Guidelines for Drinking-water Quality

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Contents

Preface

Access to safe drinking-water is essential to health, a basic human right and a component of effective policy for health protection.

The importance of water, sanitation and hygiene for health and development has been reflected in the outcomes of a series of international policy forums. These have included health-oriented conferences such as the International Conference on Primary Health Care, held in Alma-Ata, Kazakhstan (former Soviet Union), in 1978. They have also included water-oriented conferences such as the 1977 World Water Conference in Mar del Plata, Argentina, which launched the water supply and sanitation decade of 1981–1990, as well as the Millennium Declaration goals adopted by the General Assembly of the United Nations (UN) in 2000 and the outcome of the Johannesburg World Summit for Sustainable Development in 2002. Most recently, the UN General Assembly declared the period from 2005 to 2015 as the International Decade for Action, "Water for Life."

Access to safe drinking-water is important as a health and development issue at a national, regional and local level. In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit, since the reductions in adverse health effects and health care costs outweigh the costs of undertaking the interventions. This is true for major water supply infrastructure investments through to water treatment in the home. Experience has also shown that interventions in improving access to safe water favour the poor in particular, whether in rural or urban areas, and can be an effective part of poverty alleviation strategies.

In 1983–1984 and in 1993–1997, the World Health Organization (WHO) published the first and second editions of the *Guidelines for Drinking-water Quality* in three volumes as successors to previous WHO International Standards. In 1995, the decision was made to pursue the further development of the Guidelines through a process of rolling revision. This led to the publication of addenda to the second edition of the Guidelines, on chemical and microbial aspects, in 1998, 1999 and 2002; the publication of a text on *Toxic Cyanobacteria in Water*; and the preparation of expert reviews on key issues preparatory to the development of a third edition of the Guidelines.

In 2000, a detailed plan of work was agreed upon for development of the third edition of the Guidelines. As with previous editions, this work was shared between WHO Headquarters and the WHO Regional Office for Europe (EURO). Leading the process of the development of the third edition were the Programme on Water Sanitation and Health within Headquarters and the European Centre for Environment and Health, Rome, within EURO. Within WHO Headquarters, the Programme on Chemical Safety provided inputs on some chemical hazards, and the Programme on Radiological Safety contributed to the section dealing with radiological aspects. All six WHO Regional Offices participated in the process.

This revised Volume 1 of the Guidelines is accompanied by a series of publications providing information on the assessment and management of risks associated with microbial hazards and by internationally peer-reviewed risk assessments for specific chemicals. These replace the corresponding parts of the previous Volume 2. Volume 3 provides guidance on good practice in surveillance, monitoring and assessment of drinking-water quality in community supplies. The Guidelines are also accompanied by other publications explaining the scientific basis of their development and providing guidance on good practice in implementation.

This volume of the *Guidelines for Drinking-water Quality* explains requirements to ensure drinking-water safety, including minimum procedures and specific guideline values, and how those requirements are intended to be used. The volume also describes the approaches used in deriving the guidelines, including guideline values. It includes fact sheets on significant microbial and chemical hazards. The development of this third edition of the *Guidelines for Drinking-water Quality* includes a substantive revision of approaches to ensuring microbial safety. This takes account of important developments in microbial risk assessment and its linkages to risk management. The development of this orientation and content was led over an extended period by Dr Arie Havelaar (RIVM, Netherlands) and Dr Jamie Bartram (WHO).

Since the second edition of WHO's *Guidelines for Drinking-water Quality*, there have been a number of events that have highlighted the importance and furthered understanding of various aspects of drinking-water quality and health. These are reflected in this third edition of the Guidelines.

These Guidelines supersede those in previous editions (1983–1984, 1993–1997 and addenda in 1998, 1999 and 2002) and previous International Standards (1958, 1963 and 1971). The Guidelines are recognized as representing the position of the UN system on issues of drinking-water quality and health by "UN-Water," the body that coordinates amongst the 24 UN agencies and programmes concerned with water issues. This edition of the Guidelines further develops concepts, approaches and information in previous editions:

- Experience has shown that microbial hazards continue to be the primary concern in both developing and developed countries. Experience has also shown the value of a systematic approach towards securing microbial safety. This edition includes

significantly expanded guidance on ensuring microbial safety of drinking-water, building on principles – such as the multiple-barrier approach and the importance of source protection – considered in previous editions. The Guidelines are accompanied by documentation describing approaches towards fulfilling requirements for microbial safety and providing guidance to good practice in ensuring that safety is achieved.

- Information on many chemicals has been revised. This includes information on chemicals not considered previously; revisions to take account of new scientific information; and, in some cases, lesser coverage where new information suggests a lesser priority.
- Experience has also shown the necessity of recognizing the important roles of many different stakeholders in ensuring drinking-water safety. This edition includes discussion of the roles and responsibilities of key stakeholders in ensuring drinking-water safety.
- The need for different tools and approaches in supporting safe management of large piped supplies versus small community supplies remains relevant, and this edition describes the principal characteristics of the different approaches.
- There has been increasing recognition that only a few key chemicals cause large-scale health effects through drinking-water exposure. These include fluoride and arsenic. Other chemicals, such as lead, selenium and uranium, may also be significant under certain conditions. Interest in chemical hazards in drinking-water was highlighted by recognition of the scale of arsenic exposure through drinking-water in Bangladesh and elsewhere. The revised Guidelines and associated publications provide guidance on identifying local priorities and on management of the chemicals associated with large-scale effects.
- WHO is frequently approached for guidance on the application of the *Guidelines for Drinking-water Quality* to situations other than community supplies or managed utilities. This revised edition includes information on application of the Guidelines to several specific circumstances and is accompanied by texts dealing with some of these in greater detail.

The *Guidelines for Drinking-water Quality* are kept up to date through a process of rolling revision, which leads to periodic release of documents that may add to or supersede information in this volume.

The Guidelines are addressed primarily to water and health regulators, policy-makers and their advisors, to assist in the development of national standards. The Guidelines and associated documents are also used by many others as a source of information on water quality and health and on effective management approaches.

Acknowledgements

The preparation of the current edition of the *Guidelines for Drinking-water Quality* and supporting documentation covered a period of eight years and involved the participation of over 490 experts from 90 developing and developed countries. The contributions of all who participated in the preparation and finalization of the *Guidelines for Drinking-water Quality*, including those individuals listed in Annex 2, are gratefully acknowledged.

