been implemented?

(c) With respect to the incubation period, do new cases occur?

(d) Do water sample results meet microbiological or chemical requirements since at least three days?

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

Final Report

353. The work of the OMT is not yet at its end after normalisation. A formal outbreak report has to be written. The efficiency of incidence management has to 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 could be saved if adequate preventive measures would be installed. Finally, lessons learned have to be identified, order to prevent or at least to better manage future outbreaks.

VI. Essential Surveillance

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A. General

354. 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.

Why specific surveillance for Water-Related Disease?

355. 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 identify communities where 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 target resources toward 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.

356. 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. For example:

(a) Information on incidence of typhoid fever may indicate the need for targeted vaccine campaigns in specific geographic locations.

(b) 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.

(c) 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 on a household level. Studies in Uzbekistan (Semenza et al., 1998) showed that >30% of households with piped water had no detectable levels of chlorine residual in their water despite two stage 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 drinking-water contaminated in the distribution system.

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

Approaches for Waterborne Disease Surveillance

357. There are several approaches for 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 is the most important to collect and how quickly it needs to be collected and analyzed. Planning a surveillance system can be divided into several steps:

(a) What information (health outcomes, demographic data, and risk factors) should be collected in the surveillance system?

(b) What are the sources of the target information and who collects the information?

(c) What mechanisms are used to transfer the information from the data collector to the data compiler, data analyst and data user?

Waterborne Disease Health Outcomes

358. For waterborne disease, there is a spectrum of possible health outcomes ranging from asymptomatic infection to death (Table 5.1). 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 (Hepatitis A virus and Hepatitis E virus), conjunctivitis {enteroviruses), aseptic meningitis (enteroviruses), respiratory symptoms (enteroviruses), haemolytic uraemic syndrome (*E. coli* O157:H7), myocarditis (Coxackieviruses), diabetes (Coxackieviruses), reactive arthritis (*Yersinia, Shigella, Salmonella*), peptic and duodenal ulcers (*Helicobacter pylori*), stomach cancer (*Helicobacter pylori*), 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 and Bell, 1989; Turner et a;. 1990).

359. 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.

360. **Table** 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: absenteeism in sentinel institutions (schools), sales of anti-diarrhoeal medications, nurse hotline calls at large health care facilities, and gastrointestinal illness in sentinel populations (families, nursing homes). 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 certificate listing of underlying and contributing causes of death. Some of these surveillance approaches may provide a relatively rapid means of detecting an outbreak of disease and will be discussed in more detail later in this chapter. However, the information from these surveillance approaches cannot distinguish between waterborne infections and infections transmitted by 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 12 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 (ADM) • 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 ADM 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

Data collection approaches

361. After decisions about the health outcomes for the surveillance system to target, the next step is to decide how the surveillance data will be collected, and who will collect it. Some surveillance systems are "passive" systems -meaning that the system relies on voluntary participation of health workers or laboratories to report specific infections, cases

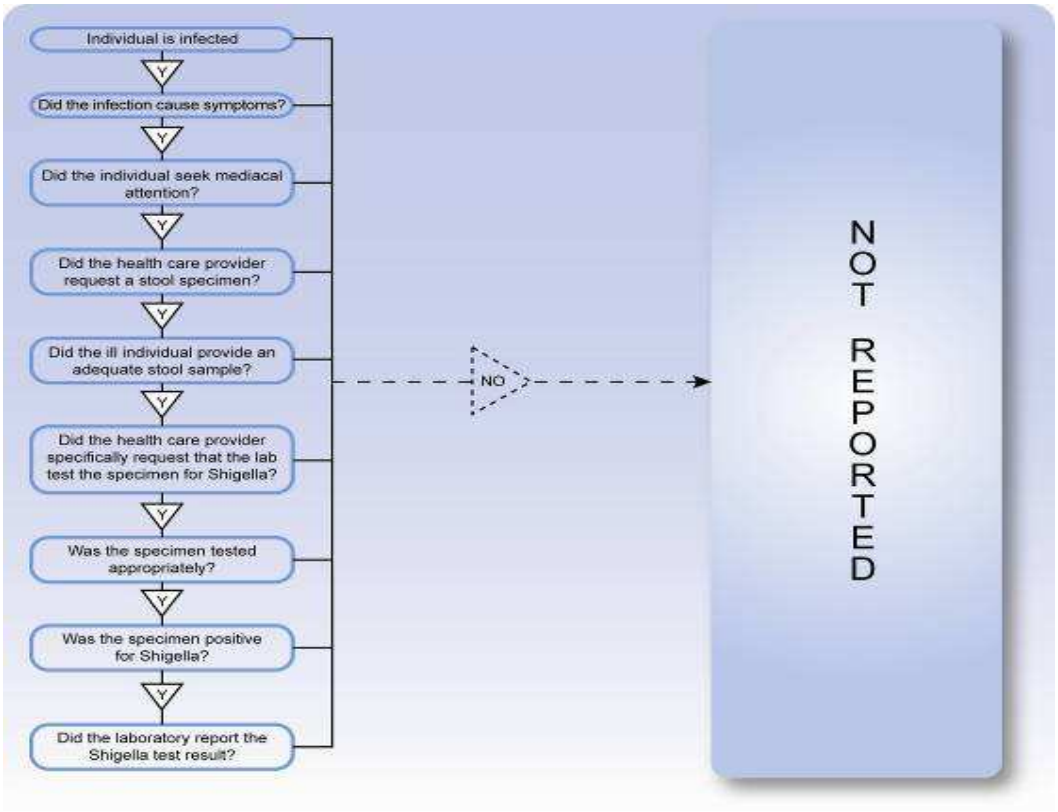
(symptoms or illness) or events (clusters of cases that may indicate an outbreak) to the surveillance authority or coordinator. Many countries have regulations on what diseases must be reported. Harmonization at the global level of these "notifiable diseases" has been achieved through the 2005 International Health Regulations.[4] Countries in Central Asia usually report cholera, salmonellosis, shigellosis, pathogenic E. coli, typhoid and hepatitis A. In some countries, clusters of >5 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, hepatitis A virus, typhoid fever, cholera, *E. coli* O157:H7, cryptosporidiosis and giardiasis. Some disadvantages of this type of passive surveillance system are that:

(a) It is not very sensitive. There are many steps in the reporting process and some cases may be lost at each step (**Figure 8**). Many cases are probably never reported.

(b) 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.

(c) 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.

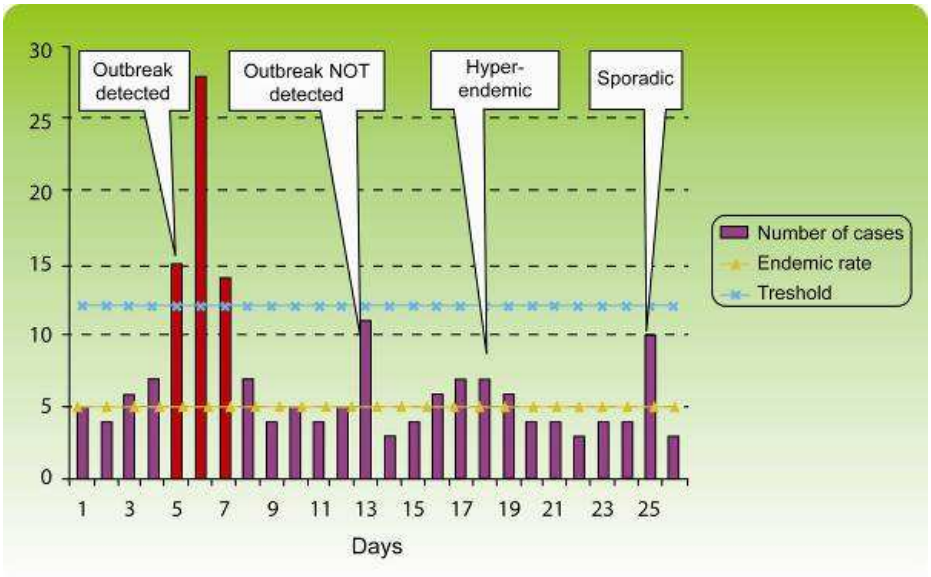
Figure 8 Sequence of events before an individual Shigellosis infection is reported



[4] For further information on the 2005 IHR visit URL: http://www.who.int/csr/ihr/wha_58_3/en/ accessed 17 November 2008.

