

# Guidelines for drinking-water quality

---

SECOND EDITION

---

***Volume 3***  
***Surveillance and control***  
***of community supplies***



World Health Organization  
Geneva  
1997

WHO Library Cataloguing in Publication Data

Guidelines for drinking-water quality.—2nd ed.

Contents: v. 3. Surveillance and control of community supplies

1. Drinking water – standards 2. Data collection – methods 3. Guidelines 4. Developing countries 1. Title: Surveillance and control of community supplies

ISBN 92 4 154503 8 (v. 3) (NLM Classification: WA 657)

The World Health Organization welcomes requests for permission to reproduce or translate its publications, in part or in full. Applications and enquiries should be addressed to the Office of Publications, World Health Organization, Geneva, Switzerland, which will be glad to provide the latest information on any changes made to the text, plans for new editions, and reprints and translations already available.

**© World Health Organization 1997**

Publications of the World Health Organization enjoy copyright protection in accordance with the provisions of Protocol 2 of the Universal Copyright Convention. All rights reserved.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the World Health Organization in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

TYPESET IN HONG KONG  
PRINTED IN MALTA  
96/11027—Best-set/Interprint—8000

# Contents

Preface	ix
Acknowledgements	xi
Acronyms and abbreviations used in the text	xii
<b>1. Introduction</b>	<b>1</b>
1.1 Scope and purpose	1
1.2 Community water supplies	1
1.3 Health implications	3
1.3.1 Water quality	4
1.3.2 Water-washed diseases	11
1.4 Objectives of surveillance and quality control	11
1.5 Organizational structure	12
1.5.1 The surveillance agency	13
1.5.2 Quality control and the role of the water supplier	13
1.6 Community participation	14
1.7 Role of surveillance in improvement of water supplies	15
<b>2. Planning and implementation of surveillance</b>	<b>17</b>
2.1 Legal and institutional basis	17
2.1.1 Laws, regulations, and standards	17
2.1.2 Institutional framework for water-quality surveillance	18
2.2 Planning	20
2.2.1 General considerations	20
2.2.2 Strategies	22
2.3 Implementation	23
2.3.1 Inventories	23
2.3.2 Designing forms	26
2.3.3 Training	28

2.3.4	Preliminary surveys	30
2.3.5	Undertaking fieldwork	31
2.3.6	Establishing routine surveillance	31
2.3.7	Evaluation	31
2.4	Information management	31
2.4.1	Flow and use of information	31
2.4.2	Information exchange with suppliers	32
2.4.3	Information exchange within the surveillance agency	34
2.4.4	Information exchange with consumers	35
2.4.5	Communication with local and national government	36
2.4.6	Communication linkage between surveillance and remedial action	36
2.4.7	Use of computers	37
2.5	Support structure	38
2.5.1	Laboratory network	38
2.5.2	Transport	39
2.5.3	Financial support	39
2.5.4	Staffing	41
<b>3.</b>	<b>Surveys</b>	<b>42</b>
3.1	Nature and scope of community surveys	42
3.2	Sanitary inspections	44
3.3	Sanitary inspection reports	44
3.3.1	Functions of sanitary inspection report forms	45
3.3.2	Design of sanitary inspection report forms	46
3.4	Carrying out sanitary inspections	47
3.5	Timing and frequency of sanitary inspections	48
3.5.1	New sources	48
3.5.2	Routine surveys of existing supplies	48
<b>4.</b>	<b>Water sampling and analysis</b>	<b>51</b>
4.1	Sampling	52
4.1.1	Location of sampling points	52
4.1.2	Sampling frequency	53
4.1.3	Sampling methods for microbiological analysis	53
4.1.4	Storage of samples for microbiological analysis	53

4.1.5	Sampling methods for physicochemical analysis	56
4.2	Bacteriological analysis	56
4.2.1	Indicator organisms	58
4.2.2	Principal analytical techniques	60
4.2.3	Choice of methods	63
4.2.4	Minimizing the cost of analysis	63
4.2.5	Laboratory-based versus on-site testing	65
4.2.6	Single-application (disposable) test kits	66
4.3	Physicochemical analysis	67
4.3.1	Chlorine residual	67
4.3.2	pH	67
4.3.3	Turbidity	68
4.4	Aesthetic parameters	68
4.4.1	Colour	68
4.4.2	Taste and odour	69
4.5	Other analyses of relevance to health	69
4.6	Analytical quality assurance and quality control	70
4.7	Safety	72
<b>5.</b>	<b>Data analysis and interpretation</b>	<b>73</b>
5.1	Introduction	73
5.2	Results of community surveys	73
5.2.1	Evaluation of water-supply systems	73
5.2.2	Hygiene practices	76
5.3	Assessment of the sanitary situation	76
5.4	Microbiological water quality	77
5.5	Risk assessment	78
5.6	Presentation of information	80
5.6.1	Target audiences	80
5.6.2	Simple data presentation	81
5.7	Use of surveillance findings	82
5.7.1	Use of data at local level	82
5.7.2	Regional use of data	82
5.7.3	Use of data for national planning	83
<b>6.</b>	<b>Technical interventions</b>	<b>84</b>
6.1	Prevention and remedial measures	84
6.2	Protecting water sources	85