The work of the following Working Groups was crucial to the development of the third edition of the *Guidelines for Drinking-water Quality*:

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Acronyms and abbreviations used in text

AAS	atomic absorption spectrometry
AD	Alzheimer disease
ADI	acceptable daily intake
AES	atomic emission spectrometry
AIDS	acquired immunodeficiency syndrome
AMPA	aminomethylphosphonic acid
BaP	benzo[*a*]pyrene
BDCM	bromodichloromethane
BMD	benchmark dose
bw	body weight
CAC	Codex Alimentarius Commission
CAS	Chemical Abstracts Service
CICAD	Concise International Chemical Assessment Document
CSAF	chemical-specific adjustment factor
Ct	product of disinfectant concentration and contact time
DAEC	diffusely adherent *E. coli*
DALY	disability-adjusted life-year
DBCM	dibromochloromethane
DBCP	1,2-dibromo-3-chloropropane
DBP	disinfection by-product
DCB	dichlorobenzene
DCP	dichloropropane
DDT	dichlorodiphenyltrichloroethane
DEHA	di(2-ethylhexyl)adipate
DEHP	di(2-ethylhexyl)phthalate
DNA	deoxyribonucleic acid

EAAS	electrothermal atomic absorption spectrometry
EAEC	enteroaggregative *E. coli*
EBCT	empty bed contact time
EC	electron capture
ECD	electron capture detector
EDTA	edetic acid; ethylenediaminetetraacetic acid
EHC	Environmental Health Criteria monograph
EHEC	enterohaemorrhagic *E. coli*
EIEC	enteroinvasive *E. coli*
ELISA	enzyme-linked immunosorbent assay
EPEC	enteropathogenic *E. coli*
ETEC	enterotoxigenic *E. coli*
EURO	WHO Regional Office for Europe
FAAS	flame atomic absorption spectrometry
FAO	Food and Agriculture Organization of the United Nations
FD	fluorescence detector
FID	flame ionization detector
FPD	flame photodiode detector
GAC	granular activated carbon
GAE	granulomatous amoebic encephalitis
GC	gas chromatography
GL	guidance level (used for radionuclides in drinking-water)
GV	guideline value
HACCP	hazard analysis and critical control points
HAd	human adenovirus
HAstV	human astrovirus
HAV	hepatitis A virus
Hb	haemoglobin
HCB	hexachlorobenzene
HCBD	hexachlorobutadiene
HCH	hexachlorocyclohexane
HEV	hepatitis E virus
HIV	human immunodeficiency virus
HPC	heterotrophic plate count
HPLC	high-performance liquid chromatography
HRV	human rotavirus
HuCV	human calicivirus
HUS	haemolytic uraemic syndrome

IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer
IC	ion chromatography
ICP	inductively coupled plasma
ICRP	International Commission on Radiological Protection
IDC	individual dose criterion
IPCS	International Programme on Chemical Safety
ISO	International Organization for Standardization
JECFA	Joint FAO/WHO Expert Committee on Food Additives
JMPR	Joint FAO/WHO Meeting on Pesticide Residues
K_{ow}	octanol/water partition coefficient
LI	Langelier Index
LOAEL	lowest-observed-adverse-effect level
MCB	monochlorobenzene
MCPA	4-(2-methyl-4-chlorophenoxy)acetic acid
MCPP	2(2-methyl-chlorophenoxy) propionic acid; mecoprop
metHb	methaemoglobin
MMT	methylcyclopentadienyl manganese tricarbonyl
MS	mass spectrometry
MX	3-chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone
NAS	National Academy of Sciences (USA)
NOAEL	no-observed-adverse-effect level
NOEL	no-observed-effect level
NTA	nitrilotriacetic acid
NTP	National Toxicology Program (USA)
NTU	nephelometric turbidity unit
P/A	presence/absence
PAC	powdered activated carbon
PAH	polynuclear aromatic hydrocarbon
PAM	primary amoebic meningoencephalitis
PCP	pentachlorophenol
PCR	polymerase chain reaction
PD	photoionization detector
PMTDI	provisional maximum tolerable daily intake
PT	purge and trap
PTDI	provisional tolerable daily intake

PTWI	provisional tolerable weekly intake
PVC	polyvinyl chloride
QMRA	quantitative microbial risk assessment
RDL	reference dose level
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (Dutch National Institute of Public Health and Environmental Protection)
RNA	ribonucleic acid
SI	Système international d'unités (International System of Units)
SOP	standard operating procedure
SPADNS	sulfo phenyl azo dihydroxy naphthalene disulfonic acid
TBA	terbuthylazine
TCB	trichlorobenzene
TCU	true colour unit
TD_{05}	tumorigenic dose$_{05}$, the intake or exposure associated with a 5% excess incidence of tumours in experimental studies in animals
TDI	tolerable daily intake
TDS	total dissolved solids
THM	trihalomethane
TID	thermal ionization detector
UF	uncertainty factor
UNICEF	United Nations Children's Fund
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USA	United States of America
US EPA	United States Environmental Protection Agency
UV	ultraviolet
UVPAD	ultraviolet photodiode array detector
WHO	World Health Organization
WHOPES	World Health Organization Pesticide Evaluation Scheme
WQT	water quality target
WSP	water safety plan
YLD	years of healthy life lost in states of less than full health, i.e., years lived with a disability
YLL	years of life lost by premature mortality

1 Introduction

1.1 General considerations and principles

The primary purpose of the *Guidelines for Drinking-water Quality* is the protection of public health.

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health. Every effort should be made to achieve a drinking-water quality as safe as practicable.

Diseases related to contamination of drinking-water constitute a major burden on human health. Interventions to improve the quality of drinking-water provide significant benefits to health.

Safe drinking-water, as defined by the Guidelines, does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Those at greatest risk of waterborne disease are infants and young children, people who are debilitated or living under unsanitary conditions and the elderly. Safe drinking-water is suitable for all usual domestic purposes, including personal hygiene. The Guidelines are applicable to packaged water and ice intended for human consumption. However, water of higher quality may be required for some special purposes, such as renal dialysis and cleaning of contact lenses, or for certain purposes in food production and pharmaceutical use. Those who are severely immunocompromised may need to take additional steps, such as boiling drinking-water, due to their susceptibility to organisms that would not normally be of concern through drinking-water. The Guidelines may not be suitable for the protection of aquatic life, or for some industries.