362. A passive surveillance system is usually too slow and insensitive to detect an outbreak at the time the outbreak occurs. However, some outbreaks may be identified retrospectively when the data is analyzed. **Figure 9** 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.

Figure 9 Epidemic to endemic illness as detected by surveillance systems (Modified from Frost et al (1996)



363. 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:

(a) Date of onset of illness

(b) Symptoms

(c) Etiology (diagnosis, laboratory confirmation)

(d) Geographic location

(e) Age

(f) Sex

(g) Risk factors such as other ill household members, source of drinking-water, exposure to animals, travel, exposure to recreational water

(h) Underlying health problems

364. 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 becomes less likely that the case will be reported. Health authorities should realize 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 and will be discussed in more detail in a section of this chapter on enhanced surveillance approaches.

365. 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. Also, passive surveillance may allow retrospective identification of outbreaks when the data is compiled and analyzed. However, it is important to use this 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 are:

(a) Passive case surveillance has low sensitivity because only a small percentage of cases provide stool specimens and are diagnosed and reported.

(b) Some waterborne diseases, such as viral gastroenteritis, may not be included on list of notifiable diseases.

(c) There is usually a significant time lag between the time of disease occurrence and the time that a case report is received.

Surveillance for Waterborne Disease Outbreaks

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

367. In the United Kingdom, some reports of waterborne disease outbreaks exist since the 1850's. However, a formal surveillance system for waterborne disease was not instituted until the 1990's (Stanwell-Smith, 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.

368. Sweden has a multi-part surveillance system for infectious diseases (Stanwell-Smith, 2003), which requires reporting of notifiable diseases by health care providers and laboratories. This includes amoebiasis, campylobacteriois, cholera, infection with enterohaemorrhagic *E. coli* 0157, giardiasis, hepatitis A virus, typhoid and paratyphoid fever, salmonellosis, shigellosis, and yersiniosis. In addition, there is voluntary reporting by laboratories of infections of noroviruses, cyclospora, cryptosporidiosis, other pathogenic *E. coli* strains and rotavirus. Waterborne disease outbreaks in Sweden are seldom detected by this surveillance system at the time they occur. Some outbreaks have been detected by an alert medical officer who notices a cluster of cases and initiates an investigation.

369. In the United States, passive voluntary surveillance for waterborne disease outbreaks started in 1971 and is a collaboration between the Centres for Disease Control and Prevention (CDC), the United States Environmental Protection Agency (USEPA) as well as 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: 1) Characterize the epidemiology of waterborne disease outbreaks; 2) Identify the etiologic agents that cause the outbreaks; 3) Determine the risk factors that contributed to the outbreak; 4) Inform and train public health personnel to detect and investigate waterborne disease outbreaks; and 5) Collaborate with local,

regional, national and international agencies on strategies to prevent waterborne diseases (Stanwell-Smith, 2003).

370. From 1971 through 2000, 731 drinking-water outbreaks have been 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 includes:

(a) Type of exposure (drinking-water or recreational water)

(b) Location and date of outbreak

(c) Actual or estimated number of persons exposed, ill, hospitalized, deaths

(d) Symptoms, incubation period, duration of illness

(e) Etiologic agent

(f) Epidemiologic data (attack rate, relative risk or odds ratio)

(g) Clinical laboratory data (results of faecal and serology tests)

(h) Type of water system (community, non-community or individual drinking-water supply)

(i) Swimming pool, hot tub, water park or lake for recreational water

(j) Environmental data (results of water analyses, sanitary survey, water plant inspection)

(k) Factors contributing to contamination of water

371. This data is summarized in biannual reports (Morbidity and Mortality Weekly Report Surveillance Summaries) that are published by the CDC and distributed to public health authorities and practitioners throughout the country. The information is also available on the internet at www.cdc.gov/mmwr. An example of the summary data on waterborne disease outbreaks associated with drinking-water for one year is shown in in Table 13.

Table 13 Waterborne disease outbreaks associated with drinking-water (USA 1998 n=10)

State	*Month*	*Class◊*	*Etiological agent*	*No of cases*	*Type of system◆*	*Deficiency∴*	*Source*	*Setting*
Florida	May	III	*Giardia intestinalis*	7	Com	2	Well	Community
Florida	Sep	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[⊥]	5	Ind	3	Well	Home
New Mexico	Jul	I	*Cryptosporidium parvum*[Π]	32	Ind	5	Well	Group housing
Ohio	Oct	III	AGI[Δ]	10	Com	4	Surface[ɜ]	Treatment
Texas	Jul	I	*Cryptosporidium parvum*[#]	1400	Com	3	Well	Subdivision
Wyoming	Jun	I	*E. Coli O157:H7*	157	Com	2	Well/ spring	Community

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

[◊] Based on the epidemiological and water-quality data provided on CDC form 52.12

[◆] 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.

[∴] 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).

[⊥] Acute gastrointestinal illness of unknown etiology

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

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

[ɜ] Surface water from an unknown source

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

372. Analyses of this surveillance data over time have provided insight into trends in waterborne disease in the United States. For example, the data shows 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 groundwater systems, especially small, groundwater systems.

373. 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 US 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: 1) It has low sensitivity (it is estimated that only one of every 25 waterborne disease outbreaks is reported); 2) It does not capture sporadic cases of waterborne disease; 3) There is lack of uniformity between states and outbreak investigation (some are well investigated including clinical and environmental samples - others only to a minimal extent); 4) There is inconsistent quality and completeness of data collected by different states; and 5) Data analyses 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 being recognized, they may not be investigated or reported because of a shortage of trained health personnel available to work on waterborne diseases at local health departments.

374. All surveillance systems of waterborne disease outbreaks need to include a method for evaluating the evidence that an outbreak is indeed due to contaminated water or whether it may be due to another transmission route. **Table** shows the criteria used by the national surveillance system for water-related diseases in England and Wales. **Table** shows the criteria used to classify waterborne disease outbreaks in the surveillance system in the United States (Stanwell-Smith, 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 14 Criteria for strength of association of water with human infectious disease

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

National surveillance for water-related diseases in England and Wales.
Source: Stanwell-Smith, Andersson and Levy 2003

Table 15 Classification of investigations of waterborne disease outbreak in the USA

Class	*Epidemiological data*	*Water quality data*
I	Adequate data to implicate water as a source of outbreak; data were provided about exposed and unexposed persons, and the relative risk or odds ratio 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	Nor provided or inadequate (e.g. stating that a lake was overcrowded)
III	Provided by limited epidemiologic data provided that did not meet the criteria for Class I, or claim made that ill persons had no exposures in common, besides water, but no data provided	Provided and adequate
IV	Provided but limited	Not provided or inadequate

Alternative Surveillance Approaches for Water-Related Diseases

375. 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 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.

376. **Table** lists a number of 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 performed in addition to traditional passive surveillance for notifiable diseases (Frost et al., 1996). Some of these approaches can be useful for rapidly identifying outbreaks of disease in a community. Each approach and its strengths and limitations will be described in the following sections.