6.2.1	Catchment protection	85
6.2.2	Groundwater protection	89
6.3	Wells	92
6.3.1	Dug wells	92
6.3.2	Hand-pumped and mechanically pumped wells	94
6.4	Springs	96
6.5	Rainwater catchment	99
6.6	Water treatment	100
6.6.1	Abstraction	100
6.6.2	Preliminary treatment by storage	102
6.6.3	Plain sedimentation	102
6.6.4	Prefiltration	104
6.6.5	Slow sand filtration	105
6.6.6	Coagulation, flocculation, and sedimentation	107
6.6.7	Rapid sand filtration	110
6.6.8	Aeration	111
6.6.9	Fluoride removal	113
6.6.10	Control of nitrites and nitrates	113
6.6.11	Disinfection	114
6.6.12	Water-treatment plants	115
6.7	Household water treatment and storage	116
6.7.1	Household water treatment	119
6.7.2	Household water storage	125
6.7.3	Storage tanks	127
<b>7.</b>	<b>Hygiene education</b>	<b>129</b>
7.1	Scope of hygiene education	129
7.1.1	Community-based surveillance	129
7.1.2	Hygiene behaviours	129
7.2	Planning hygiene education	131
7.2.1	Community participation and empowerment	131
7.2.2	Selection of behaviours to be changed	132
7.2.3	Factors influencing hygiene behaviour and selection of content of education	133
7.2.4	Selection of target groups	133
7.2.5	Information needs for hygiene education	134
7.3	Educational methods	134
7.4	Human resources for hygiene education	136
7.5	Role of the surveillance agency in hygiene education	138
7.6	Funding hygiene education activities	139

<b>8. Legislative, regulatory, policy, and basic management aspects</b>	141
8.1 Application of water-supply legislation	141
8.1.1 Short- and medium-term targets	141
8.1.2 Compliance: the role of the water-supply agency and the surveillance agency	142
8.1.3 Surveillance requirements	143
8.1.4 Sampling frequencies and parameters	144
8.1.5 Prescribed analytical methods	144
8.2 Technical regulations: construction, operation, and plumbing codes of practice	144
Selected further reading	145
Annex 1. List of contributors and reviewers	147
Annex 2. Examples of sanitary inspection forms	150
Annex 3. Examples of possible responsibilities of surveillance staff	178
Annex 4. Sampling methods for bacteriological testing	182
Annex 5. Multiple-tube method for thermotolerant (faecal) coliforms	189
Annex 6. Membrane filtration method for thermotolerant (faecal) coliforms	212
Annex 7. Field test method for thermotolerant (faecal) coliforms	219
Annex 8. Presence–absence test for total coliform bacteria	224
Annex 9. Residual free chlorine test	226
Annex 10. Turbidity and pH	231
Annex 11. Examples of regional and national monitoring report forms for water supplies and for coverage with basic sanitary facilities	234





## Preface

The first edition of *Guidelines for drinking-water quality* was published by WHO in 1984–1985 and was intended to supersede earlier European and international standards. Volume 1 contained guideline values for various constituents of drinking-water and Volume 2 the criteria monographs prepared for each substance or contaminant on which the guideline values were based; Volume 3 was concerned with the monitoring of drinking-water quality in small communities, particularly those in rural areas.

During the International Drinking-Water Supply and Sanitation Decade (1981–1990) considerable experience was gained in the surveillance and improvement of small-community supplies, notably through a series of demonstration projects supported by WHO. This new edition of Volume 3 of *Guidelines for drinking-water quality* reflects the experience of these and many other projects concerned with improving the quality of water services undertaken during the Decade.

A number of important principles were established in the first edition of Volume 3 of the *Guidelines* and these continue to form an important part of the second edition. They include the distinct and complementary roles of the water supplier and the surveillance agency; the unique nature of the problems associated with monitoring small-community supplies (especially in developing countries); the central role of the microbiological monitoring of supplies of this type; and the importance of ensuring that surveillance leads to engineering improvements and other remedial measures. Experience gained during the Decade has highlighted the importance of other fundamental concepts which have been incorporated into this new edition, including the need to consider not only drinking-water quality, but also all aspects of water-supply services that influence health, and to address the problems of small periurban areas not covered by such services.

While conditions vary from country to country as a result of differences in economic, geographical, cultural and social conditions, the strategies and procedures described here should nevertheless be widely applicable. Thus it is hoped that this Volume, like the first edition, will prove useful to all those concerned with drinking-water supply to small communities: environmental health inspectors, sanitary technicians, laboratory personnel, water engineers, planners and all those in the health and water-supply sector with managerial responsibility for

## PREFACE

improving water-supply services to communities. For the purposes of this publication, the term “communities” applies not only to villages and small private water supplies in rural areas but also to other centres of population within, or in close proximity to, urban centres.

# Acknowledgements

The preparation of this volume was begun at a Review Meeting on Surveillance of Community Supplies, held in Harare, Zimbabwe, on 24–28 June 1991, when a detailed outline was agreed. The first draft of Volume 3 was reviewed at the Final Task Group Meeting on the Revision of the *WHO guidelines for drinking-water quality*, held in Geneva on 21–25 September 1992, and a revised draft was subsequently finalized at a Meeting on Technical Revision of Volume 3, held in Tirana, Albania, on 15–20 June 1993. The final version is the outcome of the work of a number of contributors and reviewers whose names are given in Annex 1; their assistance is greatly appreciated. The coordinator for Volume 3 of the *Guidelines* was J. Bartram, Manager, Water and Wastes, WHO European Centre for Environment and Health, Rome, Italy, formerly of the Robens Institute of Health and Safety, University of Surrey, Guildford, England.

