Guidelines for Drinking-water Quality

FOURTH EDITION

World Health Organization

WHO Library Cataloguing-in-Publication Data

Guidelines for drinking-water quality - 4th ed.

1.Potable water - standards. 2.Water - standards. 3.Water quality - standards. 4.Guidelines. I.World Health Organization.

ISBN 978 92 4 154815 1 (NLM classification: WA 675)

© World Health Organization 2011

All rights reserved. Publications of the World Health Organization are available on the WHO web site (http://www.who.int) or can be purchased from WHO Press, World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland (tel.: +41 22 791 3264; fax: +41 22 791 4857; e-mail: bookorders@who.int).

Requests for permission to reproduce or translate WHO publications – whether for sale or for non-commercial distribution – should be addressed to WHO Press through the WHO web site (http://www.who.int/about/licensing/copyright_form/en/index.html).

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 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. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

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.

All reasonable precautions have been taken by the World Health Organization to verify the information contained in this publication. However, the published material is being distributed without warranty of any kind, either expressed or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall the World Health Organization be liable for damages arising from its use.

Cover designed by WHO Graphics, Switzerland

Typeset by Value Chain, India

Printed in Malta by Gutenberg

Contents

Preface xv
Acknowledgements xvii
Acronyms and abbreviations used in text xx

1. Introduction 1
1.1 General considerations and principles 1
1.1.1 Framework for safe drinking-water 3
1.1.2 Microbial aspects 4
1.1.3 Disinfection 5
1.1.4 Chemical aspects 6
1.1.5 Radiological aspects 7
1.1.6 Acceptability aspects: taste, odour and appearance 7
1.2 Roles and responsibilities in drinking-water safety management 8
1.2.1 Surveillance and quality control 8
1.2.2 Public health authorities 10
1.2.3 Local authorities 11
1.2.4 Water resource management 12
1.2.5 Drinking-water supply agencies 13
1.2.6 Community management 14
1.2.7 Water vendors 15
1.2.8 Individual consumers 15
1.2.9 Certification agencies 15
1.2.10 Plumbing 16
1.3 Supporting resources to the Guidelines 18
1.3.1 Published documents 18
1.3.2 Capacity-building networks 18

2. A conceptual framework for implementing the Guidelines 19
2.1 Health-based targets 20
2.2 Water safety plans 22
2.2.1 System assessment and design 22
2.2.2 Operational monitoring 23
2.2.3 Management plans, documentation and communication 24

2.3 Surveillance 25
2.4 Verification of drinking-water quality 25
2.4.1 Microbial water quality 26
2.4.2 Chemical water quality 26
2.5 Identifying priority concerns 27
2.5.1 Undertaking a drinking-water quality assessment 28
2.5.2 Assessing microbial priorities 29
2.5.3 Assessing chemical priorities 29
2.6 Developing drinking-water quality standards 30
2.6.1 Adapting guideline values to locally relevant standards 31
2.6.2 Periodic review and revision of standards 31
2.7 Drinking-water regulations and supporting policies and programmes 31
2.7.1 Regulations 32
2.7.2 Supporting policies and programmes 33

3. Health-based targets 35
3.1 Setting health-based targets 36
3.2 Disability-adjusted life years, tolerable disease burden and reference level of risk 37
3.3 Types of health-based targets 38
3.3.1 Health outcome targets 41
3.3.2 Water quality targets 42
3.3.3 Performance targets 43
3.3.4 Specified technology targets 43

4. Water safety plans 45
4.1 System assessment and design 49
4.1.1 New systems 50
4.1.2 Collecting and evaluating available data 51
4.1.3 Resource and source protection 53
4.1.4 Treatment 55
4.1.5 Piped distribution systems 56
4.1.6 Non-piped, community and household systems 58
4.1.7 Validation 59
4.1.8 Upgrade and improvement 60
4.2 Operational monitoring and maintaining control 61
4.2.1 Determining system control measures 61
4.2.2 Selecting operational monitoring parameters 62
4.2.3 Establishing operational and critical limits 63
4.2.4 Non-piped, community and household systems 63
4.3 Verification 64
4.3.1 Verification of microbial quality 65
4.3.2 Verification of chemical quality 66
4.3.3 Source waters 67
4.3.4 Piped distribution systems 67
4.3.5 Verification for community-managed supplies 68

4.3.6 Quality assurance and quality control 68
4.3.7 Verification of water safety plans 69
4.4 Management procedures for piped distribution systems 69
4.4.1 Predictable incidents ("deviations") 71
4.4.2 Unplanned events 71
4.4.3 Emergencies 72
4.4.4 Preparing a monitoring plan 73
4.4.5 Supporting programmes 73
4.5 Management of community and household water supplies 74
4.6 Documentation and communication 75
4.7 Planned review 76
4.7.1 Periodic review 76
4.7.2 Post-incident review 76

5. Surveillance 77
5.1 Types of approaches 79
5.1.1 Audit 79
5.1.2 Direct assessment 80
5.2 Adapting approaches to specific circumstances 81
5.2.1 Urban areas in developing countries 81
5.2.2 Surveillance of community drinking-water supplies 81
5.2.3 Surveillance of household treatment and storage systems 82
5.3 Adequacy of supply 83
5.3.1 Quantity (service level) 83
5.3.2 Accessibility 85
5.3.3 Affordability 85
5.3.4 Continuity 86
5.4 Planning and implementation 87
5.5 Reporting and communicating 89
5.5.1 Interaction with community and consumers 89
5.5.2 Regional use of data 90

6. Application of the Guidelines in specific circumstances 93
6.1 Climate change, water scarcity and heavy rainfall 94
6.2 Rainwater harvesting 94
6.3 Vended water 96
6.4 Bulk water supply 97
6.5 Desalination systems 98
6.6 Dual piped water supply systems 99
6.7 Emergencies and disasters 100
6.8 Temporary water supplies 102
6.9 Buildings 104
6.10 Health-care facilities 107
6.11 Safe drinking-water for travellers 107
6.12 Aircraft and airports 109
6.13 Ships 112

6.14 Packaged drinking-water 114
6.15 Food production and processing 116

7. Microbial aspects 117
7.1 Microbial hazards associated with drinking-water 117
7.1.1 Waterborne infections 118
7.1.2 Emerging issues 122
7.1.3 Persistence and growth in water 123
7.1.4 Public health aspects 124
7.2 Health-based target setting 124
7.2.1 Health-based targets applied to microbial hazards 124
7.2.2 Reference pathogens 125
7.2.3 Quantitative microbial risk assessment 128
7.2.4 Risk-based performance target setting 131
7.2.5 Presenting the outcome of performance target development 133
7.2.6 Adapting risk-based performance target setting to local circumstances 134
7.2.7 Health outcome targets 135
7.3 Occurrence and treatment of pathogens 136
7.3.1 Occurrence 136
7.3.2 Treatment 138
7.4 Microbial monitoring 147
7.5 Methods of detection of faecal indicator organisms 150
7.6 Identifying local actions in response to microbial water quality problems and emergencies 150
7.6.1 Boil water advisories 151
7.6.2 Actions following an incident 153

8. Chemical aspects 155
8.1 Chemical hazards in drinking-water 156
8.2 Derivation of chemical guideline values 158
8.2.1 Approaches taken 159
8.2.2 Threshold chemicals 160
8.2.3 Non-threshold chemicals 165
8.2.4 Data quality 165
8.2.5 Provisional guideline values 166
8.2.6 Chemicals with effects on acceptability 167
8.2.7 Chemicals not included in the Guidelines 167
8.2.8 Mixtures 167
8.2.9 Adapting guideline values to local circumstances 168
8.3 Analytical achievability 168
8.4 Treatment 170
8.4.1 Treatment performance 171
8.4.2 Process control measures for disinfection by-products 172
8.4.3 Treatment for corrosion control 174
8.4.4 Household treatment 175

8.5 Guideline values for individual chemicals, by source category 176
8.5.1 Naturally occurring chemicals 176
8.5.2 Chemicals from industrial sources and human dwellings 177
8.5.3 Chemicals from agricultural activities 179
8.5.4 Chemicals used in water treatment or from materials in contact with drinking-water 182
8.5.5 Chemicals of emerging concern 189
8.6 Pesticides used in water for public health purposes 190
8.7 Identifying local actions in response to chemical water quality problems and emergencies 192
8.7.1 Trigger for action 194
8.7.2 Investigating the situation 194
8.7.3 Talking to the right people 194
8.7.4 Informing the public 195
8.7.5 Evaluating the significance to public health and individuals 195
8.7.6 Determining appropriate action 198
8.7.7 Consumer acceptability 199
8.7.8 Ensuring remedial action, preventing recurrence and updating the water safety plan 199
8.7.9 Mixtures 199
8.7.10 Water avoidance advisories 200

9. Radiological aspects 203
9.1 Sources and health effects of radiation exposure 204
9.1.1 Radiation exposure through ingestion of drinking-water 205
9.1.2 Radiation-induced health effects through drinking-water 206
9.2 Rationale for screening levels and guidance levels 207
9.3 Monitoring and assessment for dissolved radionuclides 208
9.3.1 Screening of drinking-water supplies 209
9.3.2 Strategy for assessing drinking-water if screening levels are exceeded 210
9.3.3 Strategy for assessing drinking-water if guidance levels are exceeded 210
9.3.4 Sampling frequency 212
9.4 Guidance levels for radionuclides commonly found in drinking-water 212
9.5 Analytical methods 213
9.5.1 Measuring gross alpha and gross beta activity concentrations 213
9.5.2 Measuring specific radionuclides 213
9.6 Remedial measures 214
9.7 Radon 214
9.7.1 Radon in air and water 214
9.7.2 Health risks from radon 216
9.7.3 Guidance on radon in drinking-water supplies 216
9.7.4 Measuring radon in drinking-water 217

9.7.5 Decreasing radon concentrations in drinking-water 217
9.8 Risk communication 217
9.8.1 Reporting results 217
9.8.2 Communicating risks 217

10. Acceptability aspects: Taste, odour and appearance 219
10.1 Biologically derived contaminants 221
Actinomycetes and fungi 221
Cyanobacteria and algae 221
Invertebrate animal life 221
Iron bacteria 222
10.2 Chemically derived contaminants 222
Aluminium 222
Ammonia 223
Chloramines 223
Chloride 223
Chlorine 223
Chlorobenzenes 223
Chlorophenols 224
Colour 224
Copper 224
Dissolved oxygen 225
Ethylbenzene 225
Hardness 225
Hydrogen sulfide 225
Iron 226
Manganese 226
Petroleum oils 226
pH and corrosion 226
Sodium 227
Styrene 227
Sulfate 227
Synthetic detergents 227
Toluene 228
Total dissolved solids 228
Turbidity 228
Xylenes 229
Zinc 229
10.3 Treatment of taste, odour and appearance problems 230
10.4 Temperature 230

11. Microbial fact sheets 231
11.1 Bacterial pathogens 232
Acinetobacter 232
Aeromonas 234
Bacillus 235

Burkholderia pseudomallei 236
Campylobacter 237
Enterobacter sakazakii 239
Escherichia coli pathogenic strains 240
Helicobacter pylori 241
Klebsiella 242
Legionella 244
Leptospira 245
Mycobacterium 247
Pseudomonas aeruginosa 249
Salmonella 250
Shigella 252
Staphylococcus aureus 253
Tsukamurella 254
Vibrio 255
Yersinia 257
11.2 Viral pathogens 258
Adenoviruses 258
Astroviruses 260
Caliciviruses 261
Enteroviruses 263
Hepatitis A virus 264
Hepatitis E virus 265
Rotaviruses and orthoreoviruses 267
11.3 Protozoan pathogens 268
Acanthamoeba 269
Balantidium coli 270
Blastocystis 271
Cryptosporidium 273
Cyclospora cayetanensis 274
Entamoeba histolytica 276
Giardia intestinalis 277
Isospora belli 279
Microsporidia 280
Naegleria fowleri 282
Toxoplasma gondii 283
11.4 Helminth pathogens 285
Dracunculus medinensis 285
Fasciola spp. 287
Free-living nematodes 288
Schistosoma spp. 290
11.5 Toxic cyanobacteria 293
11.6 Indicator organisms 294
Total coliform bacteria 294
Escherichia coli and thermotolerant coliform bacteria 296

Heterotrophic plate counts 297
Intestinal enterococci 298
Clostridium perfringens 300
Coliphages 301
Bacteroides fragilis phages 303
Enteric viruses 305

12. Chemical fact sheets 307
12.1 Chemical contaminants in drinking-water 307
Acrylamide 307
Alachlor 308
Aldicarb 309
Aldrin and dieldrin 310
Aluminium 311
Ammonia 313
Antimony 314
Arsenic 315
Asbestos 318
Atrazine and its metabolites 319
Barium 320
Bentazone 321
Benzene 322
Beryllium 322
Boron 323
Bromate 324
Bromide 325
Brominated acetic acids 326
Cadmium 327
Carbaryl 328
Carbofuran 328
Carbon tetrachloride 329
Chloral hydrate 330
Chloramines (monochloramine, dichloramine, trichloramine) 331
Chlordane 333
Chloride 333
Chlorine 334
Chlorite and chlorate 335
Chloroacetones 337
Chlorophenols (2-chlorophenol, 2,4-dichlorophenol, 2,4,6-trichlorophenol) 337
Chloropicrin 338
Chlorotoluron 338
Chlorpyrifos 339
Chromium 340
Copper 340

Cyanazine 342
Cyanide 342
Cyanobacterial toxins: Microcystin-LR 344
Cyanogen chloride 346
2,4-D 347
2,4-DB 348
DDT and metabolites 349
Dialkyltins 350
1,2-Dibromo-3-chloropropane 350
1,2-Dibromoethane 351
Dichloroacetic acid 352
Dichlorobenzenes (1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene) 353
1,1-Dichloroethane 354
1,2-Dichloroethane 355
1,1-Dichloroethene 355
1,2-Dichloroethene 356
Dichloromethane 357
1,2-Dichloropropane 358
1,3-Dichloropropane 359
1,3-Dichloropropene 359
Dichlorprop 360
Di(2-ethylhexyl)adipate 361
Di(2-ethylhexyl)phthalate 361
Dimethoate 362
1,4-Dioxane 363
Diquat 364
Edetic acid 364
Endosulfan 365
Endrin 366
Epichlorohydrin 367
Ethylbenzene 368
Fenitrothion 368
Fenoprop 369
Fluoride 370
Formaldehyde 373
Glyphosate and AMPA 374
Halogenated acetonitriles (dichloroacetonitrile, dibromoacetonitrile, bromochloroacetonitrile, trichloroacetonitrile) 375
Hardness 376
Heptachlor and heptachlor epoxide 377
Hexachlorobenzene 378
Hexachlorobutadiene 379
Hydrogen sulfide 380

Inorganic tin 380
Iodine 381
Iron 381
Isoproturon 382
Lead 383
Lindane 385
Malathion 386
Manganese 386
MCPA 387
Mecoprop 388
Mercury 389
Methoxychlor 390
Methyl parathion 391
Methyl *tertiary*-butyl ether 392
Metolachlor 393
Molinate 393
Molybdenum 394
Monochloroacetic acid 395
Monochlorobenzene 395
MX 396
Nickel 396
Nitrate and nitrite 398
Nitrilotriacetic acid 403
Nitrobenzene 404
N-Nitrosodimethylamine 405
Parathion 406
Pendimethalin 407
Pentachlorophenol 407
Petroleum products 408
pH 409
2-Phenylphenol and its sodium salt 409
Polynuclear aromatic hydrocarbons 410
Potassium 412
Propanil 413
Selenium 413
Silver 415
Simazine 415
Sodium 416
Sodium dichloroisocyanurate 416
Styrene 418
Sulfate 419
2,4,5-T 419
Terbuthylazine 420
Tetrachloroethene 421
Toluene 422

Total dissolved solids 423
Trichloroacetic acid 423
Trichlorobenzenes (total) 424
1,1,1-Trichloroethane 424
Trichloroethene 425
Trifluralin 426
Trihalomethanes (bromoform, bromodichloromethane, dibromochloromethane, chloroform) 427
Uranium 430
Vinyl chloride 431
Xylenes 432
Zinc 433

12.2 Pesticides used for vector control in drinking-water sources and containers 434
Bacillus thuringensis israelensis 434
Diflubenzuron 435
Methoprene 436
Novaluron 437
Permethrin 438
Pirimiphos-methyl 438
Pyriproxyfen 439
Spinosad 440
Temephos 441

Annex 1 Supporting documentation to the Guidelines **443**
Annex 2 References cited **449**
Annex 3 Chemical summary tables **468**
Annex 4 Analytical methods and achievability **476**
Annex 5 Treatment methods and performance **485**
Annex 6 Supporting information on radionuclides **504**
Annex 7 Contributors to the development of the fourth edition of the *Guidelines for drinking-water quality* **509**

Index 518

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 Development 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. The UN General Assembly declared the period from 2005 to 2015 as the International Decade for Action, "Water for Life". Most recently, the UN General Assembly declared safe and clean drinking-water and sanitation a human right essential to the full enjoyment of life and all other human rights.

Access to safe drinking-water is important as a health and development issue at national, regional and local levels. In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit, as the reductions in adverse health effects and health-care costs outweigh the costs of undertaking the interventions. This is true for investments ranging from major water supply infrastructure 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.

The World Health Organization (WHO) published three editions of the *Guidelines for drinking-water quality* in 1983–1984, 1993–1997 and 2004, as successors to previous WHO *International standards for drinking water*, published in 1958, 1963 and 1971. From 1995, the Guidelines have been kept up to date through a process of rolling revision, which leads to the regular publication of addenda that may add to or supersede information in previous volumes as well as expert reviews on key issues preparatory to the development of the Guidelines.

Leading the process of the development of the fourth edition was the Water, Sanitation, Hygiene and Health Unit within WHO Headquarters, with the Programme on

Chemical Safety providing input on chemical hazards and the Radiation and Environmental Health Unit providing input on radiological hazards. All six WHO Regional Offices participated in the process, in consultation with Member States.

This edition of the *Guidelines for drinking-water quality* integrates the third edition, which was published in 2004, with both the first addendum to the third edition, published in 2006, and the second addendum to the third edition, published in 2008. It supersedes previous editions of the Guidelines and previous International Standards.

This edition of the Guidelines further develops concepts, approaches and information introduced in previous editions, including the comprehensive preventive risk management approach for ensuring drinking-water quality that was introduced in the third edition. It considers:

- drinking-water safety, including minimum procedures and specific guideline values and how these are intended to be used;
- approaches used in deriving the Guidelines, including guideline values;
- microbial hazards, which continue to be the primary concern in both developing and developed countries. Experience has shown the value of a systematic approach to securing microbial safety. This edition builds on the preventive principles introduced in the third edition on ensuring the microbial safety of drinking-water through a multiple-barrier approach, highlighting the importance of source water protection;
- climate change, which results in changing water temperature and rainfall patterns, severe and prolonged drought or increased flooding, and its implications for water quality and water scarcity, recognizing the importance of managing these impacts as part of water management strategies;
- chemical contaminants in drinking-water, including information on chemicals not considered previously, such as pesticides used for vector control in drinking-water; revisions of existing chemical fact sheets, taking account of new scientific information; and, in some cases, reduced coverage in the Guidelines where new information suggests a lesser priority;
- those key chemicals responsible for large-scale health effects through drinking-water exposure, including arsenic, fluoride, lead, nitrate, selenium and uranium, providing guidance on identifying local priorities and on management;
- the important roles of many different stakeholders in ensuring drinking-water safety. This edition furthers the discussion introduced in the third edition of the roles and responsibilities of key stakeholders in ensuring drinking-water safety;
- guidance in situations other than traditional community supplies or managed utilities, such as rainwater harvesting and other non-piped supplies or dual piped systems.

This edition of the Guidelines is accompanied by a series of supporting publications. These include internationally peer-reviewed risk assessments for specific chemicals (see list of chapter 12 background documents in Annex 2) and other publications explaining the scientific basis of the development of the Guidelines and providing guidance on good practice in their implementation (see Annex 1). The *Guidelines*

for drinking-water quality Volume 3—Surveillance and control of community supplies (1997) provides guidance on good practice in surveillance, monitoring and assessment of drinking-water quality in community supplies.

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.

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 among the 24 UN agencies and programmes concerned with water issues.

Acknowledgements

The preparation of the fourth edition of the *Guidelines for drinking-water quality* and supporting documentation covered a period of more than 5 years and involved the participation of hundreds of experts from a wide range of developing and developed countries. The contributions of all who participated in the preparation and finalization of the fourth edition, including those individuals listed in Annex 7, are gratefully acknowledged.