377. Surveys: Surveys are a flexible and often low-cost approach to collect 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 school children 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 programs such as vaccine campaigns or school-based anti-helminth treatment interventions. The limitation of some surveys may be difficult 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, 2001).

378. Monitor absenteeism: Often the first consequence of an infection is that the infected subject will stay home from school or work. Large numbers of absent school children is often an indication of an outbreak of disease in 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 if 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, then 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.

379. Monitor inquiries to community health workers or nurse hotlines: Mild cases of illness may seek advice from a community health worker or nurse via telephone or in person instead of going to 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 then the nurse decides whether the patient needs to be seen by a physician.

380. For some health care systems, it may be possible to monitor these types of inquiries and use this as an inexpensive and timely method for 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 that the symptoms are associated with water quality.

381. Monitor 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, 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, 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 that may not seek medical care and could be designed to collect information on frequent basis (weekly) in order to rapidly detect rises in gastroenteritis incidence. However, this surveillance system requires the cooperation of a large number of pharmacies and 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.

382. Monitor 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 (e.g. nursing homes) may have high background illness rates because of susceptible populations and multiple disease transmission routes within 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.

383. Monitor 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 that 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.

384. Monitor 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. cholera, etc.). Laboratory-based active surveillance and electronic reporting offers a rapid method to detect confirmed infections that cause moderate to severe symptoms 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 cases do not provide specimens.

385. Monitor 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 a particular events. Death certificate data are generally analyzed 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.

386. 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 is of variable quality, and death certificates may 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 that 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 to set up a surveillance system for such a rare event.

387. Monitor 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 customer who filed the complaint. Whenever possible, water utilities should try to send a team to collect water samples from the household with the complaint and analyze 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 Geographical Information Systems (GIS) information to a database for tracking customer complaints.

388. 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, 2001). It is important to remember that most of these approaches are surveillance for enteric illness rather than waterborne disease and many enteric pathogens can be transmitted by 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.

Surveillance Approaches for Regions with Limited Resources

389. When resources are limited, innovative surveillance approaches are needed. In these situations, it is critical that surveillance activities be linked to specific health goals. For example, if a regional health goal was 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, 2000) are described below.

390. Sentinel clinics and laboratories: One approach that works well in areas where 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 can be used to collection information on more diseases and detailed information on each case. These clinics and laboratories may receive

additional support from the national government and/or international agencies that allows them to perform more diagnostic tests and more accurately record 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, etc.

391. Focused surveys: Another useful approach is to conduct intermittent targeted surveys for a specific purpose on an as-needed basis (White, 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 for 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 on the use of oral rehydration therapy.

392. 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, etc. Some surveillance programs already sponsored by national or international agencies may be willing to share information, personnel, transportation, computers, reference laboratories etc. that would be relevant for waterborne disease surveillance.

393. Training and staff incentives: Successful surveillance programs 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 programs to include appropriate training for designated data collectors because their educational backgrounds may be inadequate. Methods to check data quality and ensure quality control should be included in the training program. The completion of surveillance activities should be part of routine formal performance evaluations for health workers responsible for data reporting. Feedback from higher levels of the surveillance system on how the surveillance data is used can provide additional incentive for quality data collection and analyses.

394. 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 analyze 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 mentioned above, sharing transportation and communication resources with other government or international programs may help 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 needing 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.

B. Setting up a National Surveillance System

Introduction

395. The success of any surveillance system starts with the commitment and quality of the staff that collect data on the 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 the disease rates look like in their region. These are the people who act as the first point of contact for data that is eventually included in national and international surveillance systems (Stanwell-Smith, 2003; Hunter, 2003, Quigley, 2003).

396. 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 with adequate personnel and resources (White, 2000). National surveillance may be less important or unnecessary if the appropriate response is more likely to involve local health, water and sanitation authorities.

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

(a) Who is responsible for reporting a case?

(b) To whom are the cases reported?

(c) What information is collected?

(d) Who collects the information?

(e) How are data transferred among administrative levels?

(f) How is information stored?

(g) Who analyzes the data?

(h) How are the data analyzed?

(i) How often are the data analyzed?

(j) What types of reports are prepared?

(k) How often are the reports disseminated?

(l) To whom are the reports disseminated?

(m) Through what mechanisms are the reports distributed?

(n) Are there any automatic responses to case reports?

Data Collection

398. The method of data collection and data transfer depends on the available technology in the region. Data collection can be done on handwritten forms or directly into a database

on laptop computer taken out on a field investigation. Laboratories may report their results directly into an electronic website that is set up for local hospital laboratories or national reference laboratories. Data storage can be on paper forms 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: 1) maintain confidentiality of personal patient information, 2) minimize data loss during storage and transfer, 3) minimize inaccurate data entry, 4) minimize inaccurate data transfer, and 5) keep multiple backups of the data both electronic versions and paper versions.

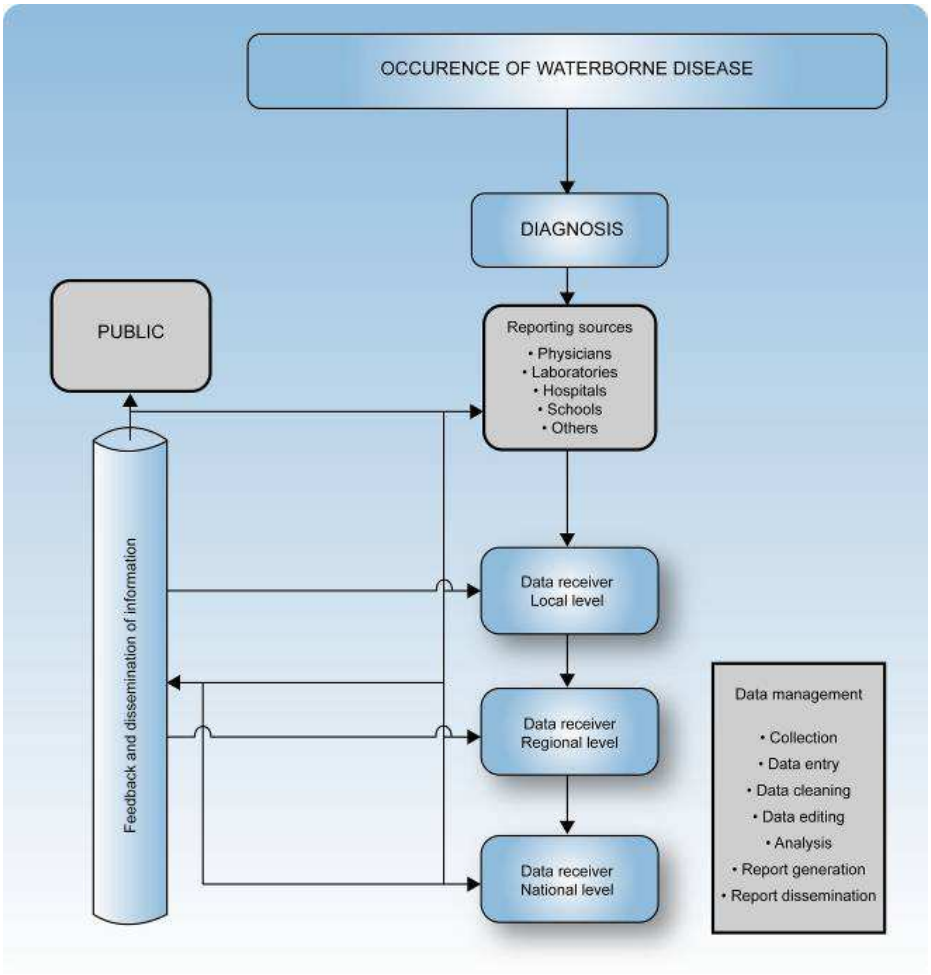
Data Management and Analysis

399. Free epidemiology software such as "Epi Info", can be used to assist with surveillance data management and analyses. Epi Info is available over the internet (http://www.cdc.gov/epiinfo/) in seven languages (English, French, Spanish, Arabic, Russian, Chinese and Serbo-Croatian), and manuals are also available in Italian, Portuguese, German, Norwegian, Hungarian, Czech, Polish, and Rumanian. It is usually not necessary to conduct complicated analyses of surveillance data. For outbreak surveillance systems, usually the number of outbreaks and the number of cases are reported by month, by geographic region, by type of water supply, by etiologic agent and sometimes by risk factor or deficiency. For surveillance systems that report number of cases of specific diseases, calculations of disease incidence by season, geographic region, age group and sex are useful for showing temporal and geographic patterns of disease occurrence and what populations 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 that the cases were reported.