The first edition of Volume 3 of the *Guidelines* provided the basis for a number of pilot projects and country programmes in Central and South America, Africa, various parts of Asia and in the Pacific region, funded jointly by the United Nations Environment Programme (UNEP) and the United Kingdom Overseas Development Administration (ODA). Regional and national training courses were conducted, which were also supported by the Danish International Development Agency (DANIDA) and which allowed for the review and evaluation of the approaches proposed in the *Guidelines*. The experience gained in the projects in Indonesia, Peru, and Zambia was evaluated and published (Lloyd B, Helmer R. *Surveillance of drinking water quality in rural areas*. Harlow, Longman Scientific and Technical, 1991), and provided the basis for much of the revised methodology in the second edition, including an intensified sanitary-inspection process and a new hazard-analysis scheme.

The revision of Volume 3 of the *Guidelines* was made possible through a grant provided by ODA to the Robens Institute of Health and Safety, University of Surrey, Guildford, England. Financial support for the review meetings was provided by DANIDA.

# Acronyms and abbreviations used in the text

CFU	colony-forming units
DPD	diethyl- <i>p</i> -phenylenediamine
ESA	external support agencies
HTH	high-test hypochlorite
ISO	International Organization for Standardization
JTU	Jackson turbidity unit
MF	membrane filtration
MPN	most probable number
MSD	minimum safe distance
MT	multiple tube
NA	not applicable
NGO	nongovernmental organization
NTU	nephelometric turbidity unit
PA	presence–absence test
TCU	true colour unit
UNCED	United Nations Conference on Environment and Development
WHO	World Health Organization

# 1.

## Introduction

### 1.1 Scope and purpose

This volume of *Guidelines for drinking-water quality* describes the methods employed in the surveillance of drinking-water quality in the light of the special problems of small-community supplies, particularly those of developing countries, and outlines the strategies necessary to ensure that surveillance is effective. It is also concerned with the linkage between surveillance and remedial action and with the form that remedial action should take.

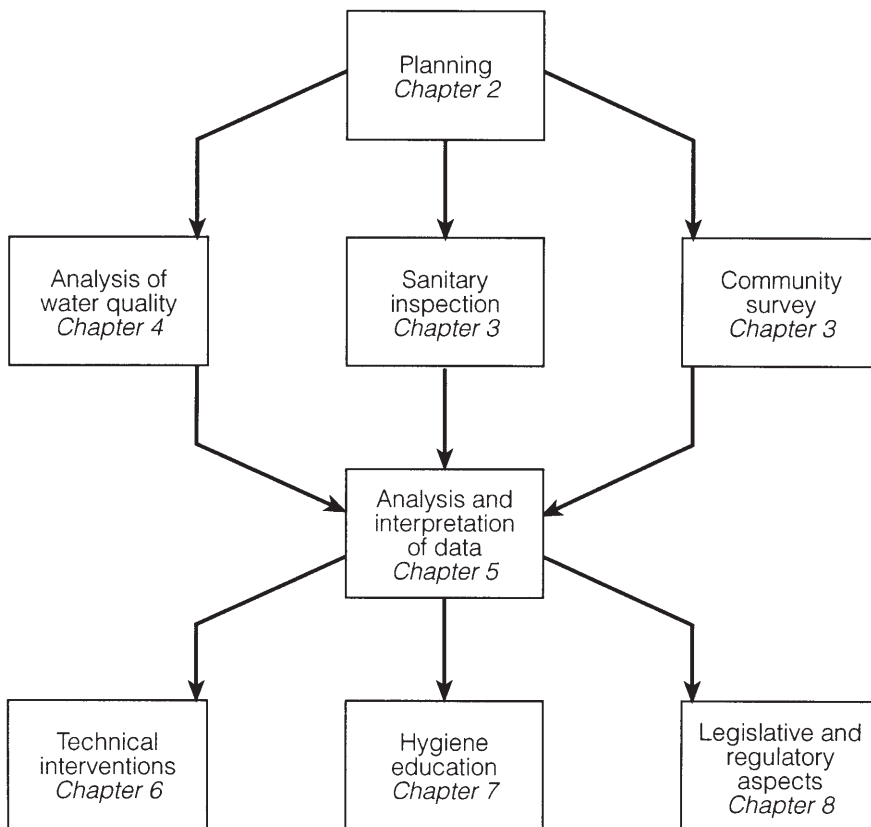
The structure of this volume reflects the key stages in the development of surveillance, as summarized in Fig. 1.1. Thus Chapter 2 covers planning, and subsequent chapters deal with the procedures used in the collection of information—sanitary inspection and community surveys (Chapter 3), and the analysis of water quality (Chapter 4). Chapter 5 considers the analysis and interpretation of the information gathered and its use in improving water-supply services. The final three chapters cover strategies for improvement—technical interventions (Chapter 6), hygiene education (Chapter 7) and legislation and regulation (Chapter 8).

### 1.2 Community water supplies

The precise definition of a “community water supply” will vary. While a definition based on population size or the type of supply may be appropriate under many conditions, it is often administration and management that set community supplies apart, and this is especially true in developing countries. The increased involvement of ordinary, often untrained and sometimes unpaid, community members in the administration and operation of water-supply systems is characteristic of small communities; this provides a ready distinction between community water supplies and the supply systems of major towns and cities. However, water supplies in periurban areas—the communities surrounding major towns and cities—are often organizationally similar to those of rural communities; these may also be classified as “community water supplies” and are therefore included in this volume.