The work of the following working group coordinators and other Drinking-water Quality Committee members was crucial to the development of the fourth edition:

Dr F. Ahmed, Bangladesh University of Engineering and Technology, Bangladesh (*Small systems*)

Dr I. Chorus, Federal Environment Agency, Germany (*Resource and source protection*)

Dr J. Cotruvo, Joseph Cotruvo & Associates/NSF International Collaborating Centre, USA (*Materials and chemicals used in the production and distribution of drinking-water*)

Dr D. Cunliffe, Department of Health, Australia (*Public health*)

Dr A.M. de Roda Husman, National Institute for Public Health and the Environment (RIVM), the Netherlands (*Viruses and risk assessment*)

Dr T. Endo, Ministry of Health, Labour and Welfare, Japan (*Parasites*)

Mr J.K. Fawell, Independent Consultant, United Kingdom (*Naturally occurring and industrial contaminants* and *Pesticides*)

Ms M. Giddings, Health Canada, Canada (*Disinfectants and disinfection by-products*)

Dr G. Howard, British High Commission, India (*Monitoring and assessment*)

Mr P. Jackson, WRc-NSF Ltd, United Kingdom (*Chemicals – Practical aspects*)

Dr S. Kumar, University of Malaya, Malaysia (*Protozoa and risk management*)

Dr S. Kunikane, Institute for Environmental Sciences, Japan (*Operations and Maintenance Network*)

Professor Y. Magara, Hokkaido University, Japan (*Analytical aspects*)

Dr A.V.F. Ngowi, Muhimbili University of Health and Allied Sciences, United Republic of Tanzania (*Pesticides*)

Dr E. Ohanian, Environmental Protection Agency, USA (*Disinfectants and disinfection by-products*)

Dr C.N. Ong, National University of Singapore, Singapore (*Emerging chemical hazards*)

Mr O. Schmoll, Federal Environment Agency, Germany (*Water safety plan capacity building and monitoring*)

Professor M. Sobsey, University of North Carolina, USA (*Risk management*)

The WHO coordinator was Mr B. Gordon, WHO Headquarters, with support from Mr P. Callan from the National Health and Medical Research Council, Australia. Ms C. Vickers and Dr A. Tritscher provided important liaisons with the international chemical risk assessment programmes at WHO Headquarters. Dr M. Perez contributed on behalf of the Radiation and Environmental Health Programme, WHO Headquarters. Dr M. Zaim, Pesticide Evaluation Scheme, WHO Headquarters, provided input on pesticides added to drinking-water for public health purposes. The Coordinator of Water, Sanitation, Hygiene and Health, WHO Headquarters (formerly Jamie Bartram and, since 2009, Robert Bos), provided strategic direction throughout the process.

Ms P. Ward provided invaluable administrative support throughout the review and publication process. Ms M. Sheffer of Ottawa, Canada, was responsible for the scientific editing of the document.

Many individuals from various countries contributed to the development of the Guidelines. The efforts of all who contributed to the preparation of this document and in particular those who provided peer or public domain review comments are greatly appreciated.

The generous financial and technical support of the following is gratefully acknowledged: the Australian Agency for International Development; Health Canada; the Federal Ministry of Health of Germany; the Ministry of Health, Labour and Welfare of Japan; the Ministry of Environment and Water Resources of Singapore; and the United States Environmental Protection Agency.

Acronyms and abbreviations used in text

2,4-D	2,4-dichlorophenoxyacetic acid
2,4-DB	2,4-dichlorophenoxybutyric acid
2,4-DP	dichlorprop
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
2,4,5-TP	2,4,5-trichlorophenoxy propionic acid; fenoprop
AAS	atomic absorption spectrometry
Absor	absorptiometry
ADI	acceptable daily intake
AES	atomic emission spectrometry
AIDS	acquired immunodeficiency syndrome
AMPA	aminomethylphosphonic acid
ARfD	acute reference dose
BDCM	bromodichloromethane
BMD	benchmark dose
BMDL	lower confidence limit on the benchmark dose
BTEX	benzene, toluene, ethylbenzene and xylenes
Bti	*Bacillus thuringiensis israelensis*
bw	body weight
CAS	Chemical Abstracts Service
Col	colorimetry
CSAF	chemical-specific adjustment factor
Ct	product of disinfectant concentration and contact time
DAEC	diffusely adherent *E. coli*
DALY	disability-adjusted life year

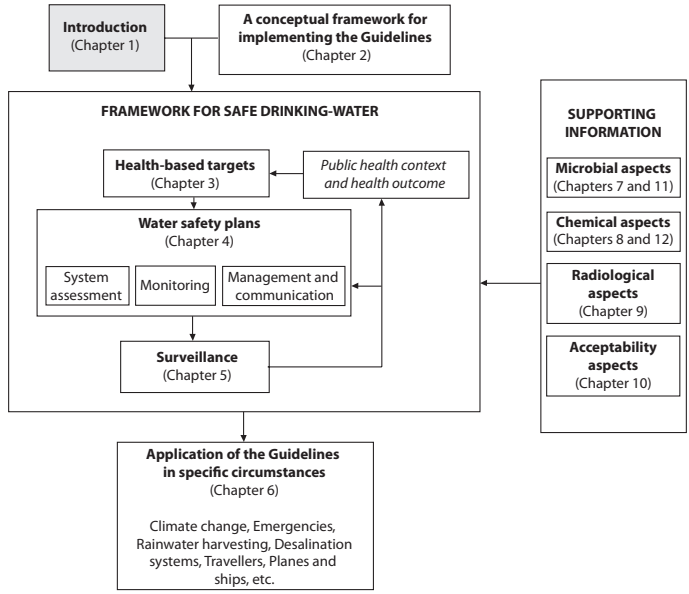
DBCM	dibromochloromethane
DBCP	1,2-dibromo-3-chloropropane
DBP	disinfection by-product
DCA	dichloroacetic acid
DCB	dichlorobenzene
DCP	dichloropropane
DDT	dichlorodiphenyltrichloroethane
DEHA	di(2-ethylhexyl)adipate
DEHP	di(2-ethylhexyl)phthalate
DNA	deoxyribonucleic acid
EAAS	electrothermal atomic absorption spectrometry
EAEC	enteroaggregative *E. coli*
ECD	electron capture detector
EDTA	ethylenediaminetetraacetic acid; edetic acid
EHEC	enterohaemorrhagic *E. coli*
EIEC	enteroinvasive *E. coli*
ELISA	enzyme-linked immunosorbent assay
EPEC	enteropathogenic *E. coli*
ETEC	enterotoxigenic *E. coli*
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
GC	gas chromatography
GL	guidance level (used for radionuclides in drinking-water)
GV	guideline value
HAA	haloacetic acid
HAV	hepatitis A virus
HCB	hexachlorobenzene
HCBD	hexachlorobutadiene
HCH	hexachlorocyclohexane
HEV	hepatitis E virus
HIV	human immunodeficiency virus
HPC	heterotrophic plate count
HPLC	high-performance liquid chromatography

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
IQ	intelligence quotient
ISO	International Organization for Standardization
JECFA	Joint FAO/WHO Expert Committee on Food Additives
JMPR	Joint FAO/WHO Meeting on Pesticide Residues
LC	liquid chromatography
LOAEL	lowest-observed-adverse-effect level
LRV	$\log_{10}$ reduction value
MCB	monochlorobenzene
MCPA	4-(2-methyl-4-chlorophenoxy)acetic acid
MCPB	2,4-MCPB; 4-(4-chloro-*o*-tolyloxy)butyric acid; 4-(4-chloro-2-methylphenoxy)butanoic acid
MCPP	2(2-methyl-chlorophenoxy)propionic acid; mecoprop
MMT	methylcyclopentadienyl manganese tricarbonyl
MS	mass spectrometry
MTBE	methyl *tertiary*-butyl ether
MX	3-chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone
NDMA	*N*-nitrosodimethylamine
NOAEL	no-observed-adverse-effect level
NOEL	no-observed-effect level
NTA	nitrilotriacetic acid
NTP	National Toxicology Program (USA)
NTU	nephelometric turbidity unit
PAC	powdered activated carbon
PAH	polynuclear aromatic hydrocarbon
PCP	pentachlorophenol
PCR	polymerase chain reaction
PD	photoionization detector
PMTDI	provisional maximum tolerable daily intake
PPA	protein phosphatase assay
PT	purge and trap
PTDI	provisional tolerable daily intake

PTMI	provisional tolerable monthly intake
PTWI	provisional tolerable weekly intake
PVC	polyvinyl chloride
QMRA	quantitative microbial risk assessment
RNA	ribonucleic acid
SI	Système international d'unités (International System of Units)
SODIS	solar water disinfection
sp.	species (singular)
spp.	species (plural)
subsp.	subspecies (singular)
TBA	terbuthylazine
TCB	trichlorobenzene
TCU	true colour unit
TD_{05}	tumorigenic $dose_{05}$, the dose associated with a 5% excess incidence of tumours in experimental animal studies
TDI	tolerable daily intake
TDS	total dissolved solids
THM	trihalomethane
TID	thermal ionization detector; total indicative dose
UF	uncertainty factor
UN	United Nations
UNICEF	United Nations Children's Fund
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USA	United States of America
UV	ultraviolet
UVPAD	ultraviolet photodiode array detector
WHO	World Health Organization
WHOPES	World Health Organization Pesticide Evaluation Scheme
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

The primary purpose of the *Guidelines for drinking-water quality* is the protection of public health. The Guidelines provide the recommendations of the World Health Organization (WHO) for managing the risk from hazards that may compromise the safety of drinking-water. The recommendations should be considered in the context of managing the risk from other sources of exposure to these hazards, such as waste, air, food and consumer products.



1.1 General considerations and principles

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 drinking-water that is as safe as practicable.

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 and the elderly, especially when living

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.

under unsanitary conditions. Those who are generally at risk of waterborne illness may need to take additional steps to protect themselves against exposure to waterborne pathogens, such as boiling their drinking-water. Safe drinking-water is required for all usual domestic purposes, including drinking, food preparation and 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. 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 derive numerical "guideline values" for constituents of water or indicators of water quality. When defining mandatory limits, it is preferable to consider the Guidelines in the context of local or national environmental, social, economic and cultural conditions. The Guidelines should also be part of an overall health protection strategy that includes sanitation and other strategies, such as managing food contamination. This strategy would also normally be incorporated into a legislative and regulatory framework that adapts the Guidelines to address local requirements and circumstances (see also section 2.6).

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 used to promote 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 or planned legislation relating to water, health and local government is taken into account and that the capacity of regulators in the country 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 or 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 improvement towards long-term health-based targets. Priorities set to remedy the most urgent problems (e.g. protection from pathogens; see section 1.1.2) may be linked to long-term targets of further water quality improvements (e.g. improvements in the acceptability of drinking-water in terms of its taste, odour and appearance; see section 1.1.6).

An important concept in the allocation of resources to improving drinking-water safety is that of incremental improvement towards long-term water quality targets.

1.1.1 Framework for safe drinking-water

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 the risk assessment and risk management of a drinking-water supply increases confidence in the safety of the 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. In this respect, climate change—in the form of increased and more severe periods of drought or more intense rainfall events leading to flooding—can have an impact on both the quality and the quantity of water and will require planning and management to minimize adverse

In Stockholm, in 1999, it was agreed that future guidelines for drinking-water, wastewater and recreational water should integrate assessment of risk, risk management options and exposure control elements within a single framework with embedded quality targets (see the supporting document *Water quality—Guidelines, standards and health*; Annex 1). Following this approach, the assessment of risk is not a goal in its own right, but rather a basis for decision-making. The framework for safe drinking-water and the recommended approach for regulations, policies and programmes are based on this overall framework, known as the Stockholm Framework (see chapter 2).

impacts on drinking-water supplies. Climate change also needs to be considered in the light of demographic change, such as the continuing growth of cities, which itself brings significant challenges for drinking-water supply.

In support of the framework for safe drinking-water, the Guidelines provide a range of supporting information, including microbial aspects (chapters 7 and 11), chemical aspects (chapters 8 and 12), radiological aspects (chapter 9) and acceptability aspects (chapter 10). Figure 1.1 provides an overview of the interrelationships among the individual chapters of the Guidelines in ensuring drinking-water safety.

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 (chapter 6), including buildings, travellers and conveyances.

1.1.2 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.

In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with faeces from humans or animals (including birds). 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 determine the microbial safety of drinking-water.

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

Particular attention should be directed to a water safety framework and implementing comprehensive water safety plans to consistently ensure drinking-water safety and thereby protect public health (see chapter 4). Failure to ensure drinking-water safety may expose the community to the risk of outbreaks of intestinal and other infectious diseases. Outbreaks of waterborne disease 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.

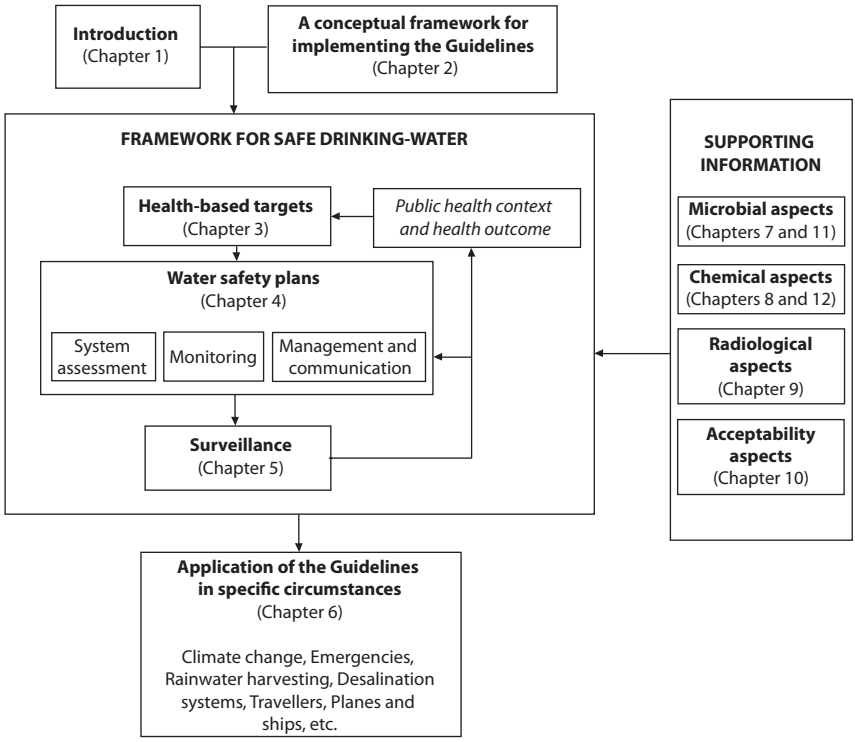


Figure 1.1 Interrelationships among the individual chapters of the *Guidelines for drinking-water quality* in ensuring drinking-water safety

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

Although 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, food intake and droplets and aerosols. Depending on the circumstances 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.

1.1.3 Disinfection

Disinfection is of unquestionable importance in the supply of safe drinking-water. The destruction of pathogenic microorganisms 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 the action of disinfectants. 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. It is essential that an overall management strategy is implemented in which multiple barriers, including source water protection and appropriate treatment processes, as well as protection during storage and distribution, are used 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 efficacy not be compromised in attempting to control such by-products.

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

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 7 and Annex 5, with fact sheets on specific disinfectants and disinfection by-products provided in chapter 12.

1.1.4 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.

The great majority of evident water-related health problems are the result of microbial (bacterial, 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.

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 (see the supporting document *Chemical safety of drinking-water*; Annex 1).

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 protecting 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 performance 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.

1.1.5 Radiological aspects

The health risks 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. Although finding levels of activity above screening values does not indicate any immediate risk to health, it should trigger further investigation to determine the radionuclides responsible and the possible risks, taking local circumstances into account.

The guidance levels for radionuclides recommended in these Guidelines 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.

1.1.6 Acceptability aspects: taste, odour and appearance

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 constituents of water 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 constituents 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 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 guideline values and aesthetic criteria when assessing drinking-water supplies and developing regulations and standards.

Changes in the normal appearance, taste or odour 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 ensuring 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 therefore take into account the vital and complementary roles of the agency respon-

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

sible 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;
- 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 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.

> 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).

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 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 one 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.

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:

1) *surveillance of health status and trends*, including outbreak detection and investigation, generally directly but in some instances through a decentralized body;
2) directly establishing 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, 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;
3) 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;
4) *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, through case–control, cohort or intervention studies, for example. Public health surveillance teams typically operate at national, regional and local levels, as well as in cities and rural health centres. Routine 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;
- 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;
- 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;
- 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 the 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 have an 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;
- 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, Sawyer & Clarke, 1996; Sawyer, Simpson-Hébert & Wood, 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 have an impact on the 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;

- other potentially polluting human activities, such as industry, mining and military sites.

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 document *Protecting groundwater for health* (see Annex 1).

1.2.5 Drinking-water supply agencies

Drinking-water supplies vary from very large urban systems servicing large populations with tens of millions of people 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 water safety plans (for more information, see chapter 4).

In many cases, the water supplier is not responsible for the management of the catchment feeding the 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 role is to recognize the need for them and to initiate 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 and politicians) can provide a valuable non-threatening forum for the interchange of ideas.

For further information, see the supporting document *Water safety plans* (see Annex 1).

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. Although 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—the communities surrounding major towns and cities—in developing countries 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 intakes 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 these situations, 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 relationship with 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;
- is aware of requirements for the protection of drinking-water supplies from pollution.

For further information, see the 1997 volume entitled *Surveillance and control of community supplies* (WHO, 1997); the supporting document *Water safety plans* (Annex 1); Simpson-Hébert, Sawyer & Clarke (1996); Sawyer, Simpson-Hébert & Wood (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 or trolleys. In the context of these Guidelines, water vending does not include bottled or packaged water (which is considered in section 6.14) 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.

More detailed information on treatment of vended water, undertaking a risk assessment of vended water supplies, operational monitoring of control measures, management plans and independent surveillance is included in section 6.3.

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 have an adverse impact 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-connections 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. This would be relevant where community supplies are absent or where community supplies are known to be contaminated or causing waterborne disease (see chapter 7). Public health surveillance or other local authorities may provide guidance to support households and individual consumers in ensuring the safety of their drinking-water. 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.

Certification can also be applied to the implementation of water safety plans. This can take the form of an independent organization or party undertaking audits to verify that plans have been properly designed, are being implemented correctly and are effective.

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;
- control of materials and chemicals used for the treatment of drinking-water, including the performance of devices for household use;
- ensuring that water safety plans are effective.

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 on the control of materials and chemicals used for the treatment of drinking-water, 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 of plumbing and, for larger buildings, on building-specific water safety plans (see section 6.9).

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;
- roof storage systems are intact and not subject to intrusion of microbial or chemical contaminants;
- hot and cold water systems are designed to minimize the proliferation of *Legionella* (see also sections 6.10 and 11.1);
- appropriate protection is in place to prevent backflow;
- the system design of multistorey buildings minimizes pressure fluctuations;
- waste is discharged without contaminating drinking-water;
- plumbing systems function efficiently.

It is important that plumbers are appropriately qualified, have the competence to undertake necessary 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.

For more information on the essential roles of proper drinking-water system and waste system plumbing in public health, see the supporting document *Health aspects of plumbing* (Annex 1).

1.3 Supporting resources to the Guidelines

1.3.1 Published documents

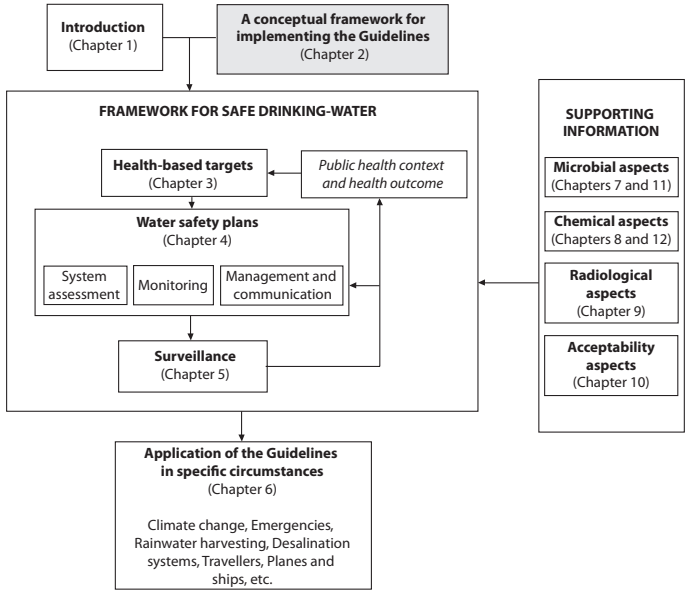
These Guidelines are accompanied by separate texts that provide background information substantiating the derivation of the Guidelines and providing guidance on good practice towards their effective implementation. These are available as published texts, for download from the WHO web site and on CD-ROM. Reference details are provided in Annex 1.