Information Flow

400. In most surveillance systems, information is collected on a local level and sent to regional and national health authorities who compile and analyze 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 **Figure 10**. In some countries, these reports are also made available to the public and to international agencies such as the World Health Organization and non-governmental organizations. It is critical that the surveillance reports get to the health policy makers who can use these results to guide decisions about water and sanitation interventions, vaccine strategies, primary health care, etc. It is also vital that there is dissemination of surveillance results and analyses back 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 the goals of the surveillance system and see evidence that the information is used to improve public health.

Figure 10 Flow of surveillance information between local, regional and national levels (From Klaucke, 1992)



Information use

401. 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 by 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 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 the surveillance system provides the type of data that public health authorities and water authorities can use to address causes of waterborne disease.

Evaluating a Surveillance System

402. Any public health program 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 continued for their own sake and lose track of the purpose they were meant to fulfil. 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.

Evaluation Criteria

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

(a) Should there be a surveillance system for waterborne diseases?

(b) Is the surveillance system useful? Does the information from this surveillance help with policy decisions about water supply and sanitation interventions?

(c) Does waterborne disease surveillance lead to improved public health?

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

(a) Magnitude of waterborne disease

(b) Level of morbidity associated with waterborne disease

(c) Severity of disease

(d) Premature mortality associated with waterborne disease

(e) Economic costs (including medical costs, absenteeism and lost productivity)

(f) Whether waterborne disease is preventable.

405. Usually, some type of surveillance system is necessary to provide the 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, 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 that indicate that waterborne disease morbidity and mortality can be reduced by improvements in water and sanitation (Esrey, 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.

406. 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 surveillance 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 to reduce waterborne disease.

Output Evaluation Criteria

407. The output of a surveillance system can be evaluated by five criteria: 1) sensitivity, 2) predictive value positive, 3) timeliness, 4) representativeness and 5) data quality.

408. Sensitivity: The sensitivity of a system is its ability to detect the events under surveillance, such as 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**).

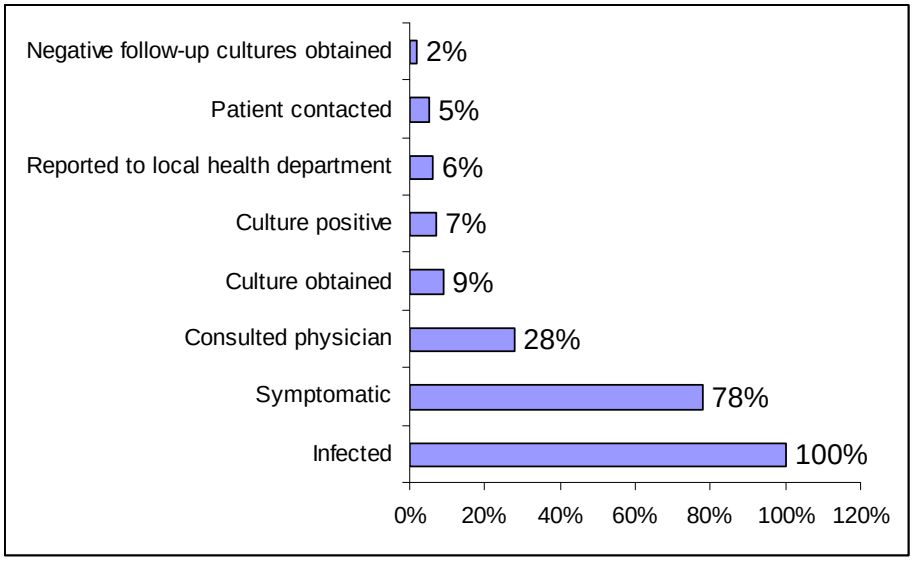
Table 16 Detection of health conditions with a surveillance system

		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

Sensitivity = A/(A+C)

409. 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 (**Figure 11**).

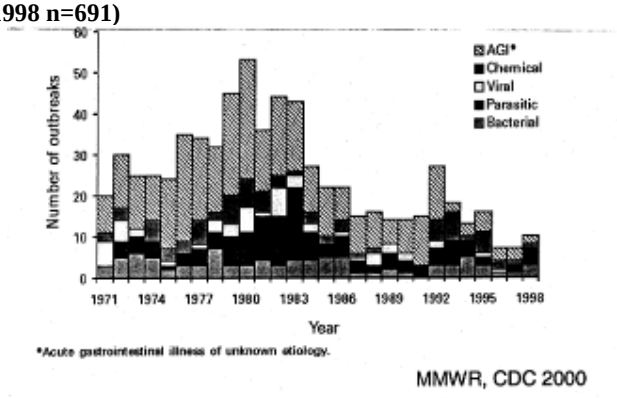
Figure 11 Stages of identification, reporting and investigation of shigellosis



410. A surveillance system should be sensitive enough to detect changes in disease incidence. For example, surveillance data on waterborne disease outbreaks in the United

States indicates that the number of reported waterborne disease outbreaks in the United States decreased from 1971 to 1998 and that there were more outbreaks associated with parasitic agents in the early 1980's (**Figure 12**). Although this voluntary, passive surveillance system is not very sensitive, it can still provide useful information on trends in the incidence of waterborne disease outbreaks and their aetiologies.

Figure 12 Number of waterborne disease outbreaks by year and by etiologic agent (USA 1971 – 1998 n=691)



411. Sensitivities of surveillance vary from system to system and between countries and geographic regions, 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 was not comparable among countries because of differences in reporting methods, case definitions, structure of the surveillance system and quality of the data (Kramer, 2001).

412. 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** , the predictive value positive is shown as A/A+B where A = the number of true positive cases that were detected by surveillance and B = 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.