The Guidelines are intended to support the development and implementation of risk management strategies that will ensure the safety of drinking-water supplies through the control of hazardous constituents of water. These strategies may include national or regional standards developed from the scientific basis provided in the Guidelines. The Guidelines describe reasonable minimum requirements of safe practice to protect the health of consumers and/or derive numerical "guideline values" for

constituents of water or indicators of water quality. Neither the minimum safe practices nor the numeric guideline values are mandatory limits. In order to define such limits, it is necessary to consider the guidelines in the context of local or national environmental, social, economic and cultural conditions.

The main reason for not promoting the adoption of international standards for drinking-water quality is the advantage provided by the use of a risk–benefit approach (qualitative or quantitative) in the establishment of national standards and regulations. Further, the Guidelines are best implemented through an integrated preventive management framework for safety applied from catchment to consumer. The Guidelines provide a scientific point of departure for national authorities to develop drinking-water regulations and standards appropriate for the national situation. In developing standards and regulations, care should be taken to ensure that scarce resources are not unnecessarily diverted to the development of standards and the monitoring of substances of relatively minor importance to public health. The approach followed in these Guidelines is intended to lead to national standards and regulations that can be readily implemented and enforced and are protective of public health.

The nature and form of drinking-water standards may vary among countries and regions. There is no single approach that is universally applicable. It is essential in the development and implementation of standards that the current and planned legislation relating to water, health and local government are taken into account and that the capacity to develop and implement regulations is assessed. Approaches that may work in one country or region will not necessarily transfer to other countries or regions. It is essential that each country review its needs and capacities in developing a regulatory framework.

The judgement of safety – or what is an acceptable level of risk in particular circumstances – is a matter in which society as a whole has a role to play. The final judgement as to whether the benefit resulting from the adoption of any of the guidelines and guideline values as national or local standards justifies the cost is for each country to decide.

Although the Guidelines describe a quality of water that is acceptable for lifelong consumption, the establishment of these Guidelines, including guideline values, should not be regarded as implying that the quality of drinking-water may be degraded to the recommended level. Indeed, a continuous effort should be made to maintain drinking-water quality at the highest possible level.

An important concept in the allocation of resources to improving drinking-water safety is that of incremental improvements towards long-term targets. Priorities set to remedy the most urgent problems (e.g., protection from pathogens; see section 1.1.1) may be linked to long-term targets of further water quality improvements (e.g., improvements in the acceptability of drinking-water; see section 1.1.5).

The basic and essential requirements to ensure the safety of drinking-water are a "framework" for safe drinking-water, comprising health-based targets established by

a competent health authority; adequate and properly managed systems (adequate infrastructure, proper monitoring and effective planning and management); and a system of independent surveillance.

A holistic approach to drinking-water supply risk assessment and risk management increases confidence in the safety of drinking-water. This approach entails systematic assessment of risks throughout a drinking-water supply – from the catchment and its source water through to the consumer – and identification of the ways in which these risks can be managed, including methods to ensure that control measures are working effectively. It incorporates strategies to deal with day-to-day management of water quality, including upsets and failures.

The Guidelines are applicable to large metropolitan and small community piped drinking-water systems and to non-piped drinking-water systems in communities and in individual dwellings. The Guidelines are also applicable to a range of specific circumstances, including large buildings, travellers and conveyances.

The great majority of evident water-related health problems are the result of microbial (bacteriological, viral, protozoan or other biological) contamination. Nevertheless, an appreciable number of serious health concerns may occur as a result of the chemical contamination of drinking-water.

1.1.1 Microbial aspects

Securing the microbial safety of drinking-water supplies is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking-water or to reduce contamination to levels not injurious to health. Safety is increased if multiple barriers are in place, including protection of water resources, proper selection and operation of a series of treatment steps and management of distribution systems (piped or otherwise) to maintain and protect treated water quality. The preferred strategy is a management approach that places the primary emphasis on preventing or reducing the entry of pathogens into water sources and reducing reliance on treatment processes for removal of pathogens.

> The potential health consequences of microbial contamination are such that its control must always be of paramount importance and must never be compromised.

In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with human or animal (including bird) faeces. Faeces can be a source of pathogenic bacteria, viruses, protozoa and helminths.

Faecally derived pathogens are the principal concerns in setting health-based targets for microbial safety. Microbial water quality often varies rapidly and over a wide range. Short-term peaks in pathogen concentration may increase disease risks considerably and may trigger outbreaks of waterborne disease. Furthermore, by the time microbial contamination is detected, many people may have been exposed. For

these reasons, reliance cannot be placed solely on end-product testing, even when frequent, to ensure the microbial safety of drinking-water.

Particular attention should be directed to a water safety framework and implementing comprehensive water safety plans (WSPs) to consistently ensure drinking-water safety and thereby protect public health (see chapter 4). Management of microbial drinking-water safety requires a system-wide assessment to determine potential hazards that can affect the system (see section 4.1); identification of the control measures needed to reduce or eliminate the hazards, and operational monitoring to ensure that barriers within the system are functioning efficiently (see section 4.2); and the development of management plans to describe actions taken under both normal and incident conditions. These are the three components of a WSP.

Failure to ensure drinking-water safety may expose the community to the risk of outbreaks of intestinal and other infectious diseases. Drinking-water-borne outbreaks are particularly to be avoided because of their capacity to result in the simultaneous infection of a large number of persons and potentially a high proportion of the community.

In addition to faecally borne pathogens, other microbial hazards (e.g., guinea worm [*Dracunculus medinensis*], toxic cyanobacteria and *Legionella*) may be of public health importance under specific circumstances.

The infective stages of many helminths, such as parasitic roundworms and flatworms, can be transmitted to humans through drinking-water. As a single mature larva or fertilized egg can cause infection, these should be absent from drinking-water. However, the water route is relatively unimportant for helminth infection, except in the case of the guinea worm.

Legionella bacteria are ubiquitous in the environment and can proliferate at the higher temperatures experienced at times in piped drinking-water distribution systems and more commonly in hot and warm water distribution systems. Exposure to *Legionella* from drinking-water is through inhalation and can be controlled through the implementation of basic water quality management measures in buildings and through the maintenance of disinfection residuals throughout the piped distribution system.

Public health concern regarding cyanobacteria relates to their potential to produce a variety of toxins, known as "cyanotoxins." In contrast to pathogenic bacteria, cyanobacteria do not proliferate within the human body after uptake; they proliferate only in the aquatic environment before intake. While the toxic peptides (e.g., microcystins) are usually contained within the cells and thus may be largely eliminated by filtration, toxic alkaloids such as cylindrospermopsin and neurotoxins are also released into the water and may break through filtration systems.