1.3.2 Capacity-building networks

To promote the rapid dissemination of information, improve knowledge exchange, translate evidence and advice into public health policy and practice and facilitate implementation of these Guidelines, a number of international networks have been established. These international networks bring together drinking-water quality specialists, drinking-water supply managers, health regulators, community managers and other stakeholders. The focus areas for these networks are water safety planning for larger systems, including effective operations and maintenance, safe management of small community water supplies, household water treatment and safe storage and optimizing drinking-water regulations to protect public health.

Further information on these networks is available at http://www.who.int/water_sanitation_health/dwq/en/.

2
A conceptual framework for implementing the Guidelines



The basic and essential requirement to ensure the safety of drinking-water is the implementation of a "framework for safe drinking-water" based on the Guidelines. This framework provides a preventive, risk-based approach to managing water quality. It would be composed of health-based targets established by a competent health authority using the Guidelines as a starting point, adequate and properly managed systems (adequate infrastructure, proper monitoring and effective planning and management) and a system of independent surveillance. Such a framework would normally be enshrined in national standards, regulations or guidelines, in conjunction with relevant policies and programmes (see sections 2.6 and 2.7). Resultant regulations and policies should be appropriate to local circumstances, taking into consideration environmental, social, economic and cultural issues and priority setting.

The framework for safe drinking-water is a preventive management approach comprising three key components:

1) health-based targets based on an evaluation of health risks (section 2.1 and chapter 3);
2) water safety plans (WSPs), comprising (section 2.2 and chapter 4):
   - a system assessment to determine whether the drinking-water supply (from source through treatment to the point of consumption) as a whole can deliver water of a quality that meets the health-based targets (section 4.1);
   - operational monitoring of the control measures in the drinking-water supply that are of particular importance in securing drinking-water safety (section 4.2);
   - management plans documenting the system assessment and monitoring plans and describing actions to be taken in normal operation and incident conditions, including upgrade and improvement, documentation and communication (sections 4.4–4.6);
3) a system of independent surveillance that verifies that the above are operating properly (section 2.3 and chapter 5).

Verification to determine whether the performance of the drinking-water supply is in compliance with the health-based targets and whether the WSP itself is effective may be undertaken by the supplier, surveillance agencies or a combination of the two (see section 4.3).

2.1 Health-based targets

Health-based targets are an essential component of the drinking-water safety framework. They should be established by a high-level authority responsible for health in consultation with others, including water suppliers and affected communities. They should take account of the overall public health situation and contribution of drinking-water quality to disease due to waterborne microbes and chemicals, as a part of overall water and health policy. They must also take account of the importance of ensuring access to water for all consumers.

Health-based targets provide the basis for the application of the Guidelines to all types of drinking-water suppliers. Some constituents of drinking-water may cause adverse health effects from single exposures (e.g. pathogenic microorganisms) or long-term exposures (e.g. many chemicals). Because of the range of constituents in water, their mode of action and the nature of fluctuations in their concentrations, there are four principal types of health-based targets used as a basis for identifying safety requirements:

1) *Health outcome targets:* Where waterborne disease contributes to a measurable and significant burden, reducing exposure through drinking-water has the potential to appreciably reduce the risks and incidence of disease. In such circumstances, it is possible to establish a health-based target in terms of a quantifiable reduction in the overall level of disease. This is most applicable where adverse effects follow shortly after exposure, where such effects are readily and reliably monitored and where changes in exposure can also be readily and reliably monitored. This type of health outcome target is primarily applicable to some microbial hazards in developing countries and chemical hazards with clearly defined health effects

largely attributable to water (e.g. fluoride, nitrate/nitrite and arsenic). In other circumstances, health outcome targets may be the basis for evaluation of results through quantitative risk assessment models. In these cases, health outcomes are estimated based on information concerning high-dose exposure and dose–response relationships. The results may be employed directly as a basis for the specification of water quality targets or provide the basis for development of the other types of health-based targets. Health outcome targets based on information on the impact of tested interventions on the health of real populations are ideal, but rarely available. More common are health outcome targets based on defined levels of tolerable risk, either absolute or fractions of total disease burden, usually based on toxicological studies in experimental animals and occasionally based on epidemiological evidence.

2) *Water quality targets:* Water quality targets are established for individual drinking-water constituents that represent a health risk from long-term exposure and where fluctuations in concentration are small. They are typically expressed as guideline values (concentrations) of the substances or chemicals of concern.
3) *Performance targets:* Performance targets are employed for constituents where short-term exposure represents a public health risk or where large fluctuations in numbers or concentration can occur over short periods with significant health implications. These are typically technology based and expressed in terms of required reductions of the substance of concern or effectiveness in preventing contamination.
4) *Specified technology targets:* National regulatory agencies may establish other recommendations for specific actions for smaller municipal, community and household drinking-water supplies. Such targets may identify specific permissible devices or processes for given situations and/or for generic drinking-water system types.

It is important that health-based targets are realistic under local operating conditions and are set to protect and improve public health. Health-based targets underpin the development of WSPs, provide information with which to evaluate the adequacy of existing installations and assist in identifying the level and type of inspection and analytical verifications that are appropriate.

Most countries apply several types of targets for different types of supplies and different contaminants. In order to ensure that they are relevant and supportive, representative scenarios should be developed, including description of assumptions, management options, control measures and indicator systems for performance tracking and verification, where appropriate. These should be supported by general guidance addressing the identification of national, regional or local priorities and progressive implementation, thereby helping to ensure that best use is made of limited resources.

Health-based targets are considered in more detail in chapter 3.

For guidance on how to prioritize constituents based on greatest risk to public health, the reader should refer to section 2.5 and the supporting document *Chemical safety of drinking-water* (Annex 1).

2.2 Water safety plans

Overall control of the microbial and chemical quality of drinking-water requires the development of management plans that, when implemented, provide the basis for system protection and process control to ensure that numbers of pathogens and concentrations of chemicals present a negligible risk to public health and that water is acceptable to consumers. The management plans developed by water suppliers are WSPs. A WSP comprises system assessment and design, operational monitoring and management plans, including documentation and communication. The elements of a WSP build on the multiple-barrier principle, the principles of hazard analysis and critical control points and other systematic management approaches. The plans should address all aspects of the drinking-water supply and focus on the control of abstraction, treatment and delivery of drinking-water.

Many drinking-water supplies provide adequate safe drinking-water in the absence of formalized WSPs. Major benefits of developing and implementing a WSP for these supplies include the systematic and detailed assessment and prioritization of hazards, the operational monitoring of barriers or control measures and improved documentation. In addition, a WSP provides for an organized and structured system to minimize the chance of failure through oversight or lapse of management and for contingency plans to respond to system failures or unforeseen events that may have an impact on water quality, such as increasing severe droughts, heavy rainfall or flood events.

2.2.1 System assessment and design

Assessment of the drinking-water system is applicable, with suitable modifications, to large utilities with piped distribution systems, piped and non-piped community supplies, including hand pumps, and individual domestic supplies, including rainwater. The complexity of a WSP varies with the circumstances. Assessment can be of existing infrastructure or of plans for new supplies or for upgrading existing supplies. As drinking-water quality varies throughout the system, the assessment should aim to determine whether the final quality of water delivered to the consumer will routinely meet established health-based targets. Understanding source quality and changes throughout the system requires expert input. The assessment of systems should be reviewed periodically.

The system assessment needs to take into consideration the behaviour of selected constituents or groups of constituents that may influence water quality. After actual and potential hazards, including events and scenarios that may affect water quality, have been identified and documented, the level of risk for each hazard can be estimated and ranked, based on the likelihood and severity of the consequences.

Validation is an element of system assessment. It is undertaken to ensure that the information supporting the plan is correct and is concerned with the assessment of the scientific and technical inputs into the WSP. Evidence to support the WSP can come from a wide variety of sources, including scientific literature, regulation and legislation departments, historical data, professional bodies and supplier knowledge.

The WSP is the management tool that should be used to assist in actually meeting the health-based targets, and it should be developed following the steps outlined in

chapter 4. If the system is unlikely to be capable of meeting the health-based targets, a programme of upgrading (which may include capital investment or training) should be initiated to ensure that the drinking-water supply would meet the targets. The WSP is an important tool in identifying deficiencies and where improvements are most needed. In the interim, the WSP should be used to assist in making every effort to supply water of the highest achievable quality. Where a significant risk to public health exists, additional measures may be appropriate, including notification, information on compensatory options (e.g. boiling or disinfection at the point of use) and availability of alternative and emergency supplies when necessary.

System assessment and design are considered in more detail in section 4.1 (see also the supporting document *Upgrading water treatment plants*; Annex 1).

2.2.2 Operational monitoring

Operational monitoring is the conduct of planned observations or measurements to assess whether the control measures in a drinking-water system are operating properly. It is possible to set limits for control measures, monitor those limits and take corrective action in response to a detected deviation before the water becomes unsafe. Operational monitoring would include actions, for example, to rapidly and regularly assess whether the structure around a hand pump is complete and undamaged, the turbidity of water following filtration is below a certain value or the chlorine residual after disinfection plants or at the far point of the distribution system is above an agreed value.

Operational monitoring is usually carried out through simple observations and tests, in order to rapidly confirm that control measures are continuing to work. Control measures are actions implemented in the drinking-water system that prevent, reduce or eliminate contamination and are identified in system assessment. They include, for example, management actions related to the catchment, the immediate area around a well, filters and disinfection infrastructure and piped distribution systems. If collectively operating properly, they would ensure that health-based targets are met.

The frequency of operational monitoring varies with the nature of the control measure—for example, checking structural integrity monthly to yearly, monitoring turbidity online or very frequently and monitoring disinfectant residual at multiple points daily or continuously online. If monitoring shows that a limit does not meet specifications, then there is the potential for water to be, or to become, unsafe. The objective is timely monitoring of control measures, with a logically based sampling plan, to prevent the delivery of potentially unsafe water.

Operational monitoring includes observing or testing parameters such as turbidity, chlorine residual or structural integrity. More complex or costly microbial or chemical tests are generally applied as part of validation and verification activities (discussed in sections 4.1.7 and 4.3, respectively) rather than as part of operational monitoring.

In order not only to have confidence that the chain of supply is operating properly, but to confirm that safe water quality is being achieved and maintained, it is necessary to carry out verification, as outlined in section 4.3.

The use of indicator organisms (see section 11.6) in the monitoring of water quality is discussed in the supporting document *Assessing microbial safety of drinking water* (see Annex 1), and operational monitoring is considered in more detail in section 4.2.

2.2.3 Management plans, documentation and communication

A management plan documents system assessment and operational monitoring and verification plans and describes actions in both normal operation and during "incidents" where a loss of control of the system may occur. The management plan should also outline procedures and other supporting programmes required to ensure optimal operation of the drinking-water system.

As the management of some aspects of the drinking-water system often falls outside the responsibility of a single agency, it is essential that the roles, accountabilities and responsibilities of the various agencies involved be defined in order to coordinate their planning and management. Appropriate mechanisms and documentation should therefore be established for ensuring stakeholder involvement and commitment. This may include establishing working groups, committees or task forces, with appropriate representatives, and developing partnership agreements, including, for example, signed memoranda of understanding (see also section 1.2).

Documentation of all aspects of drinking-water quality management is essential. Documents should describe activities that are undertaken and how procedures are performed. They should also include detailed information on:

- assessment of the drinking-water system (including flow diagrams and potential hazards);
- control measures and operational monitoring and verification plans and performance consistency;
- routine operation and management procedures;
- incident and emergency response plans;
- supporting measures, including:
  - training programmes;
  - research and development;
  - procedures for evaluating results and reporting;
  - performance evaluations, audits and reviews;
  - communication protocols;
- community consultation.

Documentation and record systems should be kept as simple and focused as possible. The level of detail in the documentation of procedures should be sufficient to provide assurance of operational control when coupled with suitably qualified and competent operators.

Mechanisms should be established to periodically review and, where necessary, revise documents to reflect changing circumstances. Documents should be assembled in a manner that will enable any necessary modifications to be made easily. A document control system should be developed to ensure that current versions are in use and obsolete documents are discarded.

Appropriate documentation and reporting of incidents or emergencies should also be established. The organization should learn as much as possible from an incident to improve preparedness and planning for future events. Review of an incident may indicate necessary amendments to existing protocols.

Effective communication to increase community awareness and knowledge of drinking-water quality issues and the various areas of responsibility helps consumers to understand and contribute to decisions about the service provided by a drinking-water supplier or land use constraints imposed in catchment areas. It can encourage the willingness of consumers to generate funds to finance needed improvements. A thorough understanding of the diversity of views held by individuals or groups in the community is necessary to satisfy community expectations.

Management, documentation and communication are considered in more detail in sections 4.4, 4.5 and 4.6.

2.3 Surveillance

Surveillance agencies are responsible for an independent (external) and periodic review of all aspects of quality and public health safety and should have the power to investigate and to compel action to respond to and rectify incidents of contamination-caused outbreaks of waterborne disease or other threats to public health. The act of surveillance includes identifying potential drinking-water contamination and waterborne illness events and, more proactively, assessing compliance with WSPs and promoting improvement of the quality, quantity, accessibility, coverage, affordability and continuity of drinking-water supplies.

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

As incremental improvement and prioritizing action in systems presenting greatest overall risk to public health are important, there are advantages to adopting a grading scheme for the relative safety of drinking-water supplies (see chapter 4). More sophisticated grading schemes may be of particular use in community supplies where the frequency of testing is low and exclusive reliance on analytical results is particularly inappropriate. Such schemes will typically take account of both analytical findings and sanitary inspection through approaches such as those presented in section 4.1.2.

The role of surveillance is discussed in section 1.2.1 and chapter 5.

2.4 Verification of drinking-water quality

Drinking-water safety is secured by application of a WSP, which includes monitoring the efficiency of control measures using appropriately selected determinants. In addition to this operational monitoring, a final verification of quality is required.

Verification is the use of methods, procedures or tests in addition to those used in operational monitoring to determine whether the performance of the drinking-water

supply is in compliance with the stated objectives outlined by the health-based targets and whether the WSP needs modification or revalidation.

Verification of drinking-water may be undertaken by the supplier, surveillance agencies or a combination of the two (see section 4.3). Although verification is most commonly carried out by the surveillance agency, a utility-led verification programme can provide an additional level of confidence, supplementing regulations that specify monitoring parameters and frequencies.

2.4.1 Microbial water quality

For microbial water quality, verification is likely to be based on the analysis of faecal indicator microorganisms, with the organism of choice being *Escherichia coli* or, alternatively, thermotolerant coliforms (see sections 4.3.1, 7.4 and 11.6). Monitoring of specific pathogens may be included on very limited occasions to verify that an outbreak was waterborne or that a WSP has been effective. *Escherichia coli* provides conclusive evidence of recent faecal pollution and should not be present in drinking-water. Under certain circumstances, additional indicators, such as bacteriophages or bacterial spores, may be used.

However, water quality can vary rapidly, and all systems are at risk of occasional failure. For example, rainfall can greatly increase the levels of microbial contamination in source waters, and waterborne outbreaks often occur following rainfall. Results of analytical testing must be interpreted taking this into account.

2.4.2 Chemical water quality

Assessment of the adequacy of the chemical quality of drinking-water relies on comparison of the results of water quality analysis with guideline values. These Guidelines provide guideline values for many more chemical contaminants than will actually affect any particular water supply, so judicious choices for monitoring and surveillance should be made prior to initiating an analytical chemical assessment.

For additives (i.e. chemicals deriving primarily from materials and chemicals used in the production and distribution of drinking-water), emphasis is placed on the direct control of the quality of these commercial products. In controlling drinking-water additives, testing procedures typically assess whether the product meets the specifications (see section 8.5.4).

As indicated in chapter 1, most chemicals are of concern only following long-term exposure; however, some hazardous chemicals that occur in drinking-water are of concern because of effects arising from sequences of exposures over a short period. Where the concentration of the chemical of interest (e.g. nitrate/nitrite, which is associated with methaemoglobinaemia in bottle-fed infants) varies widely, even a series of analytical results may fail to fully identify and describe the public health risk. In controlling such hazards, attention must be given to both knowledge of causal factors such as fertilizer use in agriculture and trends in detected concentrations, as these will indicate whether a significant problem may arise in the future. Other hazards may arise intermittently, often associated with seasonal activity or seasonal conditions. One example is the occurrence of blooms of toxic cyanobacteria in surface water.

A *guideline value* represents the concentration of a constituent that does not exceed tolerable risk to the health of the consumer over a lifetime of consumption. Guideline values for some chemical contaminants (e.g. lead, nitrate) are set to be protective for susceptible subpopulations. These guideline values are also protective of the general population over a lifetime.

It is important that recommended guideline values are scientifically justified, practical and feasible to implement as well as protective of public health. Guideline values are not normally set at concentrations lower than the detection limits achievable under routine laboratory operating conditions. Moreover, some guideline values are established taking into account available techniques for controlling, removing or reducing the concentration of the contaminant to the desired level. In some instances, therefore, provisional guideline values have been set for contaminants for which calculated health-based values are not practically achievable.

2.5 Identifying priority concerns

These Guidelines cover a large number of potential constituents in drinking-water in order to meet the varied needs of countries worldwide. Generally, however, only a few constituents will be of public health concern under any given circumstances. It is essential that the national regulatory agency and local water authorities identify and respond to the constituents of relevance to the local circumstances. This will ensure that efforts and investments can be directed to those constituents that have the greatest risk or public health significance.

Health-based targets are established for potentially hazardous water constituents and provide a basis for assessing drinking-water quality. Different parameters may require different priorities for management to improve and protect public health. In general, the priorities, in decreasing order, are to:

- ensure an adequate supply of microbially safe water and maintain acceptability to discourage consumers from using potentially less microbially safe water;
- manage key chemical hazards known to cause adverse health effects;
- address other chemical hazards, particularly those that affect the acceptability of drinking-water in terms of its taste, odour and appearance;
- apply appropriate technologies to reduce contaminant concentrations in the source to below the guideline or regulated values.

The two key features in choosing hazards for which setting a standard is desirable on health grounds are the health impacts (severity) associated with the substance and the probability of significant occurrence (exposure). Combined, these elements determine the risk associated with a particular hazard. For

Many microbial and chemical constituents of drinking-water can potentially cause adverse human health effects. The detection of these constituents in both raw water and water delivered to consumers is often slow, complex and costly, which limits early warning capability and affordability. Reliance on water quality determination alone is insufficient to protect public health. As it is neither physically nor economically feasible to test for all drinking-water quality parameters, the use of monitoring effort and resources should be carefully planned and directed at significant or key characteristics.

microbial hazards, the setting of targets will be influenced by occurrence and concentrations in source waters and the relative contribution of waterborne organisms to disease. For chemical hazards, the factors to be considered are the severity of health effects and the frequency of exposure of the population in combination with the concentration to which they will be exposed. The probability of health effects clearly depends on the toxicity and the concentration, but it also depends on the period of exposure. For most chemicals, health impacts are associated with long-term exposure. Hence, in the event that exposure is occasional, the risk of an adverse health effect is likely to be low, unless the concentration is extremely high. The substances of highest priority will therefore be those that occur widely, are present in drinking-water sources or drinking-water all or most of the time and are present at concentrations that are of health concern.

Guidance on determining which chemicals are of importance in a particular situation is given in the supporting document *Chemical safety of drinking-water* (Annex 1).

Although WHO does not set formal guideline values for substances on the basis of consumer acceptability (i.e. substances that affect the appearance, taste or odour of drinking-water), it is not uncommon for standards to be set for substances and parameters that relate to consumer acceptability. Although exceeding such a standard is not a direct issue for health, it may be of great significance for consumer confidence and may lead consumers to obtain their water from an alternative, less safe source. Such standards are usually based on local considerations of acceptability.

Priority setting should be undertaken on the basis of a systematic assessment based on collaborative effort among all relevant agencies and may be applied at national and system-specific levels. At the national level, priorities need to be set in order to identify the relevant hazards, based on an assessment of risk—i.e. severity and exposure. At the level of individual water supplies, it may be necessary to also prioritize constituents for effective system management. These processes may require the input of a broad range of stakeholders, including health, water resources, drinking-water supply, environment, agriculture and geological services/mining authorities, to establish a mechanism for sharing information and reaching consensus on drinking-water quality issues.

2.5.1 Undertaking a drinking-water quality assessment

In order to determine which constituents are, indeed, of concern, it will be necessary to undertake a drinking-water quality assessment. It is important to identify what types of drinking-water systems are in place in the country (e.g. piped water supplies, non-piped water supplies, vended water) and the quality of drinking-water sources and supplies.