Table 17 Number of waterborne disease outbreaks by year (Germany 1945 – 2008, n = 10) adapted from (Thofern, 1990)

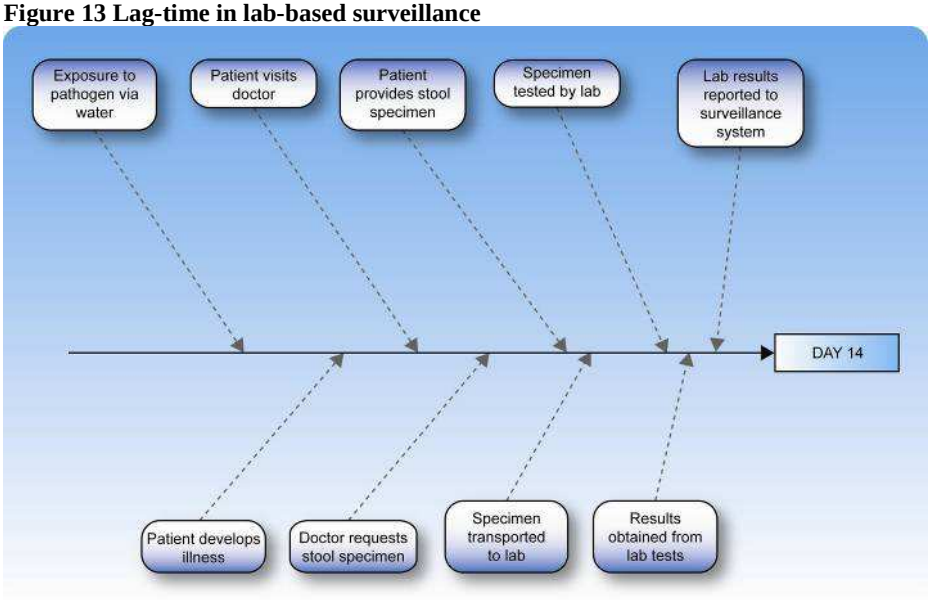
Year	*Location*	*Disease/Pathogen*	*Cases*
1946	Neu-Oetting	Typhoid	≈ 400
1948	Neu-Oetting	Typhoid	≈ 600
1956	Hagen	Typhoid/paratyphoid	≈ 500
1971	Heidenau	Dysentery	482
1972	Worbis	Dysentery	≈ 1,400

1972	Dingelstedt	Hepatitis A	≈ 40
1978	Muenchen-Ismaning	Dysentery	2,450
1980	Jena	Typhoid	69
1981	Halle	Rotavirus	11600
2000	Regensdorf	Giardiasis	10

413. 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 time a patient is exposed to a pathogen and the time the laboratory-confirmed infection is reported to the surveillance system (**Figure 13**). 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 where the data is 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.

414. Finally, the type of surveillance system, passive vs. 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 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 in the previous section 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.

Figure 13 Lag-time in lab-based surveillance



415. Representativeness: The data collected in a surveillance system should be representative of 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 they are more likely to seek medical care and 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 over-reporting or under-reporting of cases in certain economic classes or regions because of access to medical care. Often rural areas and poorer groups in the population are 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 in 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.

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

417. Smaller water utilities may be at greater risk of problems with 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 and there may be limited communication with regional or national health authorities.

418. Data Quality: The final area of output that should be evaluated is the quality of the data that is collected by the surveillance system. Assessments of data quality can be made simply by inspection of the data forms and the database. Is 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.

Process Evaluation Criteria

419. The surveillance system process can be evaluated by four criteria: 1) acceptability, 2) simplicity, 3) flexibility, and 4) cost.

(a) Acceptability: Acceptability depends on making the surveillance system easy for the user - especially for those who are responsible for making the initial reports 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 diseases. Surveillance systems must be committed to protecting the privacy of the cases that are reported.

(b) 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.

(c) 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 to accommodate future changes.

(d). 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 both financial and human resources. Public health authorities need to weigh the costs of the system against the public health benefits to decide whether the costs are acceptable and if the critical surveillance information is being collected in the most economical way. **Table 18** compares the estimated costs of active vs. passive surveillance at a local health department in the United States (Vogt, 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, 1983).

Table 18 Comparing estimated costs for active and passive surveillance systems

Vermont Health Department Costs (1 June 1980 – 31 May 1981)

	Type of surveillance system	
	Active* (USD)	Passive** (USD)
Paper	114	80
Mailing	185	48
Telephone	1947	175
Personnel (Secretary)	3000	2000
Personnel (Public health nurse)	14025	0
Total	19271	2303

*Active: weekly calls from health department to request reports

**Passive: provider-initiated reporting

(e) 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 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 is doing these activities, then it is likely that they understand the usefulness of the surveillance information for planning public health interventions and can sustain the surveillance system (White, 2000).

Summary

420. 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.

421. 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 is only being collected and not being analyzed 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 go to public health authorities who 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.

VII. Data Management and Analysis using Geographical Information Systems (GIS)

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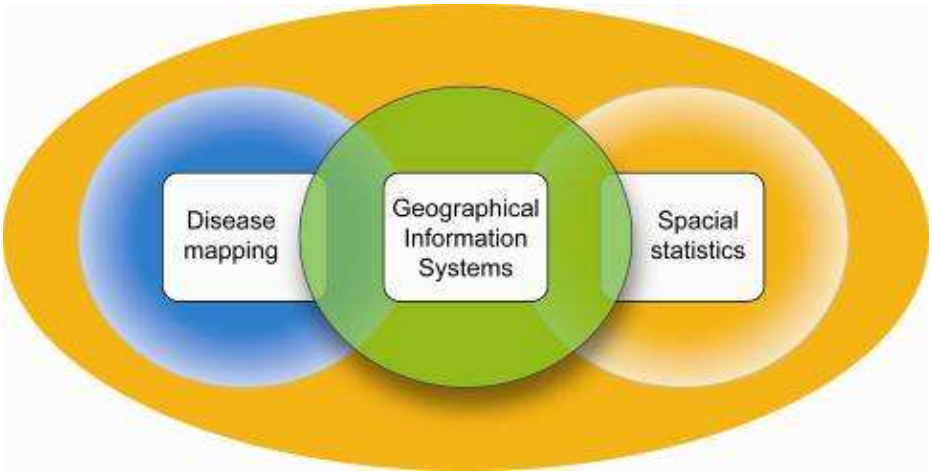
A. Introduction to GIS

422. A Geographic Information System (GIS) is a computing technology for the capture, storage, manipulation, analysis, and display of spatially referenced data (Clarke, 1996; Croner, 1996; Moore, 1999; WHO, 1999). Mostly GIS is used to combine mapping facilities and spatial statistical methods

Figure 14 Disease mapping, spatial analysis and GIS- Source: Institute for Hygiene, University of Bonn, Germany

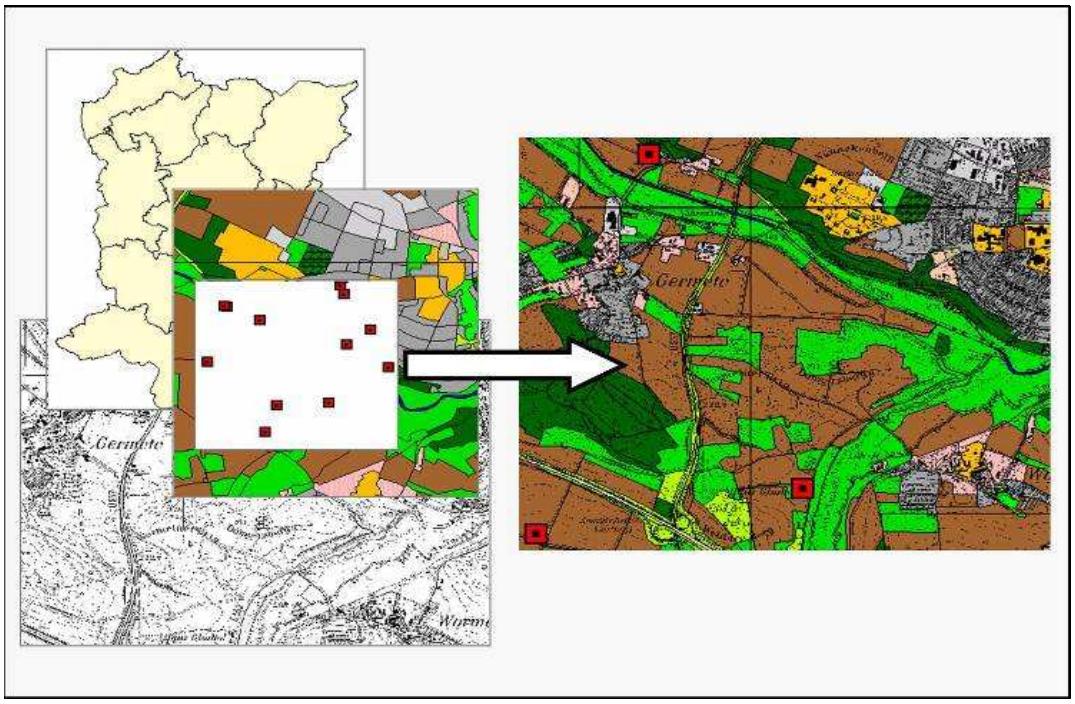


423. GIS can be used to define the condition and location of disease events, to analyse time trends, to investigate spatial patterns and to perform modelling of disease developments. The functions of a GIS are to generate thematic maps, to allow overlaying of different pieces of information, and to create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

424. A GIS is working with dynamic data bases, which permit a dynamic link between spatially related data and maps. Due to this, data updates are automatically reflected on the map.