Some microorganisms will grow as biofilms on surfaces in contact with water. With few exceptions, such as *Legionella*, most of these organisms do not cause illness in healthy persons, but they can cause nuisance through generation of tastes and odours or discoloration of drinking-water supplies. Growth following drinking-water treat-

ment is often referred to as "regrowth." It is typically reflected in measurement of increasing heterotrophic plate counts (HPC) in water samples. Elevated HPC occur especially in stagnant parts of piped distribution systems, in domestic plumbing, in some bottled water and in plumbed-in devices such as softeners, carbon filters and vending machines.

While water can be a very significant source of infectious organisms, many of the diseases that may be waterborne may also be transmitted by other routes, including person-to-person contact, droplets and aerosols and food intake. Depending on circumstance and in the absence of waterborne outbreaks, these routes may be more important than waterborne transmission.

Microbial aspects of water quality are considered in more detail in chapter 7, with fact sheets on specific microorganisms provided in chapter 11.

1.1.2 Disinfection

Disinfection is of unquestionable importance in the supply of safe drinking-water. The destruction of microbial pathogens is essential and very commonly involves the use of reactive chemical agents such as chlorine.

Disinfection is an effective barrier to many pathogens (especially bacteria) during drinking-water treatment and should be used for surface waters and for groundwater subject to faecal contamination. Residual disinfection is used to provide a partial safeguard against low-level contamination and growth within the distribution system.

Chemical disinfection of a drinking-water supply that is faecally contaminated will reduce the overall risk of disease but may not necessarily render the supply safe. For example, chlorine disinfection of drinking-water has limitations against the protozoan pathogens – in particular *Cryptosporidium* – and some viruses. Disinfection efficacy may also be unsatisfactory against pathogens within flocs or particles, which protect them from disinfectant action. High levels of turbidity can protect microorganisms from the effects of disinfection, stimulate the growth of bacteria and give rise to a significant chlorine demand. An effective overall management strategy incorporates multiple barriers, including source water protection and appropriate treatment processes, as well as protection during storage and distribution in conjunction with disinfection to prevent or remove microbial contamination.

The use of chemical disinfectants in water treatment usually results in the formation of chemical by-products. However, the risks to health from these by-products are extremely small in comparison with the risks associated with inadequate disinfection, and it is important that disinfection not be compromised in attempting to control such by-products.

Disinfection should not be compromised in attempting to control disinfection by-products (DBPs).

Some disinfectants such as chlorine can be easily monitored and controlled as a drinking-water disinfectant, and frequent monitoring is recommended wherever chlorination is practised.

Disinfection of drinking-water is considered in more detail in chapter 8, with fact sheets on specific disinfectants and DBPs provided in chapter 12.

1.1.3 Chemical aspects

The health concerns associated with chemical constituents of drinking-water differ from those associated with microbial contamination and arise primarily from the ability of chemical constituents to cause adverse health effects after prolonged periods of exposure. There are few chemical constituents of water that can lead to health problems resulting from a single exposure, except through massive accidental contamination of a drinking-water supply. Moreover, experience shows that in many, but not all, such incidents, the water becomes undrinkable owing to unacceptable taste, odour and appearance.

In situations where short-term exposure is not likely to lead to health impairment, it is often most effective to concentrate the available resources for remedial action on finding and eliminating the source of contamination, rather than on installing expensive drinking-water treatment for the removal of the chemical constituent.

There are many chemicals that may occur in drinking-water; however, only a few are of immediate health concern in any given circumstance. The priority given to both monitoring and remedial action for chemical contaminants in drinking-water should be managed to ensure that scarce resources are not unnecessarily directed towards those of little or no health concern.

Exposure to high levels of fluoride, which occurs naturally, can lead to mottling of teeth and, in severe cases, crippling skeletal fluorosis. Similarly, arsenic may occur naturally, and excess exposure to arsenic in drinking-water may result in a significant risk of cancer and skin lesions. Other naturally occurring chemicals, including uranium and selenium, may also give rise to health concern when they are present in excess.

The presence of nitrate and nitrite in water has been associated with methaemoglobinaemia, especially in bottle-fed infants. Nitrate may arise from the excessive application of fertilizers or from leaching of wastewater or other organic wastes into surface water and groundwater.

Particularly in areas with aggressive or acidic waters, the use of lead pipes and fittings or solder can result in elevated lead levels in drinking-water, which cause adverse neurological effects.

There are few chemicals for which the contribution from drinking-water to overall intake is an important factor in preventing disease. One example is the effect of fluoride in drinking-water in increasing prevention against dental caries. The Guidelines do not attempt to define minimum desirable concentrations for chemicals in drinking-water.

Guideline values are derived for many chemical constituents of drinking-water. A guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption. A number of

provisional guideline values have been established based on the practical level of treatment achievability or analytical achievability. In these cases, the guideline value is higher than the calculated health-based value.

The chemical aspects of drinking-water quality are considered in more detail in chapter 8, with fact sheets on specific chemical contaminants provided in chapter 12.

1.1.4 Radiological aspects

The health risk associated with the presence of naturally occurring radionuclides in drinking-water should also be taken into consideration, although the contribution of drinking-water to total exposure to radionuclides is very small under normal circumstances.

Formal guideline values are not set for individual radionuclides in drinking-water. Rather, the approach used is based on screening drinking-water for gross alpha and gross beta radiation activity. While finding levels of activity above screening values does not indicate any immediate risk to health, it should trigger further investigation into determining the radionuclides responsible and the possible risks, taking into account local circumstances.

The guidance values recommended in this volume do not apply to drinking-water supplies contaminated during emergencies arising from accidental releases of radioactive substances to the environment.

Radiological aspects of drinking-water quality are considered in more detail in chapter 9.

1.1.5 Acceptability aspects

Water should be free of tastes and odours that would be objectionable to the majority of consumers.

In assessing the quality of drinking-water, consumers rely principally upon their senses. Microbial, chemical and physical water constituents may affect the appearance, odour or taste of the water, and the consumer will evaluate the quality and acceptability of the water on the basis of these criteria. Although these substances may have no direct health effects, water that is highly turbid, is highly coloured or has an objectionable taste or odour may be regarded by consumers as unsafe and may be rejected. In extreme cases, consumers may avoid aesthetically unacceptable but otherwise safe drinking-water in favour of more pleasant but potentially unsafe sources. It is therefore wise to be aware of consumer perceptions and to take into account both health-related guidelines and aesthetic criteria when assessing drinking-water supplies and developing regulations and standards.