Additional information that should be considered in the assessment includes catchment type (protected, unprotected), wastewater discharges, geology, topography, agricultural land use, industrial activities, sanitary surveys, records of previous monitoring, inspections and local and community knowledge. The wider the range of data sources used, the more useful the results of the process will be.

In many situations, authorities or consumers may have already identified a number of drinking-water quality problems, particularly where they cause obvious health effects or acceptability problems. These existing problems would normally be assigned a high priority.

Drinking-water supplies that represent the greatest risks to public health should be identified, with resources allocated accordingly.

2.5.2 Assessing microbial priorities

The most common and widespread health risk associated with drinking-water is microbial contamination, the consequences of which mean that its control must always be of paramount importance. Priority needs to be given to improving and developing the drinking-water supplies that represent the greatest public health risk.

The most common and widespread health risk associated with drinking-water is microbial contamination, the consequences of which mean that its control must always be of paramount importance.

Health-based targets for microbial contaminants are discussed in section 3.2, and a comprehensive consideration of microbial aspects of drinking-water quality is contained in chapter 7.

2.5.3 Assessing chemical priorities

Not all of the chemicals with guideline values will be present in all water supplies or, indeed, all countries. If they do exist, they may not be found at levels of concern. Conversely, some chemicals without guideline values or not addressed in the Guidelines may nevertheless be of legitimate local concern under special circumstances.

Risk management strategies (as reflected in national standards and monitoring activities) and commitment of resources should give priority to those chemicals that pose a risk to human health or to those with significant impacts on the acceptability of water.

Only a few chemicals have been shown to cause widespread health effects in humans as a consequence of exposure through drinking-water when they are present in excessive quantities. These include fluoride, arsenic and nitrate. Human health effects associated with lead (from domestic plumbing) have also been demonstrated in some areas, and there is concern because of the potential extent of exposure to selenium and uranium in some areas at concentrations of human health significance. Iron and manganese are of widespread significance because of their effects on acceptability. These constituents should be taken into consideration as part of any priority-setting process. In some cases, assessment will indicate that no risk of significant exposure exists at the national, regional or system level.

Drinking-water may be only a minor contributor to the overall exposure to a particular chemical, and in some circumstances controlling the levels in drinking-water, at potentially considerable expense, may have little impact on overall exposure. Drinking-water risk management strategies should therefore be considered in conjunction with other potential sources of human exposure.

The process of "short-listing" chemicals of concern may initially be a simple classification of high and low risk to identify broad issues. This may be refined using data from more detailed assessments and analysis and may take into consideration rare events, variability and uncertainty.

Guidance on how to undertake prioritization of chemicals in drinking-water is provided in the supporting document *Chemical safety of drinking-water* (Annex 1). This deals with issues including:

- the probability of exposure (including the period of exposure) of the consumer to the chemical;
- the concentration of the chemical that is likely to give rise to health effects (see also section 8.5);
- the evidence of health effects or exposure arising through drinking-water, as opposed to other sources, and relative ease of control of the different sources of exposure.

Additional information on the hazards and risks of many chemicals not included in these Guidelines is available from several sources, including WHO Environmental Health Criteria monographs and Concise International Chemical Assessment Documents, reports by the Joint Food and Agriculture Organization of the United Nations (FAO)/WHO Meeting on Pesticide Residues and the Joint FAO/WHO Expert Committee on Food Additives and information from competent national authorities. These information sources have been peer reviewed and provide readily accessible information on toxicology, hazards and risks of many less common contaminants. They can help water suppliers and health officials to decide upon the significance (if any) of a detected chemical and on the response that might be appropriate.

2.6 Developing drinking-water quality standards

Health-based targets, including numeric guideline values and other targets described in the *Guidelines for drinking-water quality*, are not intended to be mandatory limits, but are provided as the scientific point of departure for development of national or regional numerical drinking-water quality standards. No single approach is universally applicable, and the nature and form of drinking-water standards may vary among countries and regions.

In developing national drinking-water standards based on these Guidelines, it will be necessary to take account of a variety of environmental, social, cultural, economic, dietary and other conditions affecting potential exposure. This may lead to national standards that differ appreciably from these Guidelines, both in scope as well as in risk targets. A programme based on modest but realistic goals—including fewer water quality parameters of priority health concern at attainable levels consistent with providing a reasonable degree of public health protection in terms of reduction of disease or disease risk within the population—may achieve more than an overambitious one, especially if targets are upgraded periodically.

To ensure that standards are acceptable to consumers, communities served, together with the major water users, should be involved in the standards-setting pro-

cess. Public health agencies may be closer to the community than those responsible for its drinking-water supply. At a local level, they also interact with other sectors (e.g. education), and their combined action is essential to ensure active community involvement.

2.6.1 Adapting guideline values to locally relevant standards

In order to account for variations in exposure from different sources (e.g. water, food) in different parts of the world, the proportion of the tolerable daily intake allocated to drinking-water in setting guideline values for many chemicals will vary. Where relevant exposure data are available, authorities are encouraged to develop context-specific guideline values that are tailored to local circumstances and conditions. For example, in areas where the intake of a particular contaminant in drinking-water is known to be much greater than that from other sources (e.g. air and food), it may be appropriate to allocate a greater proportion of the tolerable daily intake to drinking-water to derive a guideline value more suited to the local conditions.

Daily water intake can vary significantly in different parts of the world, seasonally and particularly where consumers are involved in manual labour in hot climates. Local adjustments to the daily water consumption value may be needed in setting local standards, as in the case of fluoride, for example.

Volatile substances in water may be released into the air during showering and through a range of other household activities. Under such circumstances, inhalation may become a significant route of exposure. Where such exposure is shown to be important for a particular substance (i.e. high volatility, low ventilation rates and high rates of showering/bathing), it may be appropriate to adjust the guideline value. For those substances that are particularly volatile, such as chloroform, the correction factor would be approximately equivalent to a doubling of exposure. For further details, the reader should refer to section 8.2.9.

2.6.2 Periodic review and revision of standards

As knowledge increases, there may be changes to specific guideline values or consideration of new hazards for the safety of drinking-water. There will also be changes in the technology of drinking-water treatment and analytical methods for contaminants. National or subnational standards must therefore be subjected to periodic review and should be structured in such a way that changes can be made readily. Changes may need to be made to modify standards, remove parameters or add new parameters, but no changes should be made without proper justification through risk assessment and prioritization of resources for protecting public health. Where changes are justified, it is important that they are communicated to all stakeholders.

2.7 Drinking-water regulations and supporting policies and programmes

The incorporation of a preventive risk management and prioritization approach to drinking-water quality regulations, policies and programmes will:

- ensure that regulations support the prioritization of drinking-water quality parameters to be tested, instead of making mandatory the testing of every parameter in these Guidelines;
- ensure implementation of appropriate sanitation measures at community and household levels and encourage action to prevent or mitigate contamination at source;
- identify drinking-water supplies that represent the greatest risks to public health and thus determine the appropriate allocation of resources.

2.7.1 Regulations

The alignment of national drinking-water quality regulations with the principles outlined in these Guidelines will ensure that:

- there is an explicit link between drinking-water quality regulations and the protection of public health;
- regulations are designed to ensure safe drinking-water from source to consumer, using multiple barriers;
- regulations are based on good practices that have been proven to be appropriate and effective over time;
- a variety of tools are in place to build and ensure compliance with regulations, including education and training programmes, incentives to encourage good practices and penalties, if enforcement is required;
- regulations are appropriate and realistic within national, subnational and local contexts, including specific provisions or approaches for certain contexts or types of supplies, such as small community water supplies;
- stakeholder roles and responsibilities, including how they should work together, are clearly defined;
- "what, when and how" information is shared between stakeholders—including consumers—and required action is clearly defined for normal operations and in response to incidents or emergencies;
- regulations are adaptable to reflect changes in contexts, understanding and technological innovation and are periodically reviewed and updated;
- regulations are supported by appropriate policies and programmes.

The aim of drinking-water quality regulations should be to ensure that the consumer has access to sustainable, sufficient and safe drinking-water. Enabling legislation should provide broad powers and scope to related regulations and include public health protection objectives, such as the prevention of waterborne disease and the provision of an adequate supply of drinking-water. Drinking-water regulations should focus on improvements to the provision and safety of drinking-water through a variety of requirements, tools and compliance strategies. Although sanctions are needed within regulations, the principal aim is not to shut down deficient water supplies.

Drinking-water quality regulations are not the only mechanism by which public health can be protected. Other regulatory mechanisms include those related to source water protection, infrastructure, water treatment and delivery, surveillance and response to potential contamination and waterborne illness events.

Drinking-water quality regulations may also provide for interim standards, permitted deviations and exemptions as part of a national or regional policy, rather than as a result of local initiatives. This may take the form of temporary exemptions for certain communities or areas for defined periods of time. Short-term and medium-term targets should be set so that the most significant risks to human health are managed first. Regulatory frameworks should support long-term progressive improvements.

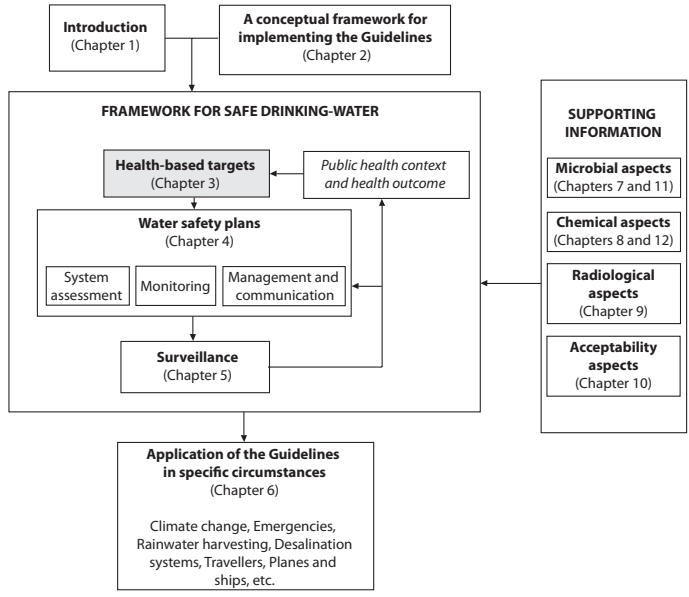
2.7.2 Supporting policies and programmes

Developing and promulgating regulations alone will not ensure that public health is protected. Regulations must be supported by adequate policies and programmes. This includes ensuring that regulatory authorities, such as enforcement agencies, have sufficient resources to fulfil their responsibilities and that the appropriate policy and programme supports are in place to assist those required to comply with regulations. In other words, the appropriate supports need to be in place so that those being regulated and those who are responsible for regulating are not destined to fail.

Implementation or modification of policies and programmes to provide safe drinking-water should not be delayed because of a lack of appropriate regulation. Even where drinking-water regulations do not yet exist, it may be possible to encourage, and even enforce, the supply of safe drinking-water through, for example, educational efforts or commercial, contractual arrangements between consumer and supplier (e.g. based on civil law).

In countries where universal access to safe drinking-water at an acceptable level of service has not been achieved, policies should refer to expressed targets for increases in sustainable access to safe drinking-water. Such policy statements should be consistent with achievement of the Millennium Development Goals (http://www.un.org/millenniumgoals/) of the United Nations Millennium Declaration and should take account of levels of acceptable access outlined in General Comment 15 on the Right to Water of the United Nations Committee on Economic, Social and Cultural Rights (http://umn.edu/humanrts/gencomm/escgencom15.htm) and associated documents.

3
Health-based targets



Health-based targets are measurable health, water quality or performance objectives that are established based on a judgement of safety and on risk assessments of waterborne hazards. These Guidelines describe four distinct types of health-based targets, applicable to all types of hazards and water supplies:

1) health outcome targets (e.g. tolerable burdens of disease);
2) water quality targets (e.g. guideline values for chemical hazards);
3) performance targets (e.g. log reductions of specific pathogens);
4) specified technology targets (e.g. application of defined treatment processes).

These targets are common components of existing drinking-water guidelines or standards that are used to protect and improve drinking-water quality and, consequently, human health. They provide benchmarks for water suppliers and regulators to confirm the adequacy of existing systems or the need for improvement. They underpin the development of water safety plans and verification of successful implementation. Where

Health-based targets can be used to support incremental improvement by marking out milestones to guide progress towards water safety and public health goals.

required, health-based targets can be used to support incremental improvement by marking out milestones to guide progress towards water safety and public health goals. This normally requires periodic review and updating of priorities and targets. In turn, norms and standards should also be periodically updated (see section 2.6.2).

Health-based targets should assist in determining specific interventions appropriate to delivering safe drinking-water, including control measures such as source protection and treatment processes.

3.1 Setting health-based targets

The use of health-based targets is applicable in countries at all levels of development. To ensure effective health protection and improvement, targets need to be realistic, measurable, based on scientific data and relevant to local conditions (including economic, environmental, social and cultural conditions) and financial, technical and institutional resources. Health-based targets should be part of an overall public health policy, taking into account public health status and trends and the contribution of drinking-water to the transmission of infectious disease and to overall exposure to hazardous chemicals both in individual settings and within overall health management.

Although water can be a source of microbial, chemical or radiological hazards, it is by no means the only source. In setting targets, consideration needs to be given to other sources, including food, air, person-to-person contact and consumer products, as well as poor sanitation and personal hygiene. Where the overall burden of disease from multiple exposure routes is very high, there is limited value in setting strict targets for drinking-water. For example, there is limited value in establishing a strict target for a chemical hazard if drinking-water provides only a small proportion of the total exposure to that chemical. The cost of meeting such targets could unnecessarily divert funding from other, more pressing health interventions and is not consistent with the public health objective of reducing overall levels of risk from all sources of exposure to environmental hazards (Prüss et al., 2002; Prüss & Corvalan, 2006).

It is also important to take account of the impact of the proposed intervention on overall rates of disease. For some pathogens and their associated diseases, interventions in water quality may be ineffective and may therefore not be justified. This may be the case where other routes of exposure dominate. For others, long experience has shown the effectiveness of improving drinking-water supply and quality management in the control of waterborne diseases such as typhoid and dysentery.

Meeting health-based targets should be viewed in the context of broader public health policy, including initiatives to improve sanitation, waste disposal, personal hygiene and public education on ways to reduce both personal exposure to hazards and impacts of personal activity on water resources. Improved public health, reduced carriage of pathogens and reduced human impacts on water

> The judgement of safety—or what is a tolerable burden of disease 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 health-based targets justifies the cost is for each country to decide.

Table 3.1 Benefits of health-based targets

Target development stage	Benefit
Formulation	Provides insight into the health of the population
	Reveals gaps in knowledge
	Supports priority setting
	Increases the transparency of health policy
	Promotes consistency among national health programmes
	Stimulates debate
Implementation	Inspires and motivates collaborating authorities to take action
	Improves commitment
	Fosters accountability
	Guides the rational allocation of resources
Evaluation	Supplies established milestones for incremental improvements
	Provides opportunity to take action to correct deficiencies and/or deviations
	Identifies data needs and discrepancies

resources all contribute to drinking-water safety (Howard et al., 2002). Public health prioritization would normally indicate that the major contributors to disease should be dealt with preferentially, taking account of the costs and impacts of potential interventions. However, this does not mean ignoring lesser targets if they can be easily achieved for little cost, as long as this does not divert attention from major targets.

An important concept in the allocation of resources to improving drinking-water safety is the possibility of establishing less stringent transitional targets supported by sound risk management systems in order to encourage incremental improvements of the quality of drinking-water. In this regard, health-based targets can be used as the basis for supporting and measuring incremental progress in water quality improvement. Improvements can relate to progression through increasingly tighter targets or evolution through target types that more precisely reflect the health protection goals (e.g. from specified technology targets to performance targets).

The processes of formulating, implementing, communicating and evaluating health-based targets provide benefits to the overall preventive management of drinking-water quality. These benefits are outlined in Table 3.1.

3.2 Disability-adjusted life years, tolerable disease burden and reference level of risk

At a national level, decisions about risk acceptance and tolerable burdens of disease are complex and need to take account of the probability and severity of impact in addition to the environmental, social, cultural, economic and political dimensions that play important roles in decision-making. Negotiations are an important part of these processes, and the outcome may very well be unique to each situation. Notwithstanding the complexity of these decisions, definitions of tolerable burdens of disease and reference levels of risk are required to provide a baseline for the development of health-based targets and as a point of departure for decisions in specific situations.

Descriptions of tolerable burdens of disease relating to water are typically expressed in terms of specific health outcomes such as maximum frequencies of diarrhoeal disease or cancer incidence. However, these descriptions do not consider the severity of the outcomes. The various hazards that may be present in water are associated with very diverse health outcomes with different impacts ranging from mild diarrhoea to potentially severe outcomes such as typhoid, cancer or skeletal fluorosis.

A common "metric" is needed that can be used to quantify and compare the burden of disease associated with different water-related hazards, taking into account varying probabilities, severities and duration of effects. Such a metric should be applicable regardless of the type of hazard (microbial, chemical or radiological) to enable the use of a consistent approach for each hazard. The metric used in these Guidelines is the disability-adjusted life year, or DALY (Box 3.1). The World Health Organization has used DALYs quite extensively to evaluate public health priorities and to assess the disease burden associated with environmental exposures, particularly for microbial hazards.

A key advantage of using the DALY is its aggregation of different impacts on the quality and quantity of life and its focus on actual outcomes rather than potential risks; hence, it supports rational public health priority setting. DALYs can be used to define tolerable burden of disease and the related reference level of risk.

"Tolerable burden of disease" represents an upper limit of the burden of health effects associated with waterborne disease that is established by national policy-makers. "Reference level of risk" is an equivalent term used in the context of quantitative risk assessments.

In these Guidelines, the tolerable burden of disease is defined as an upper limit of 10^{-6} DALY per person per year. This upper-limit DALY is approximately equivalent to a 10^{-5} excess lifetime risk of cancer (i.e. 1 excess case of cancer per 100 000 people ingesting drinking-water at the water quality target daily over a 70-year period), which is the risk level used in these Guidelines to determine guideline values for genotoxic carcinogens.

Expressing health-based targets for chemical hazards in DALYs has the advantage of enabling comparisons with microbial risks. However, use of the DALY approach for chemicals has been limited in practice due to gaps in knowledge.

The 10^{-6} DALY tolerable burden of disease target may not be achievable or realistic in some locations and circumstances in the near term. Where the overall burden of disease by multiple exposure routes (water, food, air, direct personal contact, etc.) is very high, setting a 10^{-6} DALY per person per year level of disease burden from waterborne exposure alone will have little impact on the overall disease burden. Setting a less stringent level of acceptable risk, such as 10^{-5} or 10^{-4} DALY per person per year, from waterborne exposure may be more realistic, yet still consistent with the goals of providing high-quality, safer water.

3.3 Types of health-based targets

The nature and typical application of health-based targets are presented in Table 3.2. Health-based targets differ considerably with respect to the amount of resources

Box 3.1 Disability-adjusted life years

The various hazards that can be present in water can have very different health outcomes. Some outcomes are mild (e.g. diarrhoea), whereas others can be severe (e.g. cholera, haemolytic uraemic syndrome associated with *Escherichia coli* O157 or cancer). Some are acute (e.g. diarrhoea), whereas others are delayed (e.g. infectious hepatitis or cancer). Some especially relate to certain age ranges and groups (e.g. skeletal fluorosis in older adults often arises from long-term exposure to high levels of fluoride in childhood; infection with hepatitis E virus has a very high mortality rate among pregnant women). In addition, any one hazard may cause multiple effects (e.g. gastroenteritis, Gullain-Barré syndrome, reactive arthritis and mortality associated with *Campylobacter*).

In order to support public health priority setting, a common metric is required that can be applied to all types of hazard and takes into account different health outcomes, including probabilities, severities and duration of effects. The disability-adjusted life year (DALY) provides this metric.

The basic principle of the DALY is to weight each health impact in terms of severity within the range of 0 for good health to 1 for death. The weighting is then multiplied by duration of the effect and the number of people affected. In the case of death, duration is regarded as the years lost in relation to normal life expectancy. Using this approach, a mild diarrhoea with a severity weighting of 0.1 and lasting for 7 days results in a DALY of 0.002, whereas death resulting in a loss of 30 years of life equates to a DALY of 30.

Hence, DALY = YLL (years of life lost) + YLD (years lived with a disability or illness). In this context, *disability* refers to a condition that detracts from good health.

For example, infection with rotavirus (in developed countries) causes:

- mild diarrhoea (severity rating of 0.1) lasting 7 days in 97.5% of cases;
- severe diarrhoea (severity rating of 0.23) lasting 7 days in 2.5% of cases;
- rare deaths of very young children in 0.015% of cases.