425. 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, and land use patterns, the place of residents of diseased persons, the water distribution system, or the incidence of gastrointestinal infections for example **Figure 15** 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 data.

Figure 15 Layered structure of a GIS



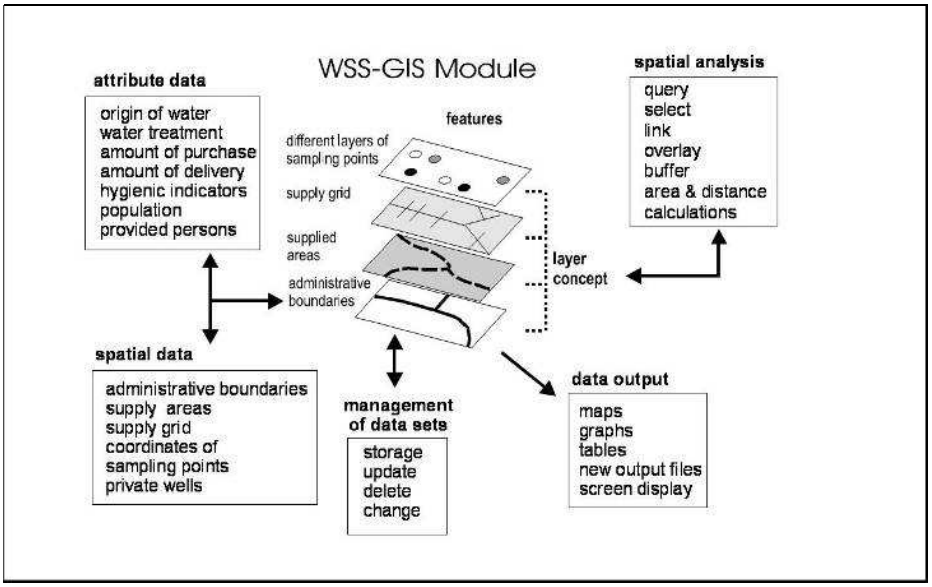
426. GIS applications can be of high value during hazard identification, exposure assessment, as well as preventive, control and surveillance measures.

B. Application of GIS to Waterborne Disease Epidemiology

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

428. In outbreak situations urgent Public Health action is needed. In those situations it is important to understand spatial relations which are a condition for successful prevention, control and surveillance of diseases. GIS is an ideal tool for monitoring waterborne disease interventions over time. It helps to determine the geographical distribution and variation of diseases, simply analysing spatial and longitudinal trends, mapping population at risk and assessing resource allocations. Much of the relevant information is space-related, for example distribution of cases, patterns of risk factors, health services, infrastructure, and emergency medical services. As a part of an incident plan or outbreak management it is an important condition 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 etc. the capacity of a Water Supply Structure-GIS (WSS-GIS) combines large volumes of data from widely different sources, makes it an ideal tool for storing, analysing and displaying data concerning water supply structures (Kistemann T, 2001). The Institute for Hygiene and Public Health (IHPH) in Bonn designed a so-called Water Supply Structure (WSS) - GIS module to handle the referring data. The principle of the module is shown on the following **Figure 16**

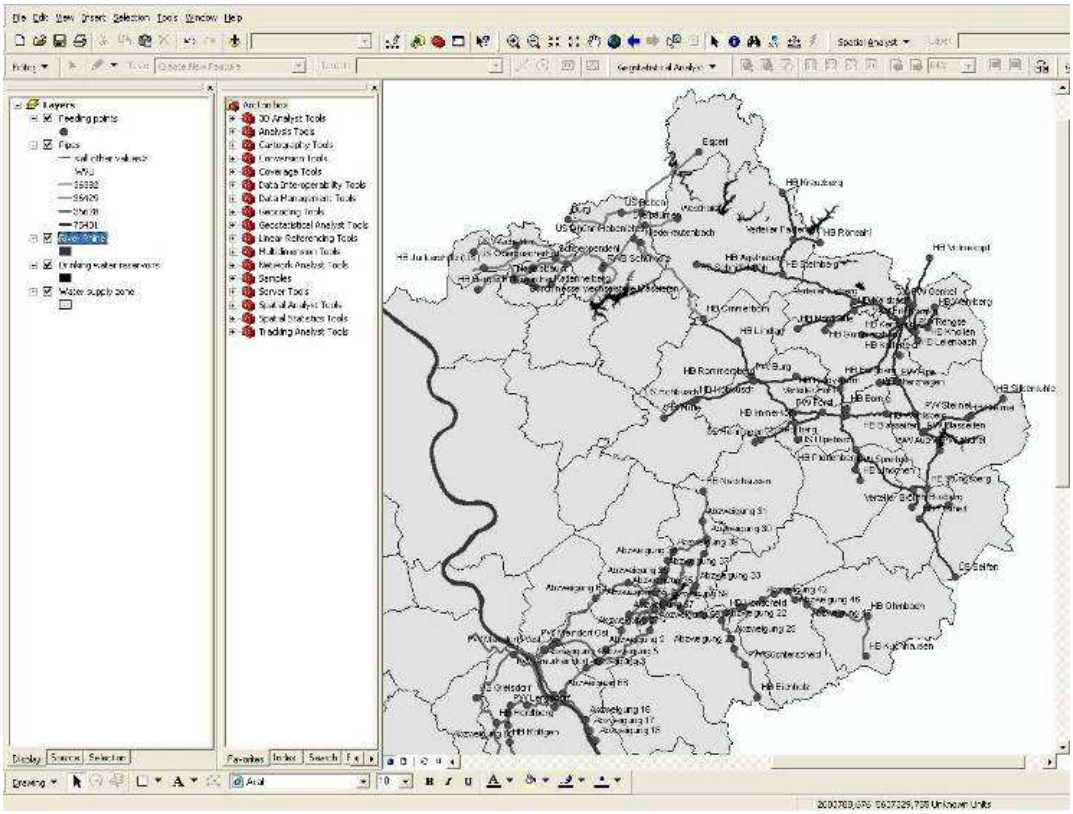
Figure 16 Elements of a WSS GIS- Source: Kistemann et al., 2001 [Kistemann, T., Herbst, S., Dangendorf, F. and Exner, M. (2001). GIS-based analysis of drinking-water supply structures: a module for microbial risk assessment, International Journal of Hygiene and Environmental Health 203, 301-310]