Changes in the normal appearance, odour or taste of a drinking-water supply may signal changes in the quality of the raw water source or deficiencies in the treatment process and should be investigated.

Acceptability aspects of drinking-water quality are considered in more detail in chapter 10.

1.2 Roles and responsibilities in drinking-water safety management

Preventive management is the preferred approach to drinking-water safety and should take account of the characteristics of the drinking-water supply from catchment and source to its use by consumers. As many aspects of drinking-water quality management are often outside the direct responsibility of the water supplier, it is essential that a collaborative multiagency approach be adopted to ensure that agencies with responsibility for specific areas within the water cycle are involved in the management of water quality. One example is where catchments and source waters are beyond the drinking-water supplier's jurisdiction. Consultation with other authorities will generally be necessary for other elements of drinking-water quality management, such as monitoring and reporting requirements, emergency response plans and communication strategies.

> A preventive integrated management approach with collaboration from all relevant agencies is the preferred approach to ensuring drinking-water safety.

Major stakeholders that could affect or be affected by decisions or activities of the drinking-water supplier should be encouraged to coordinate their planning and management activities where appropriate. These could include, for example, health and resource management agencies, consumers, industry and plumbers. Appropriate mechanisms and documentation should be established for stakeholder commitment and involvement.

1.2.1 Surveillance and quality control

In order to protect public health, a dual-role approach, differentiating the roles and responsibilities of service providers from those of an authority responsible for independent oversight protective of public health ("drinking-water supply surveillance"), has proven to be effective.

Organizational arrangements for the maintenance and improvement of drinking-water supply services should take into account the vital and complementary roles of the agency responsible for surveillance and of the water supplier. The two functions of surveillance and quality control are best performed by separate and independent entities because of the conflict of interest that arises when the two are combined. In this:

- national agencies provide a framework of targets, standards and legislation to enable and require suppliers to meet defined obligations;
- agencies involved in supplying water for consumption by any means should be required to ensure and verify that the systems they administer are capable of delivering safe water and that they routinely achieve this; and
- a surveillance agency is responsible for independent (external) surveillance through periodic audit of all aspects of safety and/or verification testing.

In practice, there may not always be a clear division of responsibilities between the surveillance and drinking-water supply agencies. In some cases, the range of professional, governmental, nongovernmental and private institutions may be wider and more complex than that discussed above. Whatever the existing framework, it is important that clear strategies and structures be developed for implementing water safety plans, quality control and surveillance, collating and summarizing data, reporting and disseminating the findings and taking remedial action. Clear lines of accountability and communication are essential.

Surveillance of drinking-water quality can be defined as "the continuous and vigilant public health assessment and review of the safety and acceptability of drinking-water supplies" (WHO, 1976).

Surveillance is an investigative activity undertaken to identify and evaluate potential health risks associated with drinking-water. Surveillance contributes to the protection of public health by promoting improvement of the quality, quantity, accessibility, coverage (i.e., populations with reliable access), affordability and continuity of drinking-water supplies (termed "service indicators"). The surveillance authority must have the authority to determine whether a water supplier is fulfilling its obligations.

In most countries, the agency responsible for the surveillance of drinking-water supply services is the ministry of health (or public health) and its regional or departmental offices. In some countries, it may be an environmental protection agency; in others, the environmental health departments of local government may have some responsibility.

Surveillance requires a systematic programme of surveys, which may include auditing, analysis, sanitary inspection and/or institutional and community aspects. It should cover the whole of the drinking-water system, including sources and activities in the catchment, transmission infrastructure, treatment plants, storage reservoirs and distribution systems (whether piped or unpiped).

Ensuring timely action to prevent problems and ensure the correction of faults should be an aim of a surveillance programme. There may at times be a need for penalties to encourage and ensure compliance. The surveillance agency must therefore be supported by strong and enforceable legislation. However, it is important that the agency develops a positive and supportive relationship with suppliers, with the application of penalties used as a last resort.

Drinking-water suppliers are responsible at all times for the quality and safety of the water that they produce.

The surveillance agency should be empowered by law to compel water suppliers to recommend the boiling of water or other measures when microbial contamination that could threaten public health is detected.

1.2.2 Public health authorities

In order to effectively support the protection of public health, a national entity with responsibility for public health will normally act in four areas:

- *Surveillance of health status and trends*, including outbreak detection and investigation, generally directly but in some instances through a decentralized body.
- Directly establish drinking-water *norms and standards*. National public health authorities often have the primary responsibility for setting norms on drinking-water supply, which may include the setting of water quality targets (WQTs), performance and safety targets and directly specified requirements (e.g., treatment). Normative activity is not restricted to water quality but also includes, for example, regulation and approval of materials and chemicals used in the production and distribution of drinking-water (see section 8.5.4) and establishing minimum standards in areas such as domestic plumbing (see section 1.2.10). Nor is it a static activity, because as changes occur in drinking-water supply practice, in technologies and in materials available (e.g., in plumbing materials and treatment processes), so health priorities and responses to them will also change.
- Representing health concerns in *wider policy development*, especially health policy and integrated water resource management (see section 1.2.4). Health concerns will often suggest a supportive role towards resource allocation to those concerned with drinking-water supply extension and improvement; will often involve lobbying for the primary requirement to satisfy drinking-water needs above other priorities; and may imply involvement in conflict resolution.
- *Direct action*, generally through subsidiary bodies (e.g., regional and local environmental health administrations) or by providing guidance to other local entities (e.g., local government) in surveillance of drinking-water supplies. These roles vary widely according to national and local structures and responsibilities and frequently include a supportive role to community suppliers, where local authorities often intervene directly.

Public health surveillance (i.e., surveillance of health status and trends) contributes to verifying drinking-water safety. It takes into consideration disease in the entire population, which may be exposed to pathogenic microorganisms from a range of sources, not only drinking-water. National public health authorities may also undertake or direct research to evaluate the role of water as a risk factor in disease – for example, through case–control, cohort or intervention studies. Public health surveillance teams typically operate at national, regional and local levels, as well as in cities and rural health centres. Routine public health surveillance includes:

— ongoing monitoring of reportable diseases, many of which can be caused by waterborne pathogens;
— outbreak detection;
— long-term trend analysis;

— geographic and demographic analysis; and
— feedback to water authorities.