The DALY per case can then be calculated as follows:

$$\begin{aligned} \text{DALY} &= (0.1 \times 7/365 \times 0.975) + (0.23 \times 7/365 \times 0.025) + (1 \times 70 \times 0.000\,15) \\ &= 0.0019 + 0.0001 + 0.0105 \\ &= 0.0125 \end{aligned}$$

Infection with *Cryptosporidium* can cause watery diarrhoea (severity weighting of 0.067) lasting for 7 days with extremely rare deaths in 0.0001% of cases. This equates to a DALY per case of 0.0015.

Further information on the use of DALYs in establishing health-based targets is included in the supporting document *Quantifying public health risk in the WHO Guidelines for drinking-water quality* (Annex 1).

needed for their development and implementation and in relation to the precision with which the public health benefits of risk management actions can be defined. The most precise are health outcome targets, which underpin the derivation of the remaining targets, as shown in Figure 3.1. Each target type is based on those above it in Table 3.2, and assumptions with default values are introduced in moving down between target types. The targets towards the top of the table require greater scientific and technical inputs and are therefore more precisely related to the level of health protection. Target types at the bottom of Table 3.2 require the least interpretation by practitioners in implementation, but depend on a number of assumptions (e.g. establishing specified technology targets in the absence of sufficient source water quality data to apply performance targets for microbial pathogens). Efforts should be made to collect additional information when critical data for applying the next stage of target setting may not be available. This incremental improvement will ensure that the health-based targets will be as pertinent as possible to local circumstances.

Table 3.2 Nature and application of health-based targets

Type of target	Nature of target	Typical applications	Notes
Health outcome	Defined tolerable burden of disease	High-level policy target set at national level, used to inform derivation of performance, water quality and specified technology targets	These Guidelines define a tolerable burden of disease of 10^{-6} DALY per person per year
	No adverse effect or negligible risk	Chemical or radiological hazards	Derived from international chemical or radionuclide risk assessments
Water quality	Guideline values	Chemical hazards	Based on individual chemical risk assessments
		Microbial water quality targets are not normally applied	*Escherichia coli* is used as an indicator of faecal contamination and to verify water quality
		Radiological water quality targets are not normally applied	Radiological screening levels are applied
Performance	Specified removal of hazards	Microbial hazards (expressed as log reductions)	Specific targets set by water supplier based on quantitative microbial risk assessment and health outcome targets or generic targets set at national level
		Chemical hazards (expressed as percentage removal)	Specific targets set by water supplier based on chemical guideline values or generic targets set at national level
Specified technology	Defined technologies	Control of microbial and chemical hazards	Set at national level; based on assessments of source water quality, frequently underpinned by established or validated performance of the specified technology (e.g. requirement of filtration for surface water)

When establishing health-based targets, care should be taken to account for short-term events and fluctuations in water quality along with "steady-state" conditions. This is particularly important when developing performance and specified technology targets. Short-term water quality can significantly deteriorate, for example, following heavy rain and during maintenance. Catastrophic events can result in periods of very degraded source water quality and greatly decreased efficiency in many processes, or even system failure, greatly increasing the likelihood of a disease outbreak. Events like these provide additional justification for the long-established "multiple-barrier principle" in water safety.

For chemical hazards, health-based targets most commonly take the form of water quality targets, using the guideline values outlined in section 8.5. Performance targets expressed as percentage removals or specified technology targets can also be applied to chemical hazards.

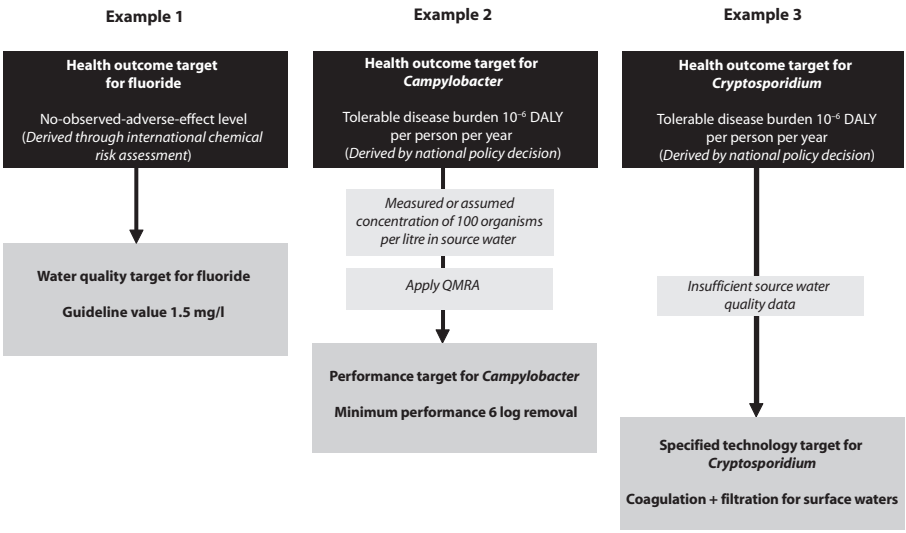


Figure 3.1 Examples of how to set health-based targets for various hazards

For microbial hazards, health-based targets usually take the form of performance or specified technology targets. The choice of target will be influenced by the number of data available on source water quality, with performance targets requiring more information. Water quality targets are typically not developed for pathogens, because monitoring finished drinking-water for pathogens is not considered a feasible or cost-effective option. Concentrations of pathogens equivalent to a health outcome target of 10^{-6} DALY per person per year are typically less than 1 organism per 10^4–10^5 litres. Therefore, it is more feasible and cost-effective to monitor for indicator organisms such as *E. coli*.

In practice, risks to public health from drinking-water are often attributable to a single hazard at a time; therefore, in deriving targets, the reference level of risk is applied independently to each hazard.

3.3.1 Health outcome targets

The most direct descriptions of drinking-water safety are health outcome targets, such as upper limits on frequencies of diarrhoeal disease or cancer incidence. These upper limits represent tolerable burdens of disease and are typically set at the national level. They underpin the derivation of water quality, performance and specified technology targets (Figure 3.1). These Guidelines define a tolerable burden of disease of 10^{-6} DALY per person per year. For threshold chemicals, the health outcome target is based on no-observed-adverse-effect levels (see section 8.2).

Health outcome targets must be translated into water quality, performance or specified technology targets in order to be actioned by the water supplier as part of the water safety plan.

3.3.2 Water quality targets

Water quality targets are the most common form of health-based target applied to chemicals that may be found in drinking-water. The guideline values for individual chemicals described in section 8.5 provide water quality targets that can be used to verify that water safety plans have been effective in managing risks from chemicals in drinking-water.

Guideline values are established on the basis of international risk assessments of the health effects associated with exposure to the chemical in water. In developing national drinking-water standards (or health-based targets) based on these guideline values, it will be necessary to take into consideration a variety of environmental, social, cultural, economic, dietary and other conditions affecting potential exposure, as well as the default assumptions that are used to derive the guideline values. Exposure from chemicals in drinking-water is typically minor in comparison with that from other sources (e.g. food, consumer products and air), with a few important exceptions (e.g. arsenic and fluoride). This may lead to national targets that differ appreciably from the guideline values. In some cases, it may be appropriate to take action to prevent exposure to a chemical from sources other than drinking-water (e.g. lead from soldered cans and from petrol).

One example is that of the health-based target for fluoride in drinking-water. A guideline value of 1.5 mg/l is recommended in Table A3.3 of Annex 3, with a comment that "Volume of water consumed and intake from other sources should be considered when setting national standards." Thus, in a country with a warm climate year-round and where piped water is the preferred source of drinking-water, authorities may select a health-based target for fluoride that is lower than this guideline value, as water consumption is expected to be higher. On a similar note, the health-based target should be reviewed in terms of its impact on the most vulnerable section of the population.

Where water treatment processes have been put in place to remove or reduce specific chemicals (see section 8.4 and Annex 5), water quality targets should be used to determine appropriate treatment requirements.

It is important that water quality targets are established only for those chemicals that, following rigorous assessment, have been determined to be of health concern or of concern for the acceptability of the drinking-water to consumers. There is little value in undertaking measurements for chemicals that are unlikely to be in the system, that will be present only at concentrations much lower than the guideline value or that have no human health effects or effects on drinking-water acceptability. One example is that of radionuclides in drinking-water, which may be present in such minute quantities that their contribution to the overall health risks from drinking-water will be negligible. Analysis of individual radionuclides requires sophisticated and expensive procedures; hence, in such cases, measurements of gross alpha and gross beta activities may be adopted as the screening tests for the presence of radionuclides in drinking-water, as discussed in section 9.3.

Water quality targets are also used in the certification process for chemicals that occur in water as a result of treatment processes or from materials in contact with water. In such applications, assumptions are made in order to derive standards for materials and chemicals that can be employed in their certification. Generally, allow-

ance must be made for the incremental increase over levels found in water sources. For some materials (e.g. domestic plumbing), assumptions must also account for the relatively high release of some substances for a short period following installation.

Escherichia coli remains an important indicator of faecal contamination for verification of water quality, but measurements of *E. coli* do not represent a risk-based water quality target. The use of *E. coli* as an indicator organism is discussed in more detail in chapter 7.

3.3.3 Performance targets

Although performance targets can be applied to chemical hazards, the most common application is for control of microbial hazards in piped supplies. Performance targets assist in the selection and use of control measures that are capable of preventing pathogens from breaching the barriers of source protection, treatment and distribution systems or preventing growth within the distribution system.

Performance targets define requirements in relation to source water quality. Ideally, this should be based on system-specific data; more commonly, however, targets will be specified in relation to broad categories of source water quality and type (see section 7.2). The derivation of performance targets requires the integration of factors such as tolerable disease burden (acceptable risk), including severity of disease outcomes, and, for pathogens, quantitative microbial risk assessment (see section 7.2). There are insufficient data, and it is not realistic, to derive performance targets for all potentially waterborne pathogens. The practical approach is to derive targets for reference pathogens representing groups of pathogens (e.g. bacteria, viruses and protozoa). Selection of reference pathogens should take into account variations in susceptibility to treatment as well as local conditions, including prevalence of waterborne transmission and source water characteristics.

The most common application of performance targets is in identifying appropriate combinations of treatment processes to reduce pathogen concentrations in source water to a level that will meet health outcome targets and hence be safe. This is normally expressed in terms of log reductions. Selection of processes requires evidence that they will meet required performance targets (i.e. validation; see sections 2.2.2 and 4.1.7). Examples of treatment processes and pathogen reductions are given in section 7.3.

Performance targets can be applied to catchment controls that are aimed at reducing pathogen concentrations through preventive measures and to measures to prevent ingress of contamination through distribution systems. Performance targets are also important in certification of point-of-use devices and specified technologies used for drinking-water treatment. Certification of devices is discussed elsewhere (see section 1.2.9).

Performance targets can be applied to chemical hazards. In comparison with targets for microbial hazards, they are typically applied to specific chemicals, with performance measured in terms of percentage reduction (see section 8.4).

3.3.4 Specified technology targets

Specified technology targets typically take the form of recommendations concerning technologies applicable in certain circumstances (e.g. filtration and disinfection of

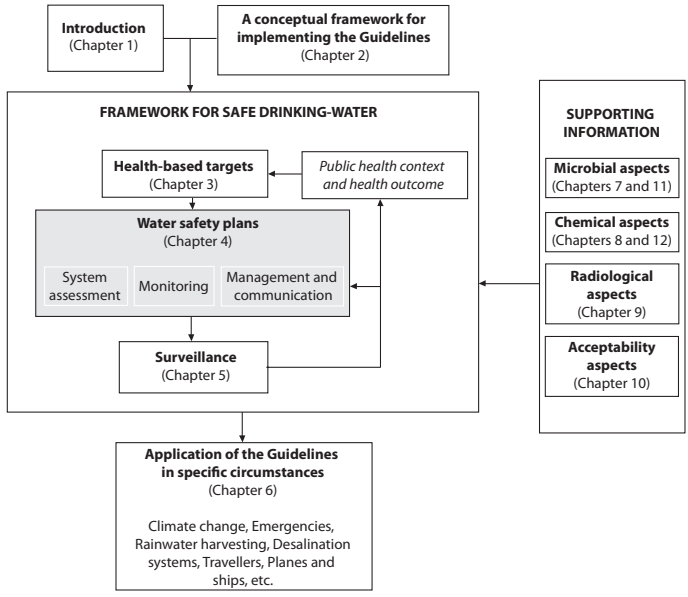
surface water). Selection of technologies is usually based on qualitative assessments of source water type and quality (e.g. impacted surface water, protected groundwater). Specified technology targets are most frequently applied to small community supplies and to devices used at the household level. They can be applied to both microbial and chemical hazards.

Smaller municipal and community drinking-water suppliers often have limited resources and ability to develop individual system assessments and health-based targets. National regulatory agencies may therefore directly specify technology requirements or approved options. These may include, for example:

- specific and approved treatment processes in relation to source types and characteristics;
- providing guidance on requirements for protection of well heads;
- requirements for protection of drinking-water quality in distribution systems.

It is important to review specified targets on a regular basis to ensure that they are kept up to date in terms of the prevailing scientific knowledge about the technology and its application.

4
Water safety plans



The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the water supply from catchment to consumer. In these Guidelines, such approaches are termed water safety plans (WSPs). The WSP approach has been developed to organize and systematize a long history of management practices applied to drinking-water and to ensure the applicability of these practices to the management of drinking-water quality. WSPs represent an evolution of the concept of sanitary surveys and vulnerability assessments that include and encompass the whole of the water supply system and its operation. The WSP approach draws on many of the principles and concepts from other risk management approaches, in particular the multiple-barrier approach and hazard assessment and critical control points (as used in the food industry).

This chapter focuses on the key principles of WSPs and is not a comprehensive guide to their application in practice. Practical information on how to develop and implement a WSP is available in the supporting document *Water safety plan manual* (Annex 1).

WSPs vary in complexity, as appropriate for the situation. In many cases, they will be quite simple, focusing on the key hazards identified for the specific drinking-water supply system. The wide range of examples of control measures given in the following text does not imply that all of these are appropriate in all cases.

WSPs should, by preference, be developed for individual drinking-water systems. For smaller systems, it may be possible to develop generic WSPs by a statutory body or accredited third-party organization. In these settings, guidance on household water storage, handling and use may also be required. Plans dealing with household water should be linked to a hygiene education programme and advice to households in maintaining water safety.

A WSP has three key components, which are guided by health-based targets (see chapter 3) and overseen through drinking-water supply surveillance (see chapter 5). They are:

A WSP comprises, as a minimum, the three key components that are the responsibility of the drinking-water supplier in order to ensure that drinking-water is safe. These are:

- a system assessment;
- effective operational monitoring;
- management and communication.

1) a *system assessment* to determine whether the drinking-water supply chain (up to the point of consumption) as a whole can deliver water of a quality that meets identified targets. This also includes the assessment of design criteria of new systems;
2) identifying control measures in a drinking-water system that will collectively control identified risks and ensure that the health-based targets are met. For each control measure identified, an appropriate means of *operational monitoring* should be defined that will ensure that any deviation from required performance is rapidly detected in a timely manner;
3) *management and communication plans* describing actions to be taken during normal operation or incident conditions and documenting the system assessment, including upgrade and improvement planning, monitoring and communication plans and supporting programmes.

The primary objectives of a WSP in ensuring good drinking-water supply practice are the prevention or minimization of contamination of source waters, the reduction or removal of contamination through treatment processes and the prevention of contamination during storage, distribution and handling of drinking-water. These objectives are equally applicable to large piped drinking-water supplies, small community supplies (see section 1.2.6) and household systems and are achieved through:

- development of an understanding of the specific system and its capability to supply water that meets water quality targets;
- identification of potential sources of contamination and how they can be controlled;
- validation of control measures employed to control hazards;
- implementation of a system for operational monitoring of the control measures within the water system;
- timely corrective actions to ensure that safe water is consistently supplied;

- undertaking verification of drinking-water quality to ensure that the WSP is being implemented correctly and is achieving the performance required to meet relevant national, regional and local water quality standards or objectives.

WSPs are a powerful tool for the drinking-water supplier to manage the supply safely. They also assist surveillance by public health authorities. Key benefits for water suppliers implementing WSPs include:

- demonstration of "due diligence";
- improved compliance;
- rationalizing and documenting existing operational procedures, leading to gains in efficiency, improvement of performance and quicker response to incidents;
- better targeted and justification for long-term capital investments based on risk assessment;
- improved management of existing staff knowledge and identification of critical gaps in skills for staff;
- improved stakeholder relationships.

One of the challenges and responsibilities of water suppliers and regulators is to anticipate, plan for and provide for climate variations and weather extremes. WSPs are an effective tool to manage such variations and extremes (see also section 6.1).

Where a defined entity is responsible for a drinking-water supply, its responsibility should include the preparation and implementation of a WSP. This plan should normally be reviewed and agreed upon with the authority responsible for protection of public health to ensure that it will deliver water of a quality consistent with the defined targets.

Where there is no formal service provider, the competent national or regional authority should act as a source of information and guidance on the adequacy of appropriate management of community and individual drinking-water supplies. This will include defining requirements for operational monitoring and management. Approaches to verification in these circumstances will depend on the capacity of local authorities and communities and should be defined in national policy.

Many water suppliers may face practical challenges in initiating, developing and implementing a WSP. These include mistaken perceptions that one prescribed methodology must be followed; that WSP steps must be undertaken with risks managed from source to tap in a defined order; that developing a WSP always requires external expertise; that WSPs supersede, rather than build on, existing good practices; and that WSPs are necessarily complicated and are not appropriate for small supplies.

Although WSP implementation demands a certain minimum standard in terms of the steps involved (Figure 4.1), it is a flexible approach that should rely on the water supplier's existing practices and fit the way that a supplier is organized.

The WSP is a vital step in identifying the hazards and risks associated with the source water catchment, particularly where the water supplier does not manage the catchment, or with established treatment and distribution systems. Starting with existing treatment to ensure that it is operating at its optimum at all times is a vital component, as this is often the key barrier that prevents hazards from reaching

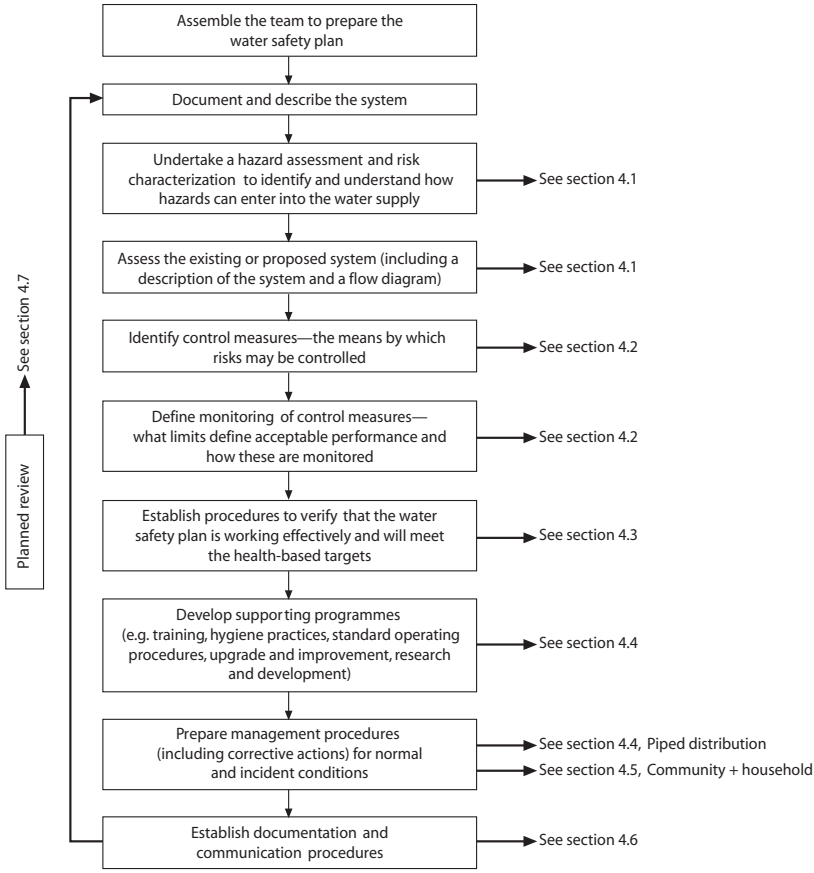


Figure 4.1 Overview of the steps in developing a water safety plan

drinking-water. It must be recognized that even if other hazards are identified in the catchment, remediation may take time, and this should not be a reason for delaying the start of WSP preparation and implementation. Similarly, initiating the process of ensuring that the distribution system is intact and managed appropriately is a vital step that is under the control of the water supplier.

Many of the procedures inherent in the WSP, such as documenting the system and ensuring that standard operating procedures are established for each of the treatment processes and the operation of the distribution system, are simply normal good practice in drinking-water supply. The WSP should therefore build on and improve existing practice.