429. As with all databases, 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 specific to the task.

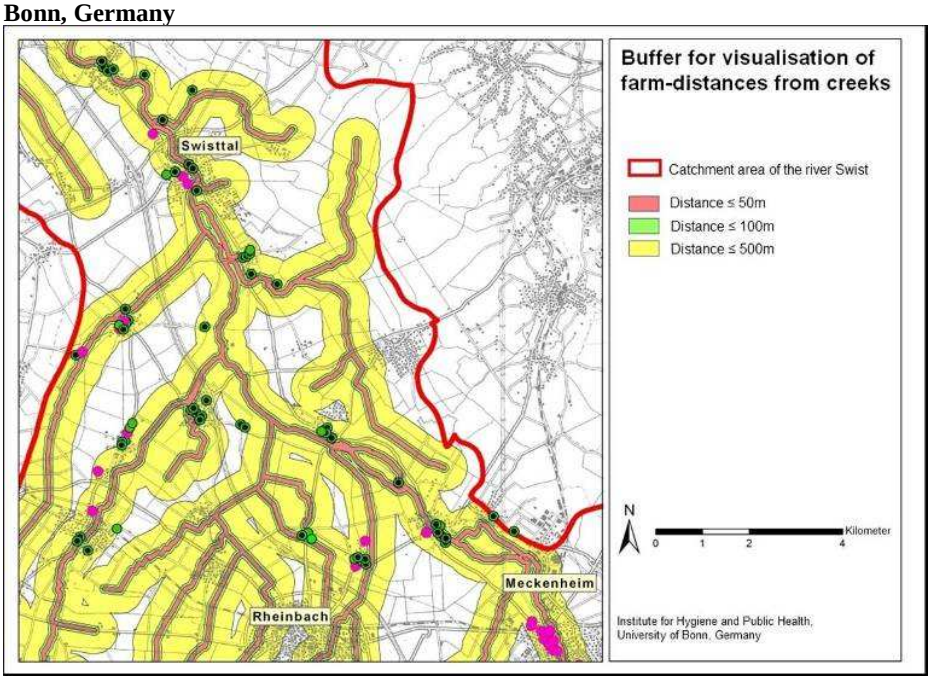
430. The water supply infrastructure strongly influences the spatial pattern of drinking-water-related-ill-health. Therefore, and in particular if applying the HACCP concept of quality management, it is a huge importance to have detailed information on water purification facilities, disinfection points, feeding points, and water distribution. One of the most immediately obvious benefits of 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 in the mass of information. In Figure 17, feeding points and digitized pipes are shown. Each different colour of the points characterizes different health authorities which are responsible for the surveillance in those regions.

Figure 17 Pipes and feeding points of water suppliers in Germany- Source: Institute for Hygiene, University of Bonn, Germany



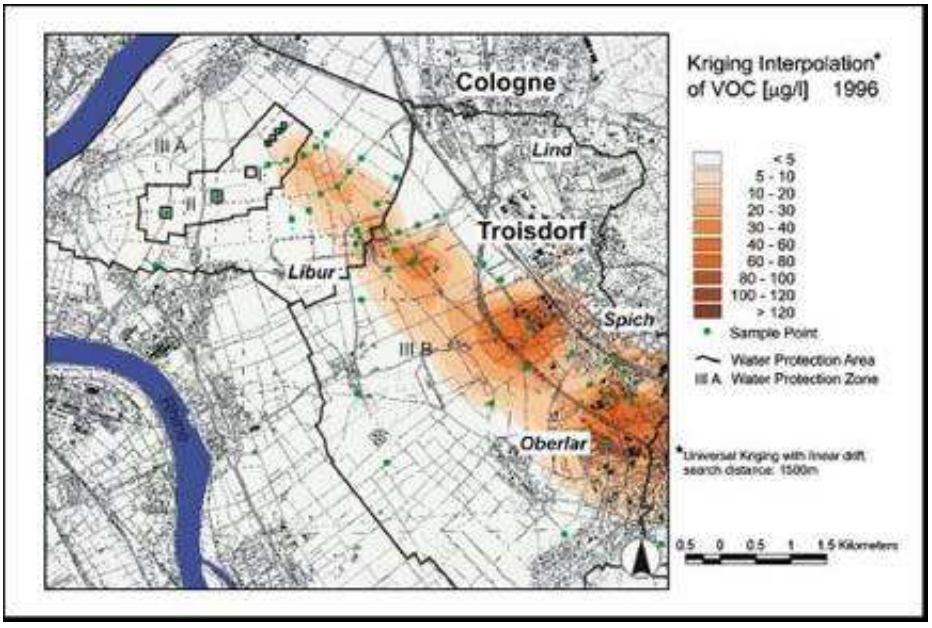
431. It is very helpful to use such a spatial tool, as water supply infrastructure, at least in densely populated areas, is often very complicated, including confusing relationships between different waterworks. By using spatial analysis tools in a GIS, it is possible to describe spatial patterns, calculate distances of selected features or predict values of unmeasured locations. Figure 18 shows the application of a buffer tool for a small creek in Germany in order to calculate areas in a specific distance of the creek that is influenced of agricultural activities, like live stock farming, etc.

Figure 18 Creating buffer areas in GIS- Source: Institute for Hygiene, University of Bonn, Germany



432. A more sophisticated approach of spatial analysis in a GIS is the use of interpolation techniques. One example is the kriging interpolation, assuming that things that are close to one another are more alike than other farther away. Figure 19 shows the spread of chemical contamination with volatile halogenated hydrocarbons (VHH) in the catchment area of ground water abstraction in Germany.

Figure 19 Kriging interpolation in a GIS- Source: Institute for Hygiene, University of Bonn, Germany



433. 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 contaminations could be displayed in series of maps. Spatial analysis showed in this example that concentrations decreased downstream, but this decrease was stronger for highly chlorinated pollutants. The GIS enabled to calculate the total VHH load of the ground water, and it was clear that contamination considerably endangered the water work.

434. Comprising, high quality spatial information on catchment areas, water supply infrastructure and epidemiology of water-related diseases allow assessing the burden of water-related disease caused by specific conditions. It is a precondition for well-founded priority defining in water-related disease management. It is obvious that high-quality map outputs may easily support results, especially to those outside the field.

C. Example: GIS-Supported Epidemiological Confirmation of the First Waterborne Giardiasis Outbreak in Germany

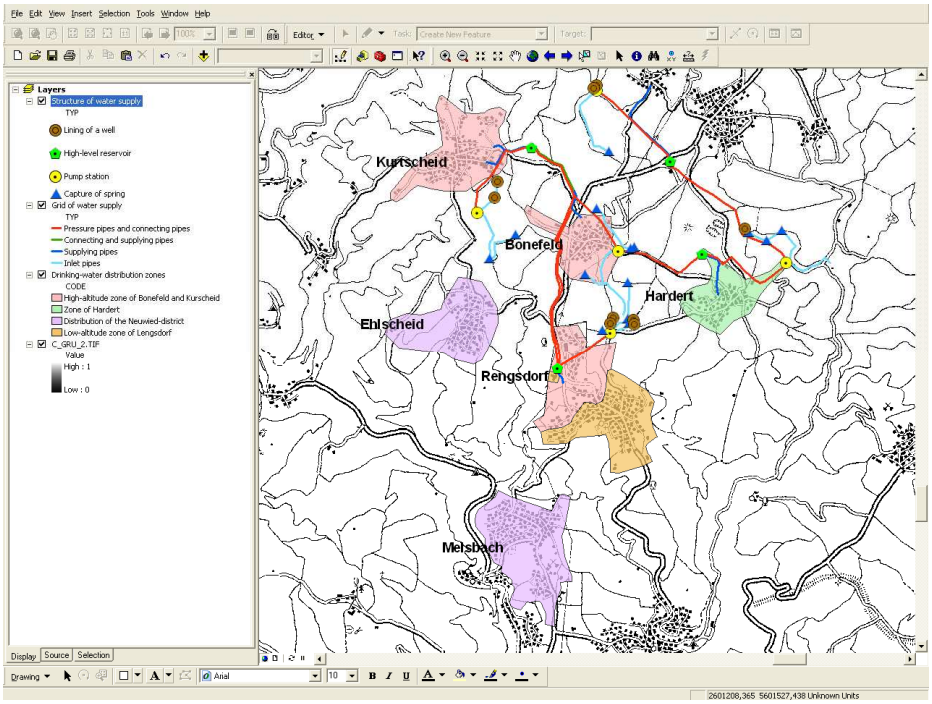
435. The aim of the last chapter was to give an idea of the numerous opportunities for epidemiology offered by GIS. Let us now take a closer look at an investigation carried out in 2000/2001, where a Giardiasis-outbreak could be identified as drinking-waterborne by a GIS-supported epidemiological study. (Kistemann, 2003; Gornik, 2001; Atherholt, 1998; Ong, 1996; Craun, 2002; Howe, 2002; Hunter, 1998; Kramer, 2001; Steiner, 1997; States, 1997; Kistemann, 2001)