Public health surveillance can be enhanced in a variety of ways to identify possible waterborne outbreaks in response to suspicion about unusual disease incidence or following deterioration of water quality. Epidemiological investigations include:

— outbreak investigations;
— intervention studies to evaluate intervention options; and
— case–control or cohort studies to evaluate the role of water as a risk factor in disease.

However, public health surveillance cannot be relied upon to provide information in a timely manner to enable short-term operational response to control waterborne disease. Limitations include:

— outbreaks of non-reportable disease;
— time delay between exposure and illness;
— time delay between illness and reporting;
— low level of reporting; and
— difficulties in identifying causative pathogens and sources.

The public health authority operates reactively, as well as proactively, against the background of overall public health policy and in interaction with all stakeholders. In accounting for public health context, priority will normally be afforded to disadvantaged groups. This will generally entail balancing drinking-water safety management and improvement with the need to ensure access to reliable supplies of safe drinking-water in adequate quantities.

In order to develop an understanding of the national drinking-water situation, the national public health authority should periodically produce reports outlining the state of national water quality and highlighting public health concerns and priorities in the context of overall public health priorities. This implies the need for effective exchange of information between local, regional and national agencies.

National health authorities should lead or participate in formulation and implementation of policy to ensure access to some form of reliable, safe drinking-water supply. Where this has not been achieved, appropriate tools and education should be made available to implement individual or household-level treatment and safe storage.

1.2.3 Local authorities

Local environmental health authorities often play an important role in managing water resources and drinking-water supplies. This may include catchment inspection and authorization of activities in the catchment that may impact on source water quality. It can also include verifying and auditing (surveillance) of the management of formal drinking-water systems. Local environmental health authorities will also give specific guidance to communities or individuals in designing and implementing

community and household drinking-water systems and correcting deficiencies, and they may also be responsible for surveillance of community and household drinking-water supplies. They have an important role to play in educating consumers where household water treatment is necessary.

Management of household and small community drinking-water supplies generally requires education programmes about drinking-water supply and water quality. Such programmes should normally include:

— water hygiene awareness raising;
— basic technical training and technology transfer in drinking-water supply and management;
— consideration of and approaches to overcoming sociocultural barriers to acceptance of water quality interventions;
— motivation, mobilization and social marketing activities; and
— a system of continued support, follow-up and dissemination of the water quality programme to achieve and maintain sustainability.

These programmes can be administered at the community level by local health authorities or other entities, such as nongovernmental organizations and the private sector. If the programme arises from other entities, the involvement of the local health authority in the development and implementation of the water quality education and training programme is strongly encouraged.

Approaches to participatory hygiene and sanitation education and training programmes are described in other WHO documents (see Simpson-Hébert et al., 1996; Sawyer et al., 1998; Brikké, 2000).

1.2.4 Water resource management

Water resource management is an integral aspect of the preventive management of drinking-water quality. Prevention of microbial and chemical contamination of source water is the first barrier against drinking-water contamination of public health concern.

Water resource management and potentially polluting human activity in the catchment will influence water quality downstream and in aquifers. This will impact on treatment steps required to ensure safe water, and preventive action may be preferable to upgrading treatment.

The influence of land use on water quality should be assessed as part of water resource management. This assessment is not normally undertaken by health authorities or drinking-water supply agencies alone and should take into consideration:

— land cover modification;
— extraction activities;
— construction/modification of waterways;
— application of fertilizers, herbicides, pesticides and other chemicals;
— livestock density and application of manure;

— road construction, maintenance and use;
— various forms of recreation;
— urban or rural residential development, with particular attention to excreta disposal, sanitation, landfill and waste disposal; and
— other potentially polluting human activities, such as industry, military sites, etc.

Water resource management may be the responsibility of catchment management agencies and/or other entities controlling or affecting water resources, such as industrial, agricultural, navigation and flood control entities.

The extent to which the responsibilities of health or drinking-water supply agencies include water resource management varies greatly between countries and communities. Regardless of government structures and sector responsibilities, it is important that health authorities liaise and collaborate with sectors managing the water resource and regulating land use in the catchment.

Establishing close collaboration between the public health authority, water supplier and resource management agency assists recognition of the health hazards potentially occurring in the system. It is also important for ensuring that the protection of drinking-water resources is considered in decisions for land use or regulations to control contamination of water resources. Depending on the setting, this may include involvement of further sectors, such as agriculture, traffic, tourism or urban development.

To ensure the adequate protection of drinking-water sources, national authorities will normally interact with other sectors in formulating national policy for integrated water resource management. Regional and local structures for implementing the policy will be set up, and national authorities will guide regional and local authorities by providing tools.

Regional environmental or public health authorities have an important task in participating in the preparation of integrated water resource management plans to ensure the best available drinking-water source quality. For further information, see the supporting documents *Protecting Surface Waters for Health* and *Protecting Groundwaters for Health* (section 1.3).

1.2.5 Drinking-water supply agencies

Drinking-water supplies vary from very large urban systems servicing populations with tens of millions to small community systems providing water to very small populations. In most countries, they include community sources as well as piped means of supply.

Drinking-water supply agencies are responsible for quality assurance and quality control (see section 1.2.1). Their key responsibilities are to prepare and implement WSPs (for more information, see chapter 4).

In many cases, the water supplier is not responsible for the management of the catchment feeding sources of its supplies. The roles of the water supplier with respect

to catchments are to participate in interagency water resource management activities; to understand the risks arising from potentially contaminating activities and incidents; and to use this information in assessing risks to the drinking-water supply and developing and applying appropriate management. Although drinking-water suppliers may not undertake catchment surveys and pollution risk assessment alone, their roles include recognizing the need for them and initiating multiagency collaboration – for example, with health and environmental authorities.

Experience has shown that an association of stakeholders in drinking-water supply (e.g., operators, managers and specialist groups such as small suppliers, scientists, sociologists, legislators, politicians, etc.) can provide a valuable non-threatening forum for interchange of ideas.

For further information, see the supporting document *Water Safety Plans* (section 1.3).

1.2.6 Community management

Community-managed drinking-water systems, with both piped and non-piped distribution, are common worldwide in both developed and developing countries. The precise definition of a community drinking-water system will vary. While a definition based on population size or the type of supply may be appropriate under many conditions, approaches to administration and management provide a distinction between the drinking-water systems of small communities and those of larger towns and cities. This includes the increased reliance on often untrained and sometimes unpaid community members in the administration and operation of community drinking-water systems. Drinking-water systems in periurban areas in developing countries – the communities surrounding major towns and cities – may also have the characteristics of community systems.