WSPs should also not be seen as a competing initiative to existing programmes already being undertaken. For example, a programme that addresses non-revenue water (e.g. leakage), although primarily addressing a water quantity issue, is also part of a WSP. A non-revenue water programme would address issues such as intermittent supply and low water pressure, both of which are contributing factors to contamination of drinking-water in the distribution system.

It is recognized that it will not be possible to fully establish a WSP all at once, but the mapping of the system, the identification of the hazards and the assessment of the risks will provide a framework for prioritizing actions and will identify the requirements for continuing improvement as resources become available. They will also identify and help make the case for resource allocation and investment so that they can be targeted to provide the greatest benefit, thus optimizing resources and investment.

In some countries, the regulatory system is relatively complex. A vital component of WSPs and the delivery of safe drinking-water is proper communication and exchange of information between regulators, including environmental authorities, and between regulators or authorities and water suppliers. This is particularly important if resources are to be optimized, and shared information can lead to savings on all sides, while ensuring that drinking-water supplies are improved.

Small supplies remain a significant challenge for many countries, partly because human, technical and financial resources are limited. The introduction of WSPs helps to identify simple and cost-effective steps that can be taken to protect and improve such supplies. It is important that health authorities emphasize the importance of safe drinking-water to the local community and raise the status of the operator's role in the community. It would also be helpful for the relevant authorities to provide a resource or point of contact where operators can obtain advice on and help for WSP implementation.

4.1 System assessment and design

The first stage in developing a WSP is to form a multidisciplinary team of experts with a thorough understanding of the drinking-water system involved. The team should be led by the drinking-water supplier and have sufficient expertise in abstraction, treatment and distribution of drinking-water. Typically, such a team would include individuals involved in each stage of the supply of drinking-water and in many cases representatives from a wider group of stakeholders with collective responsibility for the water supply system from catchment to consumer. Teams could include engineers, catchment and water managers, water quality specialists, environmental or public health or hygiene professionals, operational staff and representatives of consumers or from the community. In most settings, the team will include members from external agencies, including the relevant regulatory agency. For small water supplies, additional external expertise may be useful in addition to operational personnel.

Effective management of the drinking-water system requires a comprehensive understanding of the system, the range and magnitude of hazards and hazardous events that may affect the system and the ability of existing processes and infrastructure to manage actual or potential risks (otherwise known as a *sanitary survey*). It also requires an assessment of capabilities to meet targets. When a new system or an upgrade of an existing system is being planned, the first step in developing a WSP is the collection and evaluation of all available relevant information and consideration of what risks may arise during delivery of water to the consumer.

Assessment of the drinking-water system supports subsequent steps in the WSP in which effective strategies for control of hazards are planned and implemented.

The assessment and evaluation of a drinking-water system are enhanced through an accurate system description, including a flow diagram. The system description should provide an overview of the drinking-water system, including characterization of the source, identification of potential pollution sources in the catchment, measures for resource and source protection, treatment processes, storage and mechanisms for distribution (including piped and non-piped systems). It is essential that the description and the flow diagram of the drinking-water system are conceptually accurate. If the description is not correct, it is possible to overlook potential hazards that may be significant. To ensure accuracy, the system description should be validated by visually checking against features observed on the ground.

Effective risk management requires the identification of potential hazards and hazardous events and an assessment of the level of risk presented by each. In this context:

- a *hazard* is a biological, chemical, physical or radiological agent that has the potential to cause harm;
- a *hazardous event* is an incident or situation that can lead to the presence of a hazard (what can happen and how);
- *risk* is the likelihood of identified hazards causing harm in exposed populations in a specified time frame, including the magnitude of that harm and/or the consequences.

Data on the occurrence of pathogens and chemicals in source waters and in drinking-water combined with information concerning the effectiveness of existing controls enable an assessment of whether health-based targets can be achieved with the existing infrastructure. They also assist in identifying catchment management measures, treatment processes and distribution system operating conditions that would reasonably be expected to achieve those health-based targets if improvements are required.

It may often be more efficient to invest in preventive processes within the catchment than to invest in major treatment infrastructure to manage a hazard.

To ensure the accuracy of the assessment, including an overall estimate of risk, it is essential that all elements of the drinking-water system (catchment, treatment and distribution) are considered concurrently and that interactions among these elements are taken into consideration.

4.1.1 New systems

When drinking-water supply sources are being investigated or developed, it is prudent to undertake a wide range of analyses in order to establish overall safety and to determine potential sources of contamination of the drinking-water supply source. These analyses would normally include hydrological analysis, geological assessment and land use inventories to determine potential chemical and radiological contaminants.

When designing new systems, all water quality factors should be taken into account in selecting technologies for abstraction and treatment of new resources. Variations in the turbidity and other parameters of raw surface waters can be considerable, and allowance must be made for this. Treatment plants should be designed to take account of variations known or expected to occur with significant frequency rather than for average water quality; otherwise, for example, 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 drinking-water may be reduced and public health endangered.

4.1.2 Collecting and evaluating available data

Areas that should be taken into consideration as part of the assessment of the drinking-water system include all real or potential hazards and hazardous events associated with each step in the drinking-water system that could result in contamination or interruption of supply. In most cases, consultation with public health and other sectors, including land and water users and all those who regulate activities in the catchment, will be required for the analysis of catchments. A structured approach is important to ensure that significant issues are not overlooked and that areas of greatest risk are identified.

The overall assessment of the drinking-water system should take into consideration any historical water quality data that may assist in understanding source water characteristics and drinking-water system performance both over time and following specific events (e.g. heavy rainfall). For examples of information to consider in assessing components of the drinking-water system, see Module 3 in the supporting document *Water safety plan manual* (Annex 1).

Prioritizing hazards for control

Once potential hazards and their sources have been identified, the risk associated with each hazard or hazardous event should be compared so that priorities for risk management can be established and documented. Although there are numerous contaminants that can compromise drinking-water quality, not every hazard or hazardous event will require the same degree of attention.

The risk associated with each hazard or hazardous event may be described by identifying the likelihood of occurrence (e.g. certain, possible, rare) and evaluating the severity of consequences if the hazard occurred (e.g. insignificant, major, catastrophic). The aim should be to distinguish between important and less important hazards or hazardous events. The approach used typically involves a semiquantitative matrix.

Simple scoring matrices often apply technical information from guidelines, scientific literature and industry practice with well-informed "expert" judgement based on knowledge and experience of WSP team members, supported by peer review or benchmarking. Scoring is specific for each drinking-water system, as each system is unique. Where generic WSPs are developed for technologies used by small drinking-water systems, the scoring will be specific to the technology rather than the individual drinking-water system.

By using risk ranking, control measures can be prioritized in relation to their significance. A variety of semiquantitative and qualitative approaches to ranking risk can be applied, and Module 3 of the supporting document *Water safety plan manual* (Annex 1) provides a series of practice-based examples. An example of a semiquantitative approach is given in Table 4.1. Application of this matrix relies to a significant extent on expert opinion to make judgements on the public health risk posed by hazards or hazardous events.

Table 4.1 Example of a simple scoring matrix for ranking risks

Likelihood	Severity of consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	5	10	15	20	25
Likely	4	8	12	16	20
Moderately likely	3	6	9	12	15
Unlikely	2	4	6	8	10
Rare	1	2	3	4	5

Risk score	< 6	6–9	10–15	> 15
Risk rating	Low	Medium	High	Very high

An example of descriptors that can be used to rate the likelihood of occurrence and severity of consequences is given in Table 4.2. A "cut-off" point must be determined, above which all risks will require immediate attention. There is little value in expending large amounts of effort to consider very low risks.

Control measures

The assessment and planning of control measures should ensure that health-based targets will be met and should be based on hazard identification and risk assessment. The level of control applied to a hazard should be proportional to the associated risk ranking. Assessment of control measures involves:

- identifying existing control measures for each significant hazard or hazardous event from catchment to consumer;
- evaluating whether the control measures, when considered together, are effective in reducing risk to acceptable levels;
- if improvement is required, evaluating alternative and additional control measures that could be applied.

Identification and implementation of control measures should be based on the multiple-barrier principle. The strength of this approach is that a failure of one barrier may be compensated by effective operation of the remaining barriers, thus minimizing the likelihood of contaminants passing through the entire system and being present in sufficient amounts to cause harm to consumers. Many control measures may contribute to control more than one hazard, whereas some hazards may require more than one control measure for effective control. Examples of control measures are provided in the following sections.

Control measures are activities or processes within the drinking-water supply used to eliminate or significantly reduce the occurrence of a water safety hazard. These measures are applied collectively to ensure that drinking-water consistently meets health-based targets.

All control measures are important and should be afforded ongoing attention. They should be subject to operational monitoring and control, with the means of

Table 4.2 Examples of definitions of likelihood and severity categories that can be used in risk scoring

Item	Rating	Definition
Likelihood categories		
Almost certain	5	Once per day
Likely	4	Once per week
Moderately likely	3	Once per month
Unlikely	2	Once per year
Rare	1	Once every 5 years
Severity categories		
Catastrophic	5	Public health impact
Major	4	Regulatory impact
Moderate	3	Aesthetic impact
Minor	2	Compliance impact
Insignificant	1	No impact or not detectable

monitoring and frequency of data collection based on the nature of the control measure and the rapidity with which change may occur (see section 4.2).

4.1.3 Resource and source protection

Effective catchment management has many benefits. By decreasing the contamination of the source water, the amount of treatment required is reduced. This may reduce the production of treatment by-products and minimize operational costs.

Hazard identification

Understanding the reasons for variations in raw water quality is important, as it will influence the requirements for treatment, treatment efficiency and the resulting health risk associated with the finished drinking-water. In general, raw water quality is influenced by both natural and human use factors. Important natural factors include wildlife, climate, topography, geology and vegetation. Human use factors include point sources (e.g. wastewater discharges) and non-point sources (e.g. surface runoff). For example, discharges of municipal wastewater can be a major source of pathogens; urban runoff and livestock can contribute substantial microbial load; body contact recreation can be a source of faecal contamination; and agricultural runoff, including agrochemicals and manure, can lead to increased challenges to treatment.

Whether water is drawn from surface or underground sources, it is important that the characteristics of the local catchment or aquifer are understood and that the scenarios that could lead to water pollution are identified and managed. The extent to which potentially polluting activities in the catchment can be reduced may appear to be limited by competition for water and pressure for increased development in the catchment. However, introducing good practices in land use and in containment of hazards is often possible without substantially restricting activities, and collaboration between stakeholders may be a powerful tool to reduce pollution without reducing beneficial development.

Resource and source protection provides the first barrier in protection of drinking-water quality. Where catchment management is beyond the jurisdiction of the drinking-water supplier, the planning and implementation of control measures will require coordination with other agencies. These may include planning authorities, catchment boards, environmental and water resource regulators, road authorities, emergency services and agricultural, industrial and other commercial entities whose activities have an impact on water quality. It may not be possible to apply all aspects of resource and source protection initially; nevertheless, priority should be given to catchment management. This will contribute to a sense of ownership and joint responsibility for drinking-water resources through multistakeholder bodies that assess pollution risks and develop plans for improving management practices for reducing these risks.

Groundwater from deep and confined aquifers is usually microbially safe and chemically stable in the absence of direct contamination; however, shallow or unconfined aquifers can be subject to contamination from discharges or seepages associated with agricultural practices (e.g. pathogens, nitrates and pesticides), on-site sanitation and sewerage (e.g. pathogens and nitrates) and industrial wastes. For examples of hazards and hazardous situations that should be taken into consideration as part of a hazard analysis and risk assessment, see Module 4 in the supporting document *Water safety plan manual* and the supporting document *Protecting groundwater for health* (Annex 1).

Control measures

Effective resource and source protection includes the following elements:

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

Where a number of water sources are available, there may be flexibility in the selection of water for treatment and supply. It may be possible to avoid taking water from rivers and streams when water quality is poor (e.g. following heavy rainfall) in order to reduce risk and prevent potential problems in subsequent treatment processes.

Retention of water in reservoirs can reduce the number of faecal microorganisms through settling and inactivation, including solar (ultraviolet) disinfection, but also provides opportunities for the introduction of contamination. Most pathogenic microorganisms of faecal origin (enteric pathogens) do not survive indefinitely in the environment. Substantial die-off of enteric bacteria will occur over a period of weeks. Enteric viruses and protozoa will often survive for longer periods (weeks to months) but are often removed by settling and antagonism from indigenous microbes. Retention also allows suspended material to settle, which makes subsequent disinfection more effective and reduces the formation of disinfection by-products (DBPs).

Control measures for groundwater sources should include protecting the aquifer and the local area around the borehead from contamination and ensuring the physical

integrity of the bore (surface sealed, casing intact, etc.); further information can be found in the supporting document *Protecting groundwater for health* (Annex 1).

For examples of control measures for effective protection of source water and catchments and of water extraction and storage systems, see Module 4 in the supporting document *Water safety plan manual* (Annex 1). Further information on the use of indicator organisms in catchment characterization is also available in chapter 4 of the supporting document *Assessing microbial safety of drinking water* (Annex 1).

4.1.4 Treatment

After source water protection, the next barriers to contamination of the drinking-water system are those of water treatment processes, including disinfection and physical removal of contaminants.

Hazard identification

Hazards may be introduced during treatment, or hazardous events may allow contaminants to pass through treatment in significant concentrations. Constituents of drinking-water can be introduced through the treatment process, including chemical additives used in the treatment process or products in contact with drinking-water. Sporadic high turbidity in source water can overwhelm treatment processes, allowing enteric pathogens into treated water and the distribution system. Similarly, suboptimal filtration following filter backwashing can lead to the introduction of pathogens into the distribution system.

For examples of potential hazards and hazardous events that can have an impact on the performance of drinking-water treatment, see Module 3 in the supporting document *Water safety plan manual* (Annex 1).

Control measures

Control measures may include pretreatment, coagulation, flocculation, sedimentation, filtration and disinfection.

Pretreatment includes processes such as roughing filters, microstrainers, off-stream storage and bankside filtration. Pretreatment options may be compatible with a variety of treatment processes ranging in complexity from simple disinfection to membrane processes. Pretreatment can reduce or stabilize the microbial, natural organic matter and particulate load.

Coagulation, flocculation, sedimentation (or flotation) and filtration remove particles, including microorganisms (bacteria, viruses and protozoa). It is important that processes are optimized and controlled to achieve consistent and reliable performance. Chemical coagulation is the most important step in determining the removal efficiency of coagulation, flocculation and clarification processes. It also directly affects the removal efficiency of granular media filtration units and has indirect impacts on the efficiency of the disinfection process. While it is unlikely that the coagulation process itself introduces any new microbial hazards to finished water, a failure or inefficiency in the coagulation process could result in an increased microbial load entering drinking-water distribution.

Various filtration processes are used in drinking-water treatment, including granular, slow sand, precoat and membrane (microfiltration, ultrafiltration, nanofiltration

and reverse osmosis) filtration. With proper design and operation, filtration can act as a consistent and effective barrier for pathogenic microorganisms and may in some cases be the only treatment barrier (e.g. for removing *Cryptosporidium* oocysts by direct filtration when chlorine is used as the sole disinfectant).

Application of an adequate concentration of disinfectant is an essential element for most treatment systems to achieve the necessary level of microbial risk reduction. Taking account of the level of microbial inactivation required for the more resistant microbial pathogens through the application of the *Ct* concept (product of disinfectant concentration and contact time) for a particular pH and temperature ensures that other, more sensitive microbes are also effectively controlled. Where disinfection is used, measures to minimize DBP formation should be taken into consideration.

The most commonly used disinfection process is chlorination. Ozonation, ultraviolet irradiation, chloramination and application of chlorine dioxide are also used. These methods are very effective in killing bacteria and can be reasonably effective in inactivating viruses (depending on type), and some may inactivate many protozoa, including *Giardia* and *Cryptosporidium*. For effective removal or inactivation of protozoal cysts and oocysts, filtration with the aid of coagulation and flocculation (to reduce particles and turbidity) followed by disinfection (by one or a combination of disinfectants) is the most practical method.

Storage of water after disinfection and before supply to consumers can improve disinfection by increasing disinfectant contact times. This can be particularly important for more resistant microorganisms, such as *Giardia* and some viruses.

For examples of treatment control measures, see Module 4 in the supporting document *Water safety plan manual* (Annex 1). Further information can also be found in the supporting document *Water treatment and pathogen control* (Annex 1).

4.1.5 Piped distribution systems

Water treatment should be optimized to prevent microbial growth, corrosion of pipe materials and the formation of deposits.

Maintaining good water quality in the distribution system will depend on the design and operation of the system and on maintenance and survey procedures to prevent contamination and to prevent and remove the accumulation of internal deposits.

Hazard identification

The protection of the distribution system is essential for providing safe drinking-water. Because of the nature of the distribution system, which may include many kilometres of pipe, storage tanks, interconnections with industrial users and the potential for tampering and vandalism, opportunities for microbial and chemical contamination exist. For examples of hazards and hazardous events in piped distribution systems, see Module 3 in the supporting document *Water safety plan manual* (Annex 1).

When contamination by enteric pathogens or hazardous chemicals occurs within the distribution system, it is likely that consumers will be exposed to the pathogens or chemicals. In the case of pathogen ingress, even where disinfectant residuals are employed to limit microbial occurrence, they may be inadequate to overcome the contamination or may be ineffective against some or all of the pathogen types introduced.

As a result, pathogens may occur in concentrations that could lead to infection and illness.

Where water is supplied intermittently, the resulting low water pressure will allow the ingress of contaminated water into the system through breaks, cracks, joints and pinholes. Intermittent supplies are not desirable but are very common in many countries and are frequently associated with contamination. The control of water quality in intermittent supplies represents a significant challenge, as the risks of infiltration and backflow increase significantly. The risks may be elevated seasonally as soil moisture conditions increase the likelihood of a pressure gradient developing from the soil to the pipe. Where contaminants enter the pipes in an intermittent supply, the charging of the system when supply is restored may increase risks to consumers, as a concentrated "slug" of contaminated water can be expected to flow through the system. Where household storage is used to overcome intermittent supply, localized use of disinfectants to reduce microbial proliferation may be warranted.

Drinking-water entering the distribution system may contain free-living amoebae and environmental strains of various heterotrophic bacterial and fungal species. Under favourable conditions, amoebae and heterotrophs, including strains of *Citrobacter*, *Enterobacter* and *Klebsiella*, may colonize distribution systems and form biofilms. There is no evidence to implicate the occurrence of most microorganisms from biofilms (one exception is *Legionella*, which can colonize water systems in buildings) with adverse health effects in the general population through drinking-water, with the possible exception of severely immunocompromised people (see the supporting document *Heterotrophic plate counts and drinking-water safety*; Annex 1).

Water temperatures and nutrient concentrations are not generally elevated enough within the distribution system to support the growth of *E. coli* (or enteric pathogenic bacteria) in biofilms. Thus, the presence of *E. coli* should be considered as evidence of recent faecal contamination.

Natural disasters, including flood, drought and earth tremors, may significantly affect piped water distribution systems.

Control measures

Water entering the distribution system must be microbially safe and ideally should also be biologically stable. The distribution system itself must provide a secure barrier to contamination as the water is transported to the user. Maintaining a disinfectant residual throughout the distribution system can provide some protection against recontamination and limit microbial growth problems. Chloramination has proved successful in controlling *Naegleria fowleri* in water and sediments in long pipelines and may reduce the regrowth of *Legionella* within buildings.

Residual disinfectant will provide partial protection against microbial contamination, but it may also mask the detection of contamination through the use of conventional faecal indicator bacteria such as *E. coli*, particularly by resistant organisms. Where a disinfectant residual is used within a distribution system, measures to minimize DBP production should be taken into consideration.

Water distribution systems should be fully enclosed, and storage reservoirs and tanks should be securely roofed with external drainage to prevent contamination.

Control of short-circuiting and prevention of stagnation in both storage and distribution contribute to prevention of microbial growth. A number of strategies can be adopted to maintain the quality of water within the distribution system, including use of backflow prevention devices, maintaining positive pressure throughout the system and implementation of efficient maintenance procedures. It is also important that appropriate security measures be put in place to prevent unauthorized access to or interference with the drinking-water system infrastructure.

Control measures may include using a more stable secondary disinfecting chemical (e.g. chloramines instead of free chlorine), undertaking a programme of pipe replacement, flushing and relining and maintaining positive pressure in the distribution system. Reducing the time that water is in the system by avoiding stagnation in storage tanks, loops and dead-end sections will also contribute to maintaining drinking-water quality. For other examples of distribution system control measures, see Module 4 in the supporting document *Water safety plan manual* (Annex 1). Further information is also available in the supporting document *Safe piped water* (Annex 1).