While the safe quality of water supplied to communities is an important consideration in the protection of human health and well-being, it is not the only factor that affects consumers. *Access to water* is of paramount concern and other

**Fig. 1.1 Key stages in the development of water-supply surveillance and strategies for improvement**



WHO 96536

factors, such as the population served, the reliability of the supply and the cost to the consumer, must therefore be taken into account. At the United Nations conference at Mar del Plata in 1977, which launched the International Drinking-Water Supply and Sanitation Decade, this philosophy was adopted unambiguously: *“all peoples, whatever their stage of development and social and economic condition, have the right to have access to drinking-water in quantities and of a quality equal to their basic needs.”*

Access to water may be restricted in several ways, e.g. by prohibitive charges, daily or seasonal fluctuations in availability or lack of supplies to remote areas, and many countries face problems of this sort. In some parts of the world where water is scarce and has to be transported over long distances by road or on foot, the cost of drinking-water may absorb a significant proportion of the average daily income. Elsewhere, seasonal, geographical and hydrological factors may

conspire to deny individual households or entire communities a continuous, reliable supply of drinking-water. During dry seasons, spring sources may dwindle, reservoirs may become exhausted and excessive demands by one group of people may limit supplies to their neighbours. Such problems are not confined to poorer countries; they are also experienced with increasing frequency in industrialized countries where management of demand has failed or population growth has outpaced the development of water resources.

If the performance of a community water-supply system is to be properly evaluated, a number of factors must be considered. Some countries that have developed national strategies for the surveillance and quality control of water-supply systems have adopted *quantitative service indicators* for application at community, regional and national levels. These usually include:

- quality: the proportion of samples or supplies that comply with guideline values for drinking-water quality and minimum criteria for treatment and source protection
- coverage: the percentage of the population that has a recognizable (usually public) water-supply system
- quantity: the average volume of water used by consumers for domestic purposes (expressed as litres per capita per day)
- continuity: the percentage of the time during which water is available (daily, weekly or seasonally)
- cost: the tariff paid by domestic consumers

Together, these five service indicators provide the basis for setting targets for community water supplies. They serve as a quantitative guide to the comparative efficiency of water-supply agencies and provide consumers with an objective measure of the quality of the overall service and thus the degree of public health protection afforded.

### 1.3 Health implications

The provision of an adequate supply of safe water was one of the eight components of primary health care identified by the International Conference on Primary Health Care in Alma-Ata in 1978. The guidelines presented here are in full accord with the spirit of the Alma-Ata declaration on primary health care, which expanded the concept of health care to include broader notions of affordability, accessibility, self-reliance, intersectoral collaboration, community participation, sustainability and social justice.<sup>1</sup>

In most countries the principal risks to human health associated with the consumption of polluted water are microbiological in nature (although the importance of chemical contamination should not be underestimated). As indicated in Chapter 18 of “Agenda 21” of UNCED, “An estimated 80% of all diseases and over one-third of deaths in developing countries are caused by the

---

<sup>1</sup> *Alma-Ata 1978: primary health care*. Geneva, World Health Organization, 1978.

consumption of contaminated water and on average as much as one-tenth of each person's productive time is sacrificed to water-related diseases.”

The risk of acquiring a waterborne infection increases with the level of contamination by pathogenic microorganisms. However, the relationship is not necessarily a simple one and depends very much on factors such as infectious dose and host susceptibility. Drinking-water is only one vehicle for disease transmission. Some agents may be transmitted primarily from person to person and, for bacteria capable of multiplication in food, foodborne transmission may be more important than transmission by drinking-water. Other agents, however, such as *Salmonella typhi*, *Vibrio cholerae*, *Giardia lamblia* and hepatitis A virus, are frequently transmitted via contaminated drinking-water and, where this is the case, improvements in drinking-water quality may result in substantial reductions in disease prevalence.

Because of this multiplicity of transmission routes, improvements in the quality and availability of water, excreta disposal, and hygiene in general are all important factors in reducing diarrhoeal morbidity and mortality.

Epidemiological investigations indicate that all aspects of the quality of water supply services influence health, as do hygiene behaviours and sanitation. Experience has shown that analysis of disease incidence (epidemiological surveillance) is not a useful tool for guiding even large-scale remedial programmes for community water supplies. It is expensive and yields data that are difficult to interpret.

In the same way that indicators of the quality of water-supply services have been found useful in guiding remedial action, indicators of hygiene practices should also be used. Such indicators should be based on simple, standardized observations, and used to guide hygiene education programmes and the selection of key messages regarding hygiene behaviours.

### 1.3.1 Water quality

Guideline values for drinking-water quality are given in Volume 1 of the *Guidelines for drinking-water quality*, which also explains how the values should be interpreted. The health criteria used in establishing these values are summarized in Volume 2. A drinking-water quality guideline value represents the concentration of a constituent that does not result in any significant health risk to the consumer over a lifetime of consumption. Drinking-water should be suitable for human consumption and for all usual domestic purposes. When a guideline value is exceeded, the cause should be investigated and corrective action taken. The amount by which, and for how long, any guideline value can be exceeded without endangering human health depends on the specific substance involved.

In drawing up national standards for drinking-water quality, it will be necessary to take into account various local, geographical, socioeconomic and cultural factors. As a result, national standards may differ appreciably from the guideline values.



There may be a need for *interim standards* to provide a medium-term goal as a step towards the achievement of guideline values in the longer term. There is no objection to such a stepwise approach provided that the relevant authorities in each country, especially the ministry of health or its equivalent, are consulted and approve it. There are dangers in leaving such matters entirely to the agencies responsible for water supply because of the conflict of interests that may arise.

While supplies that fail to meet ideal criteria should be neither condoned nor ignored, interim standards permit resources to be directed first towards those communities with the greatest problems. They provide incentives to upgrade rather than blame for failure; this is particularly important in countries subject to severe economic constraints. The use of categories of bacteriological contamination of small-community supplies is useful in this context and is discussed in greater detail in Chapter 5.