Effective and sustainable programmes for the management of community drinking-water quality require the active support and involvement of local communities. These communities should be involved at all stages of such programmes, including initial surveys; decisions on siting of wells, siting of off-takes or establishing protection zones; monitoring and surveillance of drinking-water supplies; reporting faults, carrying out maintenance and taking remedial action; and supportive actions, including sanitation and hygiene practices.

A community may already be highly organized and taking action on health or drinking-water supply issues. Alternatively, it may lack a well developed drinking-water system; some sectors of the community, such as women, may be poorly represented; and there may be disagreements or factional conflicts. In this situation, achieving community participation will take more time and effort to bring people together, resolve differences, agree on common aims and take action. Visits, possibly over several years, will often be needed to provide support and encouragement and to ensure that the structures created for safe drinking-water supply continue to operate. This may involve setting up hygiene and health educational programmes to ensure that the community:

— is aware of the importance of drinking-water quality and its relation to health and of the need for safe drinking-water in sufficient quantities for domestic use for drinking, cooking and hygiene;
— recognizes the importance of surveillance and the need for a community response;
— understands and is prepared to play its role in the surveillance process;
— has the necessary skills to perform that role; and
— is aware of requirements for the protection of drinking-water supplies from pollution.

For further information, see WHO *Guidelines for Drinking-water Quality*, second edition, Volume 3; the supporting document *Water Safety Plans* (section 1.3); Simpson-Hébert et al. (1996); Sawyer et al. (1998); and Brikké (2000).

1.2.7 Water vendors

Vendors selling water to households or at collection points are common in many parts of the world where scarcity of water or faults in or lack of infrastructure limits access to suitable quantities of drinking-water. Water vendors use a range of modes of transport to carry drinking-water for sale directly to the consumer, including tanker trucks and wheelbarrows/trolleys. In the context of these Guidelines, water vending does not include bottled or packaged water (which is considered in section 6.5) or water sold through vending machines.

There are a number of health concerns associated with water supplied to consumers by water vendors. These include access to adequate volumes and concern regarding inadequate treatment or transport in inappropriate containers, which can result in contamination.

Where the source of water is uncertain or the quality of the water is unknown, water can be treated or re-treated in small quantities to significantly improve its quality and safety. The simplest and most important treatment for microbially contaminated water is disinfection. If bulk supplies in tankers are used, sufficient chlorine should be added to ensure that a free residual chlorine concentration of at least 0.5 mg/litre after a contact time of at least 30 min is present at the delivery point. Tankers should normally be reserved for potable water use. Before use, tankers should be either chemically disinfected or steam-cleaned.

Local authorities should implement surveillance programmes for water provided by vendors and, where necessary, develop education programmes to improve the collection, treatment and distribution of water to prevent contamination.

1.2.8 Individual consumers

Everyone consumes water from one source or another, and consumers often play important roles in the collection, treatment and storage of water. Consumer actions may help to ensure the safety of the water they consume and may also contribute to

improvement or contamination of the water consumed by others. Consumers have the responsibility for ensuring that their actions do not impact adversely on water quality. Installation and maintenance of household plumbing systems should be undertaken preferably by qualified and authorized plumbers (see section 1.2.10) or other persons with appropriate expertise to ensure that cross-connection or backflow events do not result in contamination of local water supplies.

In most countries, there are populations whose water is derived from household sources, such as private wells and rainwater. In households using non-piped water supplies, appropriate efforts are needed to ensure safe collection, storage and perhaps treatment of their drinking-water. In some circumstances, households and individuals may wish to treat water in the home to increase their confidence in its safety, not only where community supplies are absent, but also where community supplies are known to be contaminated or causing waterborne disease (see chapter 7). Public health, surveillance and/or other local authorities may provide guidance to support households and individual consumers in ensuring the safety of their drinking-water (see section 6.3). Such guidance is best provided in the context of a community education and training programme.

1.2.9 Certification agencies

Certification is used to verify that devices and materials used in the drinking-water supply meet a given level of quality and safety. Certification is a process in which an independent organization validates the claims of the manufacturers against a formal standard or criterion or provides an independent assessment of possible risks of contamination from a material or process. The certification agency may be responsible for seeking data from manufacturers, generating test results, conducting inspections and audits and possibly making recommendations on product performance.

Certification has been applied to technologies used at household and community levels, such as hand pumps; materials used by water supplies, such as treatment chemicals; and devices used in the household for collection, treatment and storage.

Certification of products or processes involved in the collection, treatment, storage and distribution of water can be overseen by government agencies or private organizations. Certification procedures will depend on the standards against which the products are certified, certification criteria and the party that performs the certification.

National, local government or private (third-party auditing) certification programmes have a number of possible objectives:

— certification of products to ensure that their use does not threaten the safety of the user or the general public, such as by causing contamination of drinking-water with toxic substances, substances that could affect consumer acceptability or substances that support the growth of microorganisms;
— product testing, to avoid retesting at local levels or prior to each procurement;

— ensuring uniform quality and condition of products;
— certification and accreditation of analytical and other testing laboratories; and
— control of materials and chemicals used for the treatment of drinking-water, including the performance of devices for household use.

An important step in any certification procedure is the establishment of standards, which must form the basis of assessment of the products. These standards should also – as far as possible – contain the criteria for approval. In procedures for certification on technical aspects, these standards are generally developed in cooperation with the manufacturers, the certifying agency and the consumers. The national public health authorities should have responsibility for developing the parts of the approval process or criteria relating directly to public health. For further information, see section 8.5.4.

1.2.10 Plumbing

Significant adverse health effects have been associated with inadequate plumbing systems within public and private buildings arising from poor design, incorrect installation, alterations and inadequate maintenance.

Numerous factors influence the quality of water within a building's piped distribution system and may result in microbial or chemical contamination of drinking-water. Outbreaks of gastrointestinal disease can occur through faecal contamination of drinking-water within buildings arising from deficiencies in roof storage tanks and cross-connections with wastewater pipes, for example. Poorly designed plumbing systems can cause stagnation of water and provide a suitable environment for the proliferation of *Legionella*. Plumbing materials, pipes, fittings and coatings can result in elevated heavy metal (e.g., lead) concentrations in drinking-water, and inappropriate materials can be conducive to bacterial growth. Potential adverse health effects may not be confined to the individual building. Exposure of other consumers to contaminants is possible through contamination of the local public distribution system, beyond the particular building, through cross-contamination of drinking-water and backflow.