4.1.6 Non-piped, community and household systems

Hazard identification

For non-piped, community and household drinking-water systems, hazard identification would ideally be performed on a case-by-case basis. In practice, however, reliance is typically placed on general assumptions of hazardous conditions that are relevant for technologies or system types and that may be defined at a national or regional level.

For examples of hazards and hazardous situations potentially associated with various non-piped sources of water, see Module 3 in the supporting document *Water safety plan manual* (Annex 1). Further guidance is also provided in the supporting document *Water safety plans* (Annex 1) and in the 1997 volume entitled *Surveillance and control of community supplies* (WHO, 1997).

Control measures

The control measures required ideally depend on the characteristics of the source water and the associated catchment; in practice, standard approaches may be applied for each of these, rather than customized assessment of each system.

For examples of control measures for various non-piped sources, see Module 4 in the supporting document *Water safety plan manual* (Annex 1) and the 1997 report entitled *Surveillance and control of community supplies* (WHO, 1997).

In most cases, contamination of groundwater supplies can be controlled by a combination of simple measures. In the absence of fractures or fissures, which may allow rapid transport of contaminants to the source, groundwater in confined or deep aquifers will generally be free of pathogenic microorganisms. Bores should be encased to a reasonable depth, and boreheads should be sealed to prevent ingress of surface water or shallow groundwater.

Rainwater harvesting systems, particularly those involving storage in aboveground tanks, can be a relatively safe supply of water (see section 6.2). The principal sources of contamination are birds, small mammals and debris collected on roofs. The impact

of these sources can be minimized by simple measures: guttering should be cleared regularly, overhanging branches should be kept to a minimum (because they can be a source of debris and can increase access to roof catchment areas by birds and small mammals) and inlet pipes to tanks should include leaf litter strainers. First-flush diverters, which prevent the initial roof-cleaning wash of water (20–25 litres) from entering tanks, are recommended. If first-flush diverters are not available, a detachable downpipe can be used manually to provide the same result.

In general, surface waters will require at least disinfection, and usually also filtration, to ensure microbial safety. The first barrier is based on minimizing contamination from human waste, livestock and other hazards at the source.

The greater the protection of the water source, the less the reliance on treatment or disinfection. Water should be protected during storage and delivery to consumers by ensuring that the distribution and storage systems are enclosed. This applies to both community piped systems and vendor-supplied water (section 6.3). For water stored in the home, protection from contamination can be achieved by use of enclosed or otherwise safely designed storage containers that prevent the introduction of hands, dippers or other extraneous sources of contamination.

For control of chemical hazards, reliance may be placed primarily on initial screening of sources and on ensuring the quality and performance of treatment chemicals, materials and devices available for this use, including water storage systems.

Model WSPs may be developed generically for the following types of water supply:

- groundwater from protected boreholes or wells with mechanized pumping;
- conventional treatment of water;
- multistage filtration;
- storage and distribution through supplier-managed piped systems;
- storage and distribution through community-managed piped systems;
- water vendors;
- water on conveyances (planes, ships and trains);
- tubewells from which water is collected by hand;
- springs from which water is collected by hand;
- simple protected dug wells;
- rainwater catchments.

Guidance is available regarding how water safety may be ensured for household water collection, transport and storage (see the supporting document *Managing water in the home*; Annex 1). This should be used in conjunction with hygiene education programmes to support health promotion in order to reduce water-related disease.

4.1.7 Validation

For the WSP to be relied on for anticipating and managing the hazards and hazardous events for which it was set in place, it needs to be supported by accurate and reliable technical information. Validation is concerned with obtaining evidence on the performance of control measures. Depending on the type of control, validation can be done by site inspection, using existing data and literature or targeted

monitoring programmes to demonstrate performance under normal and exceptional circumstances.

Validation is an investigative activity to identify the effectiveness of a control measure. It is typically an intensive activity when a system is initially constructed or rehabilitated. It provides information on reliably achievable water quality in preference to assumed values and also to define the operational criteria required to ensure that the control measure contributes to effective control of hazards.

Validation of treatment processes is required to show that the treatment processes can operate as required and achieve required levels of hazard reduction. In the case of microbial hazards, these required levels commonly take the form of performance targets based on the use of reference pathogens (see section 7.2). Validation can be undertaken during pilot stage studies or during initial implementation of a new or modified water treatment system. It is also a useful tool in the optimization of existing treatment processes.

The first stage of validation is to consider data and information that already exist. Sources include the scientific literature, relevant industry bodies, partnering and benchmarking with larger authorities, manufacturers' specifications and historical data. This stage will inform the testing requirements. It is important that data used in validation are relevant for system-specific conditions, as variations in water composition and quality, for example, may have a large impact on the efficacy of control measures.

Validation is not used for day-to-day management of drinking-water supplies; as a result, microbial parameters that may be inappropriate for operational monitoring can be used, and the lag time for return of results and additional costs from pathogen measurements can often be tolerated. Parameters should be chosen to reflect the microorganisms being targeted by treatment (see section 7.2). Increasingly, indicator parameters are being used in validation. For example, coliphage can be used to assess the effectiveness of virus removal by filtration processes or to measure the effectiveness of disinfection processes, whereas *Clostridium perfringens* can be used to measure the effectiveness of the removal of protozoa by filtration processes.

Validation should not be confused with routine operational monitoring, which is designed to show that validated control measures continue to work effectively (see section 4.2). The validation process often leads to improvements in operating performance through the identification of the most effective and robust operating modes. Additional benefits of the validation process may include identification of more suitable operational monitoring parameters for unit performance.

4.1.8 Upgrade and improvement

The assessment of the drinking-water system may indicate that existing practices and control measures may not ensure drinking-water safety. In some instances, all that may be needed is to review, document and formalize these practices and address any areas where improvements are required; in others, major infrastructure changes may

be needed. The assessment of the system should be used as a basis to develop a plan to address identified needs for full implementation of a WSP.

Improvement of the drinking-water system may encompass a wide range of issues, such as:

- capital works;
- training;
- enhanced operational procedures;
- community consultation programmes;
- research and development;
- developing incident protocols;
- communication and reporting.

Upgrade and improvement plans can include short-term (e.g. 1 year) or long-term programmes. Short-term improvements might include, for example, improvements to community consultation and the development of community awareness programmes. Long-term capital works projects could include covering of water storage containers or enhanced coagulation and filtration.

Implementation of improvement plans may have significant budgetary implications and therefore may require detailed analysis and careful prioritization in accord with the outcomes of risk assessment. Implementation of plans should be monitored to confirm that improvements have been made and are effective. Control measures often require considerable expenditure, and decisions about water quality improvements cannot be made in isolation from other aspects of drinking-water supply that compete for limited financial resources. Priorities will need to be established, and improvements may need to be phased in over a period of time.

4.2 Operational monitoring and maintaining control

Operational monitoring is a planned and routine set of activities used to determine that control measures continue to work effectively. In operational monitoring, the drinking-water supplier monitors each control measure in a timely manner with the objectives to enable effective system management and to ensure that health-based targets are achieved.

4.2.1 Determining system control measures

The identity and number of control measures are system specific and will be determined by the number and nature of hazards and hazardous events as well as the magnitude of associated risks.

Control measures should reflect the likelihood and consequences of loss of control. Control measures have a number of operational requirements, including the following:

- operational monitoring parameters that can be measured and for which limits can be set to define the operational effectiveness of the activity;
- operational monitoring parameters that can be monitored with sufficient frequency to reveal failures in a timely fashion;

- procedures for corrective action that can be implemented in response to deviation from limits.

4.2.2 Selecting operational monitoring parameters

Operational monitoring can include measurement of parameters or observational activities. The parameters selected for operational monitoring should reflect the effectiveness of each control measure, provide a timely indication of performance, be readily measured and provide the opportunity for an appropriate response. Examples include measurable variables, such as chlorine residuals, pH and turbidity, or observable factors, such as the integrity of vermin-proof screens.

Operational monitoring assesses the performance of control measures at appropriate time intervals. The intervals may vary widely—for example, from online control of residual chlorine to quarterly verification of the integrity of the plinth surrounding a well.

Enteric pathogens or indicator organisms are often of limited use for operational monitoring, because the time taken to process and analyse water samples does not allow operational adjustments to be made prior to supply.

A range of parameters can be used in operational monitoring:

- For source waters, these include turbidity, ultraviolet absorbency, algal growth, flow and retention time, colour, conductivity, local meteorological events and integrity of protective (e.g. fences) or abstraction infrastructures (e.g. well seals) (see the supporting document *Protecting groundwater for health*; Annex 1).
- For treatment, parameters may include disinfectant concentration and contact time, ultraviolet intensity, pH, light absorbency, membrane integrity, turbidity and colour (see the supporting document *Water treatment and pathogen control*; Annex 1).
- In piped distribution systems, operational monitoring parameters may include the following:
  - *Chlorine residual monitoring* provides a rapid indication of problems that will direct measurement of microbial parameters. A sudden disappearance of an otherwise stable residual can indicate ingress of contamination. Alternatively, difficulties in maintaining residuals at points in a distribution system or a gradual disappearance of residual may indicate that the water or pipework has a high oxidant demand due to growth of bacteria.
  - *Oxidation–reduction potential* (or redox potential) measurement can also be used in the operational monitoring of disinfection efficacy. It is possible to define a minimum level of oxidation–reduction potential necessary to ensure effective disinfection. This value has to be determined on a case-by-case basis; universal values cannot be recommended. Further research and evaluation of oxidation–reduction potential as an operational monitoring technique are highly desirable.
  - *Heterotrophic bacteria* present in a supply can be a useful indicator of changes, such as increased microbial growth potential, increased biofilm activity, extended retention times or stagnation and a breakdown of integrity of the system. The numbers of heterotrophic bacteria present in a supply may

reflect the presence of large contact surfaces within the treatment system, such as in-line filters, and may not be a direct indicator of the condition within the distribution system (see the supporting document *Heterotrophic plate counts and drinking-water safety*; Annex 1).

— *Pressure measurement* and *turbidity* are also useful operational monitoring parameters in piped distribution systems.

Guidance for management of distribution system operation and maintenance is available (see the supporting document *Safe piped water*; Annex 1) and includes the development of a monitoring programme for water quality and other parameters such as pressure.

Examples of operational monitoring parameters are provided in Table 4.3.

4.2.3 Establishing operational and critical limits

Control measures need to have defined limits for operational acceptability—termed operational limits—that can be applied to operational monitoring parameters. Operational limits should be defined for parameters applying to each control measure. If monitoring shows that an operational limit has been exceeded, then predetermined corrective actions (see section 4.4) need to be applied. The detection of the deviation and implementation of corrective action should be possible in a time frame adequate to maintain performance and water safety.

For some control measures, a second series of "critical limits" may also be defined, outside of which confidence in water safety would be lost. Deviations from critical limits will usually require urgent action, including immediate notification of the appropriate health authority.

Operational and critical limits can be upper limits, lower limits, a range or an "envelope" of performance measures.

4.2.4 Non-piped, community and household systems

Generally, surface water or shallow groundwater should not be used as a source of drinking-water without sanitary protection or treatment.

Monitoring of water sources (including rainwater tanks) by community operators or households will typically involve periodic sanitary inspection (for details, see the 1997 volume entitled *Surveillance and control of community supplies*; WHO, 1997). The sanitary inspection forms used should be comprehensible and easy to use; for instance, the forms may be pictorial. The risk factors included should be preferably related to activities that are under the control of the operator and that may affect water quality. The links to action from the results of operational monitoring should be clear, and training will be required.

Operators should also undertake regular physical assessments of the water, especially after heavy rains, to monitor whether any obvious changes in water quality have occurred (e.g. changes in colour, odour, taste or turbidity).

Maintaining the quality of water during collection and manual transport is the responsibility of the household. Good hygiene practices are required and should be supported through hygiene education. Hygiene education programmes should provide households and communities with skills to monitor and manage their water hygiene.

Table 4.3 Examples of operational monitoring parameters that can be used to monitor control measures

Operational parameter	Raw water	Coagulation	Sedimentation	Filtration	Disinfection	Distribution system
pH		✓	✓		✓	✓
Turbidity (or particle count)	✓	✓	✓	✓	✓	✓
Dissolved oxygen	✓					
Stream/river flow	✓					
Rainfall	✓					
Colour	✓					
Conductivity (total dissolved solids)	✓					
Organic carbon	✓		✓			
Algae, algal toxins and metabolites	✓					✓
Chemical dosage		✓			✓	
Flow rate		✓	✓	✓	✓	
Net charge		✓				
Streaming current value		✓				
Headloss				✓		
Ct (disinfectant concentration × contact time)					✓	
Disinfectant residual					✓	✓
Oxidation–reduction potential					✓	
DBPs					✓	✓
Heterotrophic bacteria					✓	✓
Hydraulic pressure						✓

If treatment is applied to water from community sources (e.g. boreholes, wells and springs) as well as household rainwater collection, then operational monitoring is advisable. When household treatment is introduced, it is essential that information (and, where appropriate, training) be provided to users to ensure that they understand basic operational monitoring requirements.

4.3 Verification

Verification provides a final check on the overall performance of the drinking-water supply chain and the safety of drinking-water being supplied to consumers. Verification should be undertaken by the surveillance agency; water suppliers may also undertake internal verification programmes.

For microbial verification, testing is typically for faecal indicator bacteria in treated water and water in distribution. For verification of chemical safety, testing for chemicals of concern may be at the end of treatment, in distribution or at the point of consumption (depending on whether the concentrations are likely to change in distribution). Trihalomethanes and haloacetic acids are the most common DBPs and occur at among the highest concentrations in drinking-water. Under many circumstances, they can serve as a suitable measure that will reflect the concentration of a wide range of related chlorinated DBPs.

In addition to operational monitoring of the performance of the individual components of a drinking-water system, it is necessary to undertake final *verification* for reassurance that the system as a whole is operating safely. Verification may be undertaken by the supplier, by an independent authority or by a combination of these, depending on the administrative regime in a given country. It typically includes testing for faecal indicator organisms and hazardous chemicals, as well as auditing that WSPs are being implemented as intended and are working effectively.

Frequencies of sampling should reflect the need to balance the benefits and costs of obtaining more information. Sampling frequencies are usually based on the population served or on the volume of water supplied, to reflect the increased population risk. Frequency of testing for individual characteristics will also depend on variability. Sampling and analysis are required most frequently for microbial and less often for chemical constituents. This is because even brief episodes of microbial contamination can lead directly to illness in consumers, whereas episodes of chemical contamination that would constitute an acute health concern, in the absence of a specific event (e.g. chemical overdosing at a treatment plant), are rare. Sampling frequencies for water leaving treatment depend on the quality of the water source and the type of treatment.

Plans should be developed to respond to results that do not meet water quality targets. These should include investigation of the cause of non-compliance and, where necessary, corrective action, such as boil water advisories. Repeated failure to meet targets should lead to review of the WSP and development of improvement plans.

4.3.1 Microbial water quality

Verification of the microbial quality of drinking-water typically includes testing for *Escherichia coli* as an indicator of faecal pollution. In practice, testing for thermotolerant coliform bacteria can be an acceptable alternative in many circumstances. Although *E. coli* is useful, it has limitations. Enteric viruses and protozoa are more resistant to disinfection; consequently, the absence of *E. coli* will not necessarily indicate freedom from these organisms. Under certain circumstances, the inclusion of more resistant indicators, such as bacteriophages and/or bacterial spores, should be considered (see section 7.4).

Verification of the microbial quality of water in supply must be designed to ensure the best possible chance of detecting contamination. Sampling should therefore account for potential variations of water quality in distribution. This will normally mean taking account of locations and of times of increased likelihood of contamination.

Faecal contamination will not be distributed evenly throughout a piped distribution system. In systems where water quality is good, this significantly reduces the probability of detecting faecal indicator bacteria in the relatively few samples collected.

The chances of detecting contamination in systems reporting predominantly negative results for faecal indicator bacteria can be increased by using more frequent presence/absence testing. Presence/absence testing can be simpler, faster and less expensive than quantitative methods. Comparative studies of the presence/absence and quantitative methods demonstrate that the presence/absence methods can maximize the detection of faecal indicator bacteria. However, presence/absence testing is appropriate only in a system where the majority of tests for indicator organisms provide negative results.

The more frequently the water is examined for faecal indicator organisms, the more likely it is that contamination will be detected. Frequent examination by a simple method is more valuable than less frequent examination by a complex test or series of tests.

The nature and likelihood of contamination can vary seasonally, with rainfall and with other local conditions. Sampling should normally be random but should be increased at times of epidemics, flooding or emergency operations or following interruptions of supply or repair work.

Recommended minimum sample numbers for verification of the microbial quality of drinking-water are shown in Table 4.4.

4.3.2 Chemical water quality

Issues that need to be addressed in developing chemical verification include the availability of appropriate analytical facilities, the cost of analyses, the possible deterioration of samples, the stability of the contaminant, the likely occurrence of the contaminant in various supplies, the most suitable point for monitoring and the frequency of sampling.

For a given chemical, the location and frequency of sampling will be determined by its principal sources (see chapter 8) and variability in its concentration. Substances that do not change significantly in concentration over time require less frequent sampling than those that might vary significantly.

In many cases, analysis of source water quality once per year, or even less, may be adequate, particularly in stable groundwaters, where the concentrations of naturally occurring substances of concern will vary very slowly over time. Concentrations of naturally occurring substances are likely to be more variable in surface waters, and surface waters therefore may require a greater number of samples, depending on the contaminant and its importance.

Sampling locations will depend on the water quality characteristic being examined. Sampling at the treatment plant or at the head of the distribution system may be sufficient for constituents whose concentrations do not change during delivery. However, for those constituents whose concentrations can change during distribution, sampling should be undertaken following consideration of the behaviour or source of the specific substance. Samples should include points near the extremities of the distribution system and taps connected directly to the mains in houses and large

Table 4.4 Recommended minimum sample numbers for faecal indicator testing in distribution systems[a]

Type of water supply and population	Total number of samples per year
Point sources	Progressive sampling of all sources over 3- to 5-year cycles (maximum)
Piped supplies	
< 5000	12
5000–100 000	12 per 5000 population
> 100 000–500 000	12 per 10 000 population plus an additional 120 samples
> 500 000	12 per 50 000 population plus an additional 600 samples

[a] Parameters such as chlorine, turbidity and pH should be tested more frequently as part of operational and verification monitoring.

multioccupancy buildings. Lead, for example, should be sampled at consumers' taps, as the source of lead is usually service connections or plumbing in buildings.

For further information, see the supporting document *Chemical safety of drinking-water* (Annex 1).

4.3.3 Source waters

Verification testing of source waters is particularly important where there is no water treatment. It will also be useful following failure of the treatment process or as part of an investigation of a waterborne disease outbreak. The frequency of testing will depend on the reason for carrying out the sampling. Testing frequency may be:

- on a regular basis (the frequency of verification testing will depend on several factors, including the size of the community supplied, the reliability of the quality of the drinking-water or degree of treatment and the presence of local risk factors);
- on an occasional basis (e.g. random or during visits to community-managed drinking-water supplies);
- increased following degradation of source water quality resulting from predictable incidents, emergencies or unplanned events considered likely to increase the potential for a breakthrough in contamination (e.g. following a flood, upstream spills).

Prior to commissioning a new drinking-water supply, a wider range of analyses should be carried out, including parameters identified as potentially being present from a review of data from similar supplies or from a risk assessment of the source.

4.3.4 Piped distribution systems

The choice of sampling points will be dependent on the individual water supply. The nature of the public health risk posed by pathogens and the contamination potential throughout distribution systems mean that collection of samples for microbial analysis (and associated parameters, such as chlorine residual, pH and turbidity) will typically be done frequently and from dispersed sampling sites. Careful consideration of sampling points and frequency is required for chemical constituents that arise

from piping and plumbing materials and that are not controlled through their direct regulation and for constituents whose concentrations change in distribution, such as trihalomethanes. The use of stratified random sampling in distribution systems has proven to be effective.

4.3.5 Community-managed supplies

If the performance of a community drinking-water 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 drinking-water systems have adopted *quantitative service indicators* (i.e. quality, quantity, accessibility, coverage, affordability and continuity) for application at community, regional and national levels. Usual practice would be to include the critical parameters for microbial quality (normally *E. coli*, chlorine, turbidity and pH) and for a sanitary inspection to be carried out. Methods for these tests must be standardized and approved. It is recommended that field test kits be validated for performance against reference or standard methods and approved for use in verification testing.

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

Periodic testing and sanitary inspection of community drinking-water supplies should typically be undertaken by the surveillance agency and should assess microbial hazards and known problem chemicals (see also chapter 5). Frequent sampling is unlikely to be possible, and one approach is therefore a rolling programme of visits to ensure that each supply is visited once every 3–5 years. The primary purpose is to inform strategic planning and policy rather than to assess compliance of individual drinking-water supplies. Comprehensive analysis of the chemical quality of all sources is recommended prior to commissioning as a minimum and preferably every 3–5 years thereafter.