436. Since May 2000, a general practitioner (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 within these diarrhoea patients. However, the GP got the stool of all of her patients with diarrhoea tested for G. lamblia. The stool samples of 8 out of totally 43 patients were tested positive for Giardia a cyst, which means a prevalence of 18.60%. The GP suspected the cases to be interrelated and reported all infections to the District Health Authority as in accordance with the Federal Epidemic Act every infection normally has to be. The Public Health Officer knew about water being a possible route for transfer of Giardia infections and asked the Institute for Hygiene and Public Health in Bonn to support the performance of parasitological and epidemiological investigations into the question whether the Rengsdorf Giardia cases were related to water.

437. A retrospective cohort study was conducted in November 2000 comprising the catchment area of the GP practice (primary school Rengsdorf) as well as a control area (Melsbach). All primary school pupils were chosen as investigation population (N=418). 383 pupils participated in the study, the response rate being 91,6% and the share of the total population being 4.1%.

438. 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 back 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 use of a standard software package (Epilnfo2000®). Geo-referenced data were transferred to a Geographical Information System (ArcView®) via SQL-connections to support spatial analysis and communication of results. The following **Figure 20 Water supply structures shown as layers in a GIS** shows the complex structure of water supply in the investigated area:

Figure 20 Water supply structures shown as layers in a GIS



439. In the village of Rengsdorf, the water supply is divided up 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 l 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. Additionally, continuously about 10% of the water come from the low-altitude zone reservoir. About 700,000 l 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 sub-municipalities 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 derived by clicking the info-button. Additionally, photos were connected to the GIS via hotlinks.

440. 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 **Figure 21** and **Figure 22**).

Figure 21 Cases of giardiasis in each village

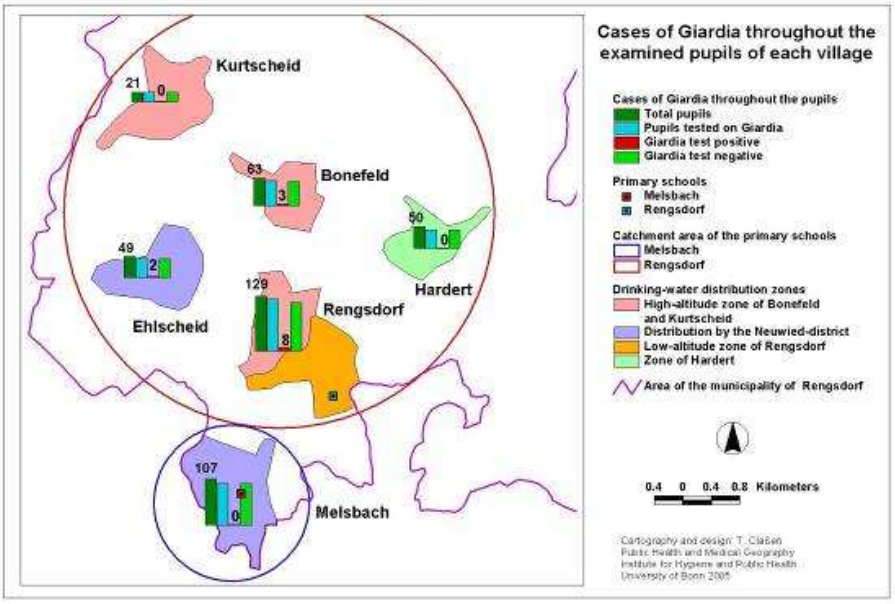
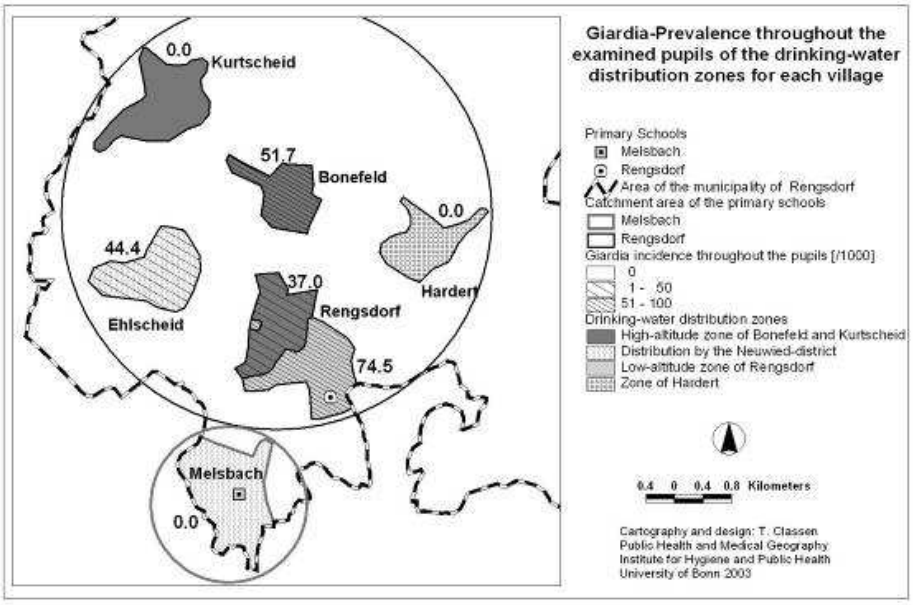


Figure 22 Giardia incidence throughout the examined pupils, differentiated for drinking-water distribution zones and individual villages



441. To investigate the potential relation between cases and water supply, those supply zones were combined which are not related to the Rengsdorf supply zones, i.e. 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, as well, the risk was significantly increased by 3.5 (p=0.078). The combination of both zones showed an increase by 5.1 (p=0.009). The results concerning water consumption habits showed that the risk of Giardia infection is significantly increased if a soda streamer is used at home to prepare tap water for consumption. Other factors like nutritional habits, travelling, animal contacts and bathing in natural waters were not identified to be significant for acquiring a Giardia infection.

442. Simultaneously with the epidemiological investigation, microbiological and parasitological investigations of the raw and drinking-water in Rengsdorf as well as a field investigation were conducted. 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 hotlinks) confirmed several environmental risk factors very close to a spring to have been responsible for contamination of raw water with high probability just like a deer enclosure or the outlet of combined sewage overflow. But it was impossible to definitely identify the contamination source of the spring retrospectively.

443. Rengsdorf has re-vitalised the discussion about water-related diseases in Germany. Politicians, authorities, the waterworks organisation 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 possibly do occur more often than we get to know.

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