The delivery of water that complies with relevant standards within buildings generally relies on a plumbing system that is not directly managed by the water supplier. Reliance is therefore placed on proper installation and servicing of plumbing and, for larger buildings, on building-specific WSPs (see section 6.1).

To ensure the safety of drinking-water supplies within the building system, plumbing practices must prevent the introduction of hazards to health. This can be achieved by ensuring that:

— pipes carrying either water or wastes are watertight, durable, of smooth and unobstructed interior and protected against anticipated stresses;
— cross-connections between the drinking-water supply and the wastewater removal systems do not occur;

— water storage systems are intact and not subject to intrusion of microbial and chemical contaminants;
— hot and cold water systems are designed to minimize the proliferation of *Legionella* (see also sections 6.1 and 11.1.9);
— appropriate protection is in place to prevent backflow;
— the system design of multistorey buildings minimizes pressure fluctuations;
— waste is discharged without contaminating drinking-water; and
— plumbing systems function efficiently.

It is important that plumbers are appropriately qualified, have the competence to undertake necessary installation and servicing of plumbing systems to ensure compliance with local regulations and use only materials approved as safe for use with drinking-water.

Design of the plumbing systems of new buildings should normally be approved prior to construction and be inspected by an appropriate regulatory body during construction and prior to commissioning of the buildings.

1.3 Supporting documentation to the guidelines

These Guidelines are accompanied by separate texts that provide background information substantiating the derivation of the guidelines and providing guidance on good practice towards effective implementation. These are available as published texts and electronically through the Internet (http://www.who.int/water_sanitation_health/dwq/en/) and CD-ROM. Reference details are provided in Annex 1.

Assessing Microbial Safety of Drinking Water: Improving Approaches and Methods

This book provides a state-of-the-art review of approaches and methods used in assessing the microbial safety of drinking-water. It offers guidance on the selection and use of indicators alongside operational monitoring to meet specific information needs and looks at potential applications of "new" technologies and emerging methods.

Chemical Safety of Drinking-water: Assessing Priorities for Risk Management

This document provides tools that assist users to undertake a systematic assessment of their water supply system(s) locally, regionally or nationally; to prioritize the chemicals likely to be of greatest significance; to consider how these might be controlled or eliminated; and to review or develop standards that are appropriate.

Domestic Water Quantity, Service Level and Health

This paper reviews the requirements for water for health-related purposes to determine acceptable minimum needs for consumption (hydration and food preparation) and basic hygiene.

Evaluation of the H_2S Method for Detection of Fecal Contamination of Drinking Water

This report critically reviews the scientific basis, validity, available data and other information concerning the use of "H_2S tests" as measures or indicators of faecal contamination in drinking-water.

Hazard Characterization for Pathogens in Food and Water: Guidelines

This document provides a practical framework and structured approach for the characterization of microbial hazards, to assist governmental and research scientists.

Heterotrophic Plate Counts and Drinking-water Safety: The Significance of HPCs for Water Quality and Human Health

This document provides a critical assessment of the role of the HPC measurement in drinking-water safety management.

Managing Water in the Home: Accelerated Health Gains from Improved Water Supply

This report describes and critically reviews the various methods and systems for household water collection, treatment and storage. It assesses the ability of household water treatment and storage methods to provide water with improved microbial quality.

Pathogenic Mycobacteria in Water: A Guide to Public Health Consequences, Monitoring and Management

This book describes the current knowledge about the distribution of pathogenic environmental mycobacteria (PEM) in water and other parts of the environment. Included are discussions of the routes of transmission that lead to human infection, the most significant disease symptoms that can follow infection and the classical and modern methods of analysis of PEM species. The book concludes with a discussion of the issues surrounding the control of PEM in drinking-water and the assessment and management of risks.

Quantifying Public Health Risk in the WHO Guidelines for Drinking-water Quality: A Burden of Disease Approach

This report provides a discussion paper on the concepts and methodology of Disability Adjusted Life Years (DALYs) as a common public health metric and its usefulness for drinking-water quality and illustrates the approach for several drinking-water contaminants already examined using the burden of disease approach.

Safe Piped Water: Managing Microbial Water Quality in Piped Distribution Systems

The development of pressurized pipe networks for supplying drinking-water to individual dwellings, buildings and communal taps is an important component in

the continuing development and health of many communities. This publication considers the introduction of microbial contaminants and growth of microorganisms in distribution networks and the practices that contribute to ensuring drinking-water safety in piped distribution systems.

Toxic Cyanobacteria in Water: A Guide to their Public Health Consequences, Monitoring and Management

This book describes the state of knowledge regarding the impact of cyanobacteria on health through the use of water. It considers aspects of risk management and details the information needed for protecting drinking-water sources and recreational water bodies from the health hazards caused by cyanobacteria and their toxins. It also outlines the state of knowledge regarding the principal considerations in the design of programmes and studies for monitoring water resources and supplies and describes the approaches and procedures used.

Upgrading Water Treatment Plants

This book provides a practical guide to improving the performance of water treatment plants. It will be an invaluable source of information for those who are responsible for designing, operating, maintaining or upgrading water treatment plants.

Water Safety Plans

The improvement of water quality control strategies, in conjunction with improvements in excreta disposal and personal hygiene, can be expected to deliver substantial health gains in the population. This document provides information on improved strategies for the control and monitoring of drinking-water quality.

Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking-water

This publication provides a critical analysis of the literature on removal and inactivation of pathogenic microbes in water to aid the water quality specialist and design engineer in making decisions regarding microbial water quality.

Texts in preparation or in revision:

Arsenic in Drinking-water: Assessing and managing health risks (in preparation)
Desalination for Safe Drinking-water Supply (in preparation)
Guide to Hygiene and Sanitation in Aviation (in revision)
Guide to Ship Sanitation (in revision)
Health Aspects of Plumbing (in preparation)
Legionella and the Prevention of Legionellosis (in finalization)
Protecting Groundwaters for Health – Managing the Quality of Drinking-water Sources (in preparation)

Protecting Surface Waters for Health – Managing the Quality of Drinking-water Sources (in preparation)

Rapid Assessment of Drinking-water Quality: A Handbook for Implementation (in preparation)