In some countries, health authorities have adopted interim standards for intractable natural contaminants such as fluoride, pending the development of appropriate treatments for their removal from community supplies.

No attempt is made here to establish guideline values for service indicators other than drinking-water quality, such as those for the coverage, continuity, and cost of community water supplies. It is for national authorities to establish medium- and long-term targets for such factors. This should be done on a multisectoral basis, since the setting of these targets will have a number of social and economic implications. Nevertheless, because of the importance to public health of adequate access to safe water, the adoption of standards in this area is strongly recommended.

### ***Microbiological aspects***

Ideally, drinking-water should not contain any microorganisms known to be pathogenic—capable of causing disease—or any bacteria indicative of faecal pollution. To ensure that a drinking-water supply satisfies these guidelines, samples should be examined regularly. The detection of *Escherichia coli* provides definite evidence of faecal pollution; in practice, the detection of thermotolerant (faecal) coliform bacteria is an acceptable alternative.

Guideline values for bacteriologically safe supplies of drinking-water are provided in Volume 1 of the *Guidelines*. Although developed for large water-supply systems, the values for treated and untreated water supplies are also applicable to community supplies and are therefore reproduced in Table 1.1. Background information on the significance and choice of indicator organisms, as well as the selection of analytical methods, is given in Chapter 4.

A complementary strategy for securing the microbiological safety of drinking-water supplies has also been advocated by WHO and a number of other agencies, based on the minimum treatment for certain types of water. This helps to ensure the elimination of faecal pathogens by specifying the conditions to be observed and treatments to be applied at the water-treatment plant. For example,

**Table 1.1 Guideline values for bacteriological quality<sup>a</sup>**

Organisms	Guideline value
<b>All water intended for drinking</b>	
<i>E. coli</i> or thermotolerant coliform bacteria <sup>b,c</sup>	Must not be detectable in any 100-ml sample
<b>Treated water entering the distribution system</b>	
<i>E. coli</i> or thermotolerant coliform bacteria <sup>b</sup>	Must not be detectable in any 100-ml sample
Total coliform bacteria	Must not be detectable in any 100-ml sample
<b>Treated water in the distribution system</b>	
<i>E. coli</i> or thermotolerant coliform bacteria <sup>b</sup>	Must not be detectable in any 100-ml sample
Total coliform bacteria	Must not be detectable in any 100-ml sample. In the case of large supplies, where sufficient samples are examined, must not be present in 95% of samples taken throughout any 12-month period

<sup>a</sup> Immediate investigative action must be taken if either *E. coli* or total coliform bacteria are detected. The minimum action in the case of total coliform bacteria is repeat sampling; if these bacteria are detected in the repeat sample, the cause must be determined by immediate further investigation.

<sup>b</sup> Although *E. coli* is the more precise indicator of faecal pollution, the count of thermotolerant coliform bacteria is an acceptable alternative. If necessary, proper confirmatory tests must be carried out. Total coliform bacteria are not acceptable indicators of the sanitary quality of rural water supplies, particularly in tropical areas where many bacteria of no sanitary significance occur in almost all untreated supplies.

<sup>c</sup> It is recognized that, in the great majority of rural water supplies in developing countries, faecal contamination is widespread. Under these conditions, the national surveillance agency should set medium-term targets for the progressive improvement of water supplies.

cysts of protozoa such as *Giardia* and *Cryptosporidium* are efficiently removed by means of slow sand filters. Similarly, enteric viruses are inactivated by the maintenance of a disinfectant residual of at least 0.5 mg/litre free chlorine for a minimum of 30 minutes in waters with a turbidity of less than 1 NTU and a pH of less than 8.0. Another aspect of the minimum treatment approach is the protection of sources and catchments in order to minimize both contamination and the sophistication of the treatment processes needed to ensure potability.

It is not easy to provide generally applicable guidelines for other biological hazards, particularly parasitic protozoa and helminths. The application of any proposed guidelines and procedures must be governed by epidemiological considerations in at least two respects:

- Many parasites have a complex geographical distribution and it may be unnecessary to take precautions against those that do not occur locally.

- The majority of waterborne parasites are also transmissible by other routes, such as food and direct faecal–oral spread, and these routes should also be considered in the formulation of strategies for control.

Species of protozoa known to have been transmitted by the ingestion of contaminated drinking-water include *Entamoeba histolytica* (which causes amoebiasis), *Giardia* spp., and *Cryptosporidium*. These organisms can be introduced into a water supply through human or, in some instances, animal faecal contamination. Coliform organisms do not appear to be a good indicator of *Giardia* or *E. histolytica* in drinking-water: enteroviruses and protozoa are more resistant to disinfection than *E. coli*, so that absence of *E. coli* will not necessarily indicate freedom from these organisms.

The infective stages of many helminths such as parasitic roundworms and flatworms can be transmitted to humans through drinking-water. A single mature larva or fertilized egg can cause infection, and such infective stages should be absent from drinking-water. However, the water route is relatively unimportant except in the case of *Dracunculus medinensis* (the guinea worm), which is encountered mainly in unpiped water supplies. While there are methods for detecting this parasite, they are unsuitable for routine monitoring.

### **Disinfection**

Terminal disinfection is essential for surface waters after treatment and for protected groundwater sources when *E. coli* or thermotolerant (faecal) coliforms are detected. Chlorine in one form or another is the most commonly used disinfectant worldwide.

For terminal chlorination, there should be a free chlorine residual of at least 0.5 mg/litre after a minimum contact time of 30 minutes at a pH of less than 8.0, as for inactivation of enteric viruses. When chlorine is used as a disinfectant in a piped distribution system, it is desirable to maintain a free chlorine residual of 0.2–0.5 mg/litre throughout, to reduce the risk of microbial regrowth and the health risk of recontamination. In emergencies, e.g. in refugee camps, during outbreaks of potentially waterborne disease, or when faecal contamination of a water supply is detected, the concentration of free chlorine should be increased to greater than 0.5 mg/litre throughout the system.

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. Effective disinfection requires that turbidity is less than 5 NTU; ideally, median turbidity should be below 1 NTU.

Chlorine can be easily monitored and controlled as a drinking-water disinfectant, and regular, frequent monitoring is recommended wherever chlorination is practised. Chlorine determination is described in section 6.6.11. The health-based guideline value for free chlorine in water supplied to the public is

5 mg/litre. However, concentrations that are detectable by consumers and may provoke rejection may be much lower than this (typically 0.6–1 mg/litre); an upper limit should therefore be established based on local experience.

Disinfection is of unquestionable importance in the supply of safe water for drinking purposes. The destruction of microbial pathogens is essential and very commonly involves the use of reactive chemical agents such as chlorine. The use of chemical disinfectants usually results in the formation of chemical by-products, some of which are potentially hazardous, but the risks to health posed by these by-products are extremely small in comparison with those associated with inadequate disinfection. It is important that disinfection should not be compromised by attempts to control such by-products.

### ***Chemical aspects***

In rural areas of developing countries, the great majority of health-related water-quality problems are the result of bacteriological or other biological contamination. Nevertheless, a significant number of very serious problems may occur as a result of the chemical contamination of water resources.

Some potentially chronic effects may occur in rural areas where overuse of agrochemicals leads to significant levels of pesticides in water sources. The presence of nitrate and nitrite in water may result from the excessive application of fertilizers or from leaching of wastewater or other organic wastes into surface water and groundwater. Although effects may be difficult to detect in human populations, such contaminants may pose a risk to health.

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 may, after long-term exposure, affect the mental development of children. Exposure to high levels of naturally occurring fluoride can lead to mottling of teeth and (in severe cases) skeletal fluorosis and crippling. Similarly, arsenic may occur naturally, and long-term exposure via drinking-water may result in a risk to health.

More acute health effects of chemical contamination of small-community supplies include methaemoglobinaemia in infants due to high levels of nitrate, and toxicosis due to accidental and other discharges of solvents and heavy metals from mining activities.

In order to establish whether or not this type of problem exists, a selected number of physicochemical parameters may have to be measured. However, it may be both very costly and physically impractical to cover a large number of parameters, particularly in the case of rural water supplies in developing countries.

If certain chemical contaminants are of special local significance, the levels should be measured and the results evaluated in the light of the guideline values and other recommendations made in Volume 1. It should also be noted that some health effects may occur as a result of specific chemical deficiencies in the diet, of which water forms a part. Important examples are ophthalmic goitre

caused by iodine deficiency and dental caries resulting from low fluoride intake. No attempt has been made in these guidelines to define a minimum desirable concentration of such substances in drinking-water.

### ***Physical and aesthetic aspects***

The chemical and physical quality of water may affect its acceptability to consumers. Turbidity, colour, taste, and odour, whether of natural or other origin, affect consumer perceptions and behaviour. In extreme cases, consumers may avoid aesthetically unacceptable but otherwise safe supplies in favour of more pleasant but less wholesome sources of drinking-water.

Although guidelines for drinking-water quality are based on the best available public health advice, there is no guarantee that consumers will be satisfied or dissatisfied by water supplies that meet or fail to meet those guidelines. 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.

- *Turbidity* in excess of 5 NTU (5 JTU) may be noticeable and consequently objectionable to consumers.
- *Colour* in drinking-water may be due to the presence of organic matter such as humic substances, metals such as iron and manganese, or highly coloured industrial wastes. Experience has shown that consumers may turn to alternative, perhaps unsafe, sources, when their water displays aesthetically displeasing levels of colour, typically exceeding 15 TCU. Drinking-water should ideally be colourless.
- *Odour* in water is due mainly to the presence of organic substances. Some odours are indicative of increased biological activity, while others may originate from industrial pollution. Sanitary surveys should include investigations of sources of odour when odour problems are identified.

The combined perception of substances detected by the senses of taste and smell is often called “taste”. “Taste” problems in drinking-water supplies are often the largest single cause of consumer complaints. Changes in the normal taste of a public water supply may signal changes in the quality of the raw water source or deficiencies in the treatment process.

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

### ***Critical parameters of drinking-water quality in community supplies***

The principal risks to human health associated with community water supplies are microbiological, and it has been traditional to rely on relatively few water-quality tests to establish the safety of supplies. Some agencies refer to this strategy as “*minimum monitoring*”, while others use the term “*critical-parameter testing*”.

The approach is based on the assumption that health authorities will be aware of other specific sources of risk in each region, such as chemical contamination, and will include these in the monitoring scheme. It is much more effective to test for a narrow range of key parameters as frequently as possible (*in conjunction* with a sanitary inspection) than to conduct comprehensive but lengthy and largely irrelevant analyses less frequently.

The parameters recommended for the minimum monitoring of community supplies are those that best establish the hygienic state of the water and thus the risk (if any) of waterborne infection. The critical parameters of water quality are thus:

- *E. coli*; thermotolerant (faecal) coliforms are accepted as suitable substitutes;
- chlorine residual (if chlorination is practised).

These should be supplemented, where appropriate, by:

- pH (if chlorination is practised);
- turbidity (if *any* treatment is effected).

The value and application of these tests are described in greater detail in Chapter 4. However, an advantage worth noting here is that these critical parameters may be measured *on site* using relatively unsophisticated testing equipment. On-site testing is essential for the determination of turbidity and chlorine residual, which change rapidly during transport and storage; it is also important for the other parameters where laboratory support is lacking or where transportation problems would render conventional sampling and analysis difficult or impossible.

Water suppliers need to carry out a wider range of analyses relevant to the operation and maintenance of water-treatment and distribution systems, in addition to the health-related parameters laid down in national water-quality standards. Analyses should also embrace the concept of acceptability: Volume 1 indicates that water supplied for drinking purposes should be inoffensive to consumers. Consumers may resort to a more palatable, but possibly unsafe, source if water is considered unacceptable; acceptability is therefore also considered a critical parameter. It may be assessed by observation (taste, colour, odour, visible turbidity) and requires no laboratory determinations.

Other health-related parameters of local significance should also be measured. It may sometimes be useful to include total coliforms in the bacteriological analysis, e.g. if chlorination is practised and there is an extensive distribution network.

### **Other important analyses**

When supply sources are being investigated for the first time or when new sources are being developed, it is prudent to undertake a wide range of analyses in order to establish the overall safety and wholesomeness of the water.

It is essential that all water-quality factors are taken fully into account when technologies for abstraction and treatment of new resources are selected. Seasonal variations in the turbidity of raw surface waters can be very great, and allowance must be made for this; treatment plants should be designed for worst-case conditions rather than for average water quality, otherwise filters may rapidly become blocked or sedimentation tanks overloaded. The chemical aggressiveness of some groundwaters may affect the integrity of borehole casings and pumps, leading to unacceptably high levels of iron in the supply, eventual breakdown, and expensive repair work. Both the quality and availability of water may then be reduced and public health endangered.

In most water sources, especially groundwaters, the majority of chemical parameters vary relatively little with time. Thus, for routine assessments, it is advisable to investigate those parameters most closely related to health risk and/or most liable to change over short periods.

### 1.3.2 Water-washed diseases

A reliable, safe water supply plays an important role in disease prevention, especially by facilitating personal, domestic, and food hygiene. The diseases most affected by the provision of adequate quantities of water for hygienic purposes are referred to as *water-washed*. They may be divided into the following three groups:

- Diseases transmitted by the faecal–oral route, such as hepatitis A, bacillary dysentery, and many diarrhoeal diseases; these are transmitted by water and also by other means, such as food or hands. Improved hygiene therefore contributes to their control.
- Infections of the skin and eyes, such as trachoma, skin infections, and fungal skin diseases. The prevalence of these diseases is related to poor hygiene.
- Infections carried by lice or mites, such as scabies (mites), and louse-borne epidemic typhus (caused by *Rickettsia prowazeki* and transmitted largely by body lice). Good personal hygiene can assist in control.

Provision of water for domestic purposes in adequate quantities and quality will contribute to reducing the incidence of diseases transmitted by the faecal–oral route and other transmissible diseases.

## 1.4 Objectives of surveillance and quality control

Surveillance is an investigative activity undertaken to identify and evaluate factors associated with drinking-water which could pose a risk to health. Surveillance contributes to the protection of public health by promoting improvement of the quality, quantity, coverage, cost, and continuity of water supplies. It is also both preventive—detecting risks so that action may be taken before public health

problems occur—and remedial—identifying the sources of outbreaks of waterborne disease so that corrective action may be taken promptly.

Surveillance requires a systematic programme of surveys that combine analysis, sanitary inspection, and institutional and community aspects. Sanitary inspection should cover the whole of the water-supply system including sources, conduction lines, treatment plants, storage reservoirs, and distribution systems.

Surveillance is indispensable for the development of rational strategies for the improvement of the quality of water-supply services.

Quality control is designed to ensure that water services meet agreed national standards and institutional targets.

Water suppliers are responsible at all times for the quality and safety of the water that they produce, and they achieve this by a combination of good operating practice and preventive maintenance, supported by quality control. Water-quality control is the responsibility of the water supplier and involves the establishment of safeguards in the production and distribution of drinking-water as well as the routine testing of water quality to ensure compliance with national standards.

Quality control is distinguished from surveillance on the basis of institutional responsibilities and the frequency of the monitoring activities conducted. The surveillance agency is responsible for an independent (external) and periodic audit of all aspects of safety, whereas the water supplier is responsible at all times for regular quality control, and for monitoring and ensuring good operating practice.

## 1.5 Organizational structure

Organizational arrangements for the improvement of 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 outlined in section 1.4, i.e. surveillance and quality control, are best performed by separate and independent entities because of the conflict of interests that arises when the two are combined. Nevertheless, because the two are essentially complementary, the monitoring of water-supply services should involve both the surveillance agency and the supplier.

Important aspects of a surveillance programme include the following:

- The surveillance agency should have sole responsibility within the health authority for providing surveillance services to protect the public from waterborne diseases and other hazards associated with the water supply.
- Water-supply surveillance should be integrated with other environmental health measures, especially sanitation.
- Surveillance requires specialized knowledge, and the agency should thus include personnel specially trained in sanitary engineering, community health, epidemiology, chemistry, biology, etc. Additional support should



be provided by the medical profession, particularly during an outbreak of enteric disease.

- Health authorities should have centralized laboratories and other services needed for programmes of water-supply surveillance.
- Periodic reports to the government regarding the public health status of the country's water supplies should be produced.

In countries where urban water suppliers have established effective quality control, the surveillance agency may choose to place greater emphasis on the problems of the less well served populations. Such populations are specifically addressed in this publication, and include both rural communities and urban fringe areas.

### 1.5.1 The surveillance agency

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 there is an environmental protection agency; in others, the environmental health departments of local government may have some responsibility. The surveillance agency should preferably be an established institution designated by national legislation, should be represented at national level, and should operate at central, provincial (departmental/regional), and local (district) levels. Its responsibilities should encompass the monitoring of compliance with supply service standards (including quality, coverage, quantity, continuity, and cost) by water suppliers, approving sources of drinking-water, and surveying the provision of drinking-water to the population as a whole.

Surveillance is concerned with *all* water used for domestic purposes by the population, whether supplied by a formal water-supply agency or collected from individual sources or supplies. The agency's area of responsibility should therefore embrace all sources of water used, or intended for use, for human consumption. Nevertheless, in many developing countries, especially where there are many sources that may each supply a small population, such a goal may be difficult and expensive to achieve. Priority should therefore be given to systems that provide water to larger populations and those suspected of causing a substantial risk to human health, and to the identification of the most common risks and shortcomings in the supplies.

### 1.5.2 Quality control and the role of the water supplier

What is said above does not exclude water-supply and construction agencies from involvement in surveillance; in fact, it is vital that they should be involved. While it is the responsibility of the surveillance agency to generate and summarize surveillance data and to promote improvements, it is the water-supply sector that will carry out many of the actions designed to improve supplies. In addition,

supply and construction agencies are responsible for quality control of the service they provide. However, there may not always be a clear division of responsibilities between the health and water-supply sectors. 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 are developed for implementing surveillance and quality control, collating and summarizing data, reporting and disseminating the findings, and taking remedial action. Similarly, clear lines of accountability and communication are essential.

The organizational arrangements for carrying out surveillance and quality-control activities may be modified as programmes move from the pilot stage to regional and then national implementation. It is important that basic local, regional, and national frameworks should be in place from the outset in order to avoid subsequent confusion, but they may well be refined and improved in the light of experience during the implementation of activities. It is preferable to develop and build on existing frameworks than to impose radical changes immediately before or during a programme.

## 1.6 Community participation

Community participation is an essential component of the surveillance framework. As primary beneficiaries of improved water supplies, community members have a right to take part in decision-making about their own future. They represent a resource that can be drawn upon for local knowledge, experience, financial support, and labour. They are the people who are most likely to notice problems in the water supply first and can therefore take immediate remedial action. Establishing a genuine partnership with the community creates a climate of trust and understanding, which itself generates interest and enthusiasm. This provides a good foundation for other educational activities such as the promotion of latrines and of good hygiene practices.

The community's role in the planning and implementation of surveillance can valuably include the following:

- assisting in the establishment of procedures for surveillance;
- assisting in data collection;
- assisting field workers in water sampling;
- monitoring water quantity and quality and regularly reporting findings to surveillance staff;
- ensuring appropriate use of water supplies;
- setting priorities for remedial action, including improvement of water supplies, sanitation, and hygiene;
- undertaking simple maintenance and repairs;
- referral of problems that require special attention.

In involving the community in surveillance it is important to:

- provide an effective method, easily used by volunteers, to identify sanitary hazards associated with the water supply;
- provide training to community members in undertaking sanitary surveys and remedial action, and provide long-term support for such training in order to ensure sustainability.

## 1.7 Role of surveillance in improvement of water supplies

For water-supply surveillance to lead to improved drinking-water supply services it is vital that the mechanisms for promoting improvement are recognized and used.

A checklist of mechanisms for water-supply improvement based on the output of surveillance is given in Table 1.2. Similar concepts can be applied to

***Table 1.2 Mechanisms for the improvement of water-supply services based on the results of water-supply surveillance***

- 
- **Establishing national priorities**  
When the commonest problems and shortcomings in water-supply systems have been identified, national strategies can be formulated for improvements and remedial measures; these might include changes in training (of managers, administrators, engineers, or field staff), rolling programmes for rehabilitation or improvement, or changes in funding strategies to target specific needs.
  - **Establishing regional priorities**  
Regional offices of water-supply agencies can decide which communities to work in and which remedial activities are priorities; public health criteria should be considered when priorities are set.
  - **Establishing hygiene education**  
Not all of the problems revealed by surveillance are technical in nature, and not all are solved by supply and construction agencies; surveillance also looks at problems involving private supplies, water collection and transport, and household treatment and storage. The solutions to many of these problems are likely to require educational and promotional activities coordinated by the health agency.
  - **Enforcement of standards**  
Many countries have laws and standards related to public water supply. The information generated by surveillance can be used to assess compliance with standards by supply agencies. Corrective action can be taken where necessary, but its feasibility must be considered, and enforcement of standards should be linked to strategies for progressive improvement.
  - **Ensuring community operation and maintenance**  
Support should be provided by a designated authority to enable community members to be trained so that they are able to assume responsibility for the operation and maintenance of their water supplies.
-

water-quality control programmes, but it is then likely that greater emphasis will be placed on the setting of investment priorities at regional and national levels than on hygiene education and enforcement. Each of the mechanisms is discussed in greater detail in subsequent chapters.

Information alone does not lead to improvement. It is the effective management and use of the information generated by surveillance that makes possible the rational improvement of water supplies—where “rational” implies that available resources are used for maximum public health benefit.