Advice on the design of sampling programmes and on the frequency of sampling for community supplies is given in the 1997 volume, *Surveillance and control of community supplies* (WHO, 1997).

4.3.6 Quality assurance and quality control

Appropriate quality assurance and analytical quality control procedures should be implemented for all activities linked to the production of drinking-water quality data. These procedures will ensure that the data are fit for purpose—in other words, that the results produced are of adequate accuracy. Fit for purpose, or adequate accuracy, will be defined in the water quality monitoring programme, which will include a statement about accuracy and precision of the data. Because of the wide range of substances, methods, equipment and accuracy requirements likely to be involved in the monitoring of drinking-water, many detailed, practical aspects of analytical quality control are concerned. These are beyond the scope of this publication.

The design and implementation of a quality assurance programme for analytical laboratories are described in detail in *Water quality monitoring: A practical guide to the*

design and implementation of freshwater quality studies and monitoring programmes (Bartram & Ballance, 1996). The relevant chapter relates to standard ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories,* which provides a framework for the management of quality in analytical laboratories.

Guidance on sampling is given in the International Organization for Standardization (ISO) standards listed in Table 4.5.

4.3.7 Water safety plans

In addition to testing of water quality, verification should include audits of WSPs to demonstrate that the plans have been properly designed, are being implemented correctly and are effective. Factors to consider include the following:

- all significant hazards and hazardous events have been identified;
- appropriate control measures have been included;
- appropriate operational monitoring procedures have been established;
- appropriate operational limits have been defined;
- corrective actions have been identified;
- appropriate verification monitoring procedures have been established.

Audits can be undertaken as part of internal or external reviews and may form part of surveillance by independent authorities. Auditing can have both an assessment and a compliance-checking function.

4.4 Management procedures for piped distribution systems

Much of a management plan will describe actions to be taken to maintain optimal operation under normal operating conditions. These will include both responses to normal variations in operational monitoring parameters and responses when operational monitoring parameters reach critical limits. All activities, including standard operating procedures applied during normal conditions and planned responses to incidents and emergencies, should be documented.

> Effective management implies definition of actions to be taken during normal operational conditions, of actions to be taken in specific "incident" situations where a loss of control of the system may occur and of procedures to be followed in unforeseen (emergency) situations. Management procedures should be documented alongside system assessment, monitoring plans, supporting programmes and communication required to ensure safe operation of the system.

A significant deviation in operational monitoring where a critical limit is exceeded (or in verification) is often referred to as an "incident". An incident is any situation in which there is reason to suspect that water being supplied for drinking may be, or may become, unsafe (i.e. confidence in water safety is lost). As part of a WSP, management procedures should be defined for response to predictable incidents as well as unpredictable incidents and emergencies.

Incident response plans can have a range of alert levels. These can be minor early warning, necessitating no more than additional investigation, through to emergency. Emergencies are likely to require the resources of organizations beyond the drinking-water supplier, particularly the public health authorities.

Table 4.5 International Organization for Standardization (ISO) standards for water quality giving guidance on sampling[a]

ISO standard no.	Title (water quality)
5667-1:2006	Sampling—Part 1: Guidance on the design of sampling programmes and sampling techniques
5667-3:2003	Sampling—Part 3: Guidance on the preservation and handling of water samples
5667-4:1987	Sampling—Part 4: Guidance on sampling from lakes, natural and man-made
5667-5:2006	Sampling—Part 5: Guidance on sampling of drinking water and water from treatment works and piped distribution systems
5667-6:2005	Sampling—Part 6: Guidance on sampling of rivers and streams
5667-11:2009	Sampling—Part 11: Guidance on sampling of groundwaters
5667-13:1997	Sampling—Part 13: Guidance on sampling of sludges from sewage and water treatment works
5667-14:1998	Sampling—Part 14: Guidance on quality assurance of environmental water sampling and handling
5667-16:1998	Sampling—Part 16: Guidance on biotesting of samples
5667-20:2008	Sampling—Part 20: Guidance on the use of sampling data for decision making—Compliance with thresholds and classification systems
5667-21:2010	Sampling—Part 21: Guidance on sampling of drinking water distributed by tankers or means other than distribution pipes
5667-23:2011	Sampling—Part 23: Guidance on passive sampling in surface waters
5668-17:2008	Sampling—Part 17: Guidance on sampling of bulk suspended sediments
13530:2009	Guidance on analytical quality control for chemical and physicochemical water analysis
17381:2003	Selection and application of ready-to-use test kit methods in water analysis

[a] ISO has also established quality management standards relating to drinking-water supply, including ISO 24510:2007, Activities relating to drinking water and wastewater services—Guidelines for the assessment and for the improvement of the service to users; and ISO 24512:2007, Activities relating to drinking water and wastewater services—Guidelines for the management of drinking water utilities and for the assessment of drinking water services.

Incident response plans typically comprise:

- accountabilities and contact details for key personnel, often including several organizations and individuals;
- lists of measurable indicators and limit values/conditions that would trigger incidents, along with a scale of alert levels;
- clear description of the actions required in response to alerts;
- location and identity of the standard operating procedures and required equipment;
- location of backup equipment;
- relevant logistical and technical information;
- checklists and quick reference guides.

The plan may need to be followed at very short notice, so standby rosters, effective communication systems and up-to-date training and documentation are required.

Staff should be trained in response procedures to ensure that they can manage incidents or emergencies effectively. Incident and emergency response plans should be periodically reviewed and practised. This improves preparedness and provides opportunities to improve the effectiveness of plans before an emergency occurs.

Following any incident or emergency, an investigation should be undertaken involving all concerned staff. The investigation should consider factors such as:

- the cause of the problem;
- how the problem was first identified or recognized;
- the most essential actions required;
- any communication problems that arose, and how they were addressed;
- the immediate and longer-term consequences;
- how well the emergency response plan functioned.

Appropriate documentation and reporting of the incident or emergency should also be established. The organization should learn as much as possible from the incident or emergency to improve preparedness and planning for future incidents. Review of the incident or emergency may indicate necessary amendments to the WSP and existing protocols.

The preparation of clear procedures, definition of accountability and provision of equipment for the sampling and storing of water in the event of an incident can be valuable for follow-up epidemiological or other investigations, and the sampling and storage of water from early on during a suspected incident should be part of the response plan.

4.4.1 Predictable incidents ("deviations")

Many incidents (e.g. exceedance of a critical limit) can be foreseen, and management plans can specify resulting actions. Actions may include, for example, temporary change of water sources (if possible), increasing coagulation dose, use of backup disinfection or increasing disinfectant concentrations in distribution systems.

4.4.2 Unplanned events

Some scenarios that lead to water being considered potentially unsafe might not be specifically identified within incident response plans. This may be either because the events were unforeseen or because they were considered too unlikely to justify preparing detailed corrective action plans. To allow for such events, a general incident response plan should be developed. The plan would be used to provide general guidance on identifying and handling of incidents along with specific guidance on responses that would be applied to many different types of incident.

A protocol for situation assessment and declaring incidents would be provided in a general incident response plan that includes personal accountabilities and categorical selection criteria. The selection criteria may include time to effect, population affected and nature of the suspected hazard.

The success of general incident responses depends on the experience, judgement and skill of the personnel operating and managing the drinking-water supply. However, generic activities that are common in response to many incidents can be incorporated within general incident response plans. For example, for piped systems, emergency flushing standard operating procedures can be prepared and tested for use in the event that contaminated water needs to be flushed from a piped system. Similarly, standard operating procedures for rapidly changing or bypassing reservoirs can be prepared, tested and incorporated. The development of such a "toolkit" of supporting material limits the likelihood of error and speeds up responses during incidents.

4.4.3 Emergencies

Water suppliers should develop plans to be invoked in the event of an emergency. These plans should consider potential natural disasters (e.g. earthquakes, floods, damage to electrical equipment by lightning strikes), accidents (e.g. spills in the watershed, interruptions in electricity supply), damage to treatment plant and distribution system and human actions (e.g. strikes, sabotage). Emergency plans should clearly specify responsibilities for coordinating measures to be taken, a communication plan to alert and inform users of the drinking-water supply and plans for providing and distributing emergency supplies of drinking-water.

Plans should be developed in consultation with relevant regulatory authorities and other key agencies and should be consistent with national and local emergency response arrangements. Key areas to be addressed in emergency response plans include:

- response actions, including increased monitoring;
- responsibilities of authorities internal and external to the organization;
- plans for emergency drinking-water supplies;
- communication protocols and strategies, including notification procedures (internal, regulatory body, media and public);
- mechanisms for increased public health surveillance.

Response plans for emergencies and unforeseen events involving microorganisms or chemicals should also include the basis for issuing boil water advisories (see section 7.6.1) and water avoidance advisories (see section 8.7.10). The objective of the advisory should be taken in the public interest. Therefore, the advisory should be issued after rapid, but careful, consideration of available information and conclusion that there is an ongoing risk to public health that outweighs any risk from the advice to boil or avoid water. The advisory will typically be managed by public health authorities. A decision to close a drinking-water supply carries an obligation to provide an alternative safe supply and is very rarely justifiable because of the adverse effects, especially to health, of restricting access to water. Specific actions in the event of a guideline exceedance or an emergency are discussed in section 7.6 (microbial hazards) and section 8.7 (chemical hazards); more general considerations are discussed in section 6.7. "Practice" emergencies are an important part of the maintenance of readiness for emergencies. They help to determine the potential actions that can be taken in different circumstances for a specific water supply.

4.4.4 Preparing a monitoring plan

Programmes should be developed for operational and verification monitoring and documented as part of a WSP, detailing the strategies and procedures to follow for monitoring the various aspects of the drinking-water system. The monitoring plans should be fully documented and should include the following information:

- parameters to be monitored;
- sampling location and frequency;
- sampling methods and equipment;
- schedules for sampling;
- references to corrective action procedures, including responsibilities;
- qualifications and certification requirements for testing laboratories;
- methods for quality assurance and validation of sampling results;
- requirements for checking and interpreting results;
- responsibilities and necessary qualifications of staff;
- requirements for documentation and management of records, including how monitoring results will be recorded and stored;
- requirements for reporting and communication of results.

4.4.5 Supporting programmes

Many actions are important in ensuring drinking-water safety but do not directly affect drinking-water quality and are therefore not control measures. These are referred to as "supporting programmes" and should also be documented in a WSP. Supporting programmes could involve:

Actions that are important in ensuring drinking-water safety but do not directly affect drinking-water quality are referred to as supporting programmes.

- controlling access to treatment plants, catchments and reservoirs and implementing the appropriate security measures to prevent transfer of hazards from people when they do enter source water;
- developing verification protocols for the use of chemicals and materials in the drinking-water supply—for instance, to ensure the use of suppliers that participate in quality assurance programmes;
- using designated equipment for attending to incidents such as mains bursts (e.g. equipment should be designated for potable water work only and not for sewage work);
- training and educational programmes for personnel involved in activities that could influence drinking-water safety; training should be implemented as part of induction programmes and frequently updated;
- research and development to improve understanding of water quality, including the quality of source waters, and treatment.

Supporting programmes will consist almost entirely of items that drinking-water suppliers and handlers will ordinarily have in place as part of their normal operation. For most, the implementation of supporting programmes will involve:

- collation of existing operational and management practices;
- initial and, thereafter, periodic review and updating to continually improve practices;
- promotion of good practices to encourage their use;
- audit of practices to check that they are being used, including taking corrective actions in case of non-conformance.

Codes of good operating and management practice and hygienic working practice are essential elements of supporting programmes. These are often captured within standard operating procedures. They include, but are not limited to:

- hygienic working practices in maintenance;
- attention to personal hygiene;
- training and competence of personnel involved in drinking-water supply;
- tools for managing the actions of staff, such as quality assurance systems;
- securing stakeholder commitment, at all levels, to the provision of safe drinking-water;
- education of communities whose activities may influence drinking-water quality;
- calibration of monitoring equipment;
- record keeping.

Comparison of one set of supporting programmes with the supporting programmes of other suppliers, through peer review, benchmarking and personnel or document exchange, can stimulate ideas for improved practice.

Supporting programmes can be extensive, be varied and involve multiple organizations and individuals. Many supporting programmes involve water resource protection measures and typically include aspects of land use control. Some water resource protection measures are engineered, such as effluent treatment processes and stormwater management practices that may be used as control measures.

4.5 Management of community and household water supplies

Community-managed drinking-water supplies worldwide are more frequently contaminated than larger drinking-water supplies, may be more prone to operating discontinuously (or intermittently) and break down or fail more frequently.

To ensure safe drinking-water, the focus in small supplies should be on:

- informing the public;
- assessing the water supply to determine whether it is able to meet identified health-based targets (see section 4.1);
- monitoring identified control measures and training operators to ensure that all likely hazards can be controlled and that risks are maintained at a tolerable level (see section 4.2);
- operational monitoring of the drinking-water system (see section 4.2);
- implementing systematic water quality management procedures (see section 4.4), including documentation and communication (see section 4.6);
- establishing appropriate incident response protocols (usually encompassing actions at the individual supply, backed by training of operators, and actions required by local or national authorities) (see sections 4.4.2 and 4.4.3); and

- developing programmes to upgrade and improve existing water delivery (usually defined at a national or regional level rather than at the level of individual supplies) (see section 4.1.8).

For small point sources serving communities or individual households, the emphasis should be on selecting source water of the best available quality and on protecting its quality by the use of multiple barriers (usually within source protection) and maintenance programmes. Whatever the source (groundwater, surface water or rainwater tanks), communities and householders should assure themselves that the water is safe to drink. Generally, surface water and shallow groundwater under the direct influence of surface water (which includes shallow groundwater with preferential flow paths) should receive treatment.

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 of waterborne disease. The essential parameters of water quality are *E. coli*—thermotolerant (faecal) coliforms are accepted as suitable substitutes—and chlorine residual (if chlorination is practised). These should be supplemented, where appropriate, by pH adjustment (if chlorination is practised) and measurement of turbidity.

These parameters may be measured on site using relatively unsophisticated testing equipment, and improved and relatively low cost systems continue to be developed. 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 impractical.

Other health-related parameters of local significance should also be measured. The overall approach to control of chemical contamination is outlined in chapter 8.

4.6 Documentation and communication

Documentation of a WSP should include:

- description and assessment of the drinking-water system (see section 4.1), including programmes to upgrade and improve existing water delivery (see section 4.1.8);
- the plan for operational monitoring and verification of the drinking-water system (see sections 4.2 and 4.3);
- water safety management procedures for normal operation, incidents (specific and general) and emergency situations (see sections 4.4.1, 4.4.2 and 4.4.3), including communication plans; and
- description of supporting programmes (see section 4.4.5).

Records are essential to review the adequacy of the WSP and to demonstrate the adherence of the drinking-water system to the WSP. Several types of records are generally kept:

- supporting documentation for developing the WSP, including validation;
- records and results generated through operational monitoring and verification;
- outcomes of incident investigations;

- documentation of methods and procedures used;
- records of employee training programmes.

By tracking records generated through operational monitoring and verification, an operator or manager can detect that a process is approaching its operational or critical limit. Review of records can be instrumental in identifying trends and in making operational adjustments. Periodic review of WSP records is recommended so that trends can be noted and appropriate actions decided upon and implemented. Records are also essential when surveillance is implemented through auditing-based approaches.

Communication strategies should include:

- procedures for promptly advising of any significant incidents within the drinking-water supply, including notification of the public health authority;
- summary information to be made available to consumers—for example, through annual reports and on the Internet;
- establishment of mechanisms to receive and actively address community complaints in a timely fashion.

The right of consumers to health-related information on the water supplied to them for domestic purposes is fundamental. However, in many communities, the simple right of access to information will not ensure that individuals are aware of the quality of the water supplied to them; furthermore, the probability of consuming unsafe water may be relatively high. The agencies responsible for monitoring should therefore develop strategies for disseminating and explaining the significance of health-related information. Further information on communication is provided in section 5.5.

4.7 Planned review

4.7.1 Periodic review

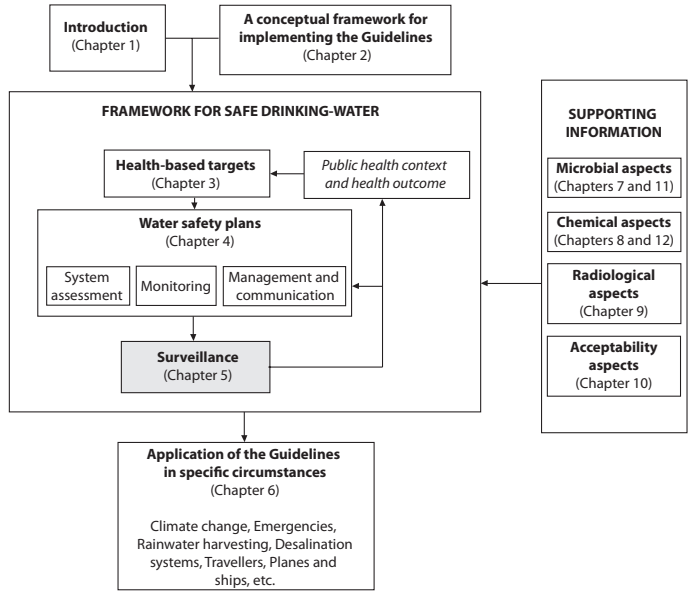
WSPs should not be regarded as static documents. They need to be regularly reviewed and revised to ensure that they are functioning correctly and that they are kept up to date in light of changes in water systems or new developments. Reviews should consider:

- data collected as part of monitoring processes;
- changes to water sources and catchments;
- changes to treatment, demand and distribution;
- implementation of improvement and upgrade programmes;
- revised procedures;
- emerging hazards and risks.

4.7.2 Post-incident review

WSPs should also be reviewed following incidents and emergencies to ensure that, where possible, incidents do not recur and, where this is not possible (e.g. floods), to reduce impacts. Post-incident reviews may identify areas for improvement and the need for revision of WSPs.

5
Surveillance



Drinking-water supply surveillance is "the continuous and vigilant public health assessment and review of the safety and acceptability of drinking-water supplies" (WHO, 1976). This surveillance contributes to the protection of public health by promoting improvement of the quality, quantity, accessibility, coverage, affordability and continuity of water supplies (known as service indicators) and is complementary to the quality control function of the drinking-water supplier. Drinking-water supply surveillance does not remove or replace the responsibility of the drinking-water supplier to ensure that a drinking-water supply is of acceptable quality and meets predetermined health-based targets.

All members of the population receive drinking-water by some means—including the use of piped supplies with or without treatment and with or without pumping (supplied via domestic connection or public standpipe), delivery by tanker truck or carriage by beasts of burden or collection from groundwater sources (springs or wells) or surface sources (lakes, rivers and streams). It is important for the surveillance agency to build up a picture of the frequency of use of the different types of supply, especially as a preliminary step in the planning of a surveillance programme. There

is little to be gained from surveillance of piped water supplies alone if these are available to only a small proportion of the population or if they represent a minority of supplies.

Information alone does not lead to improvement. Instead, the effective management and use of the information generated by surveillance make possible the rational improvement of water supplies—where "rational" implies that available resources are used for maximum public health benefit.

Surveillance is an important element in the development of strategies for incremental improvement of the quality of drinking-water supply services. It is important that strategies be developed for implementing surveillance, collating, analysing and summarizing data and reporting and disseminating the findings and that the strategies are accompanied by recommendations for remedial action. Follow-up will be required to ensure that remedial action is taken.

Surveillance extends beyond drinking-water supplies operated by a discrete drinking-water supplier to include drinking-water supplies that are managed by communities and includes assurance of good hygiene in the collection and storage of household water.

The surveillance agency must have, or have access to, legal expertise in addition to expertise on drinking-water and water quality. Drinking-water supply surveillance is also used to ensure that any transgressions that may occur are appropriately investigated and resolved. In many cases, it will be more appropriate to use surveillance as a mechanism for collaboration between public health agencies and drinking-water suppliers to improve drinking-water supply than to resort to enforcement, particularly where the problem lies mainly with community-managed drinking-water supplies.

The authorities responsible for drinking-water supply surveillance may be the public health ministry or other agency (see section 1.2.1), and their roles encompass four areas of activity:

1) public health oversight of organized drinking-water supplies;
2) public health oversight and information support to populations without access to organized drinking-water supplies, including communities and households;
3) consolidation of information from diverse sources to enable understanding of the overall drinking-water supply situation for a country or region as a whole as an input to the development of coherent public health–centred policies and practices;
4) participation in the investigation, reporting and compilation of outbreaks of waterborne disease.

A drinking-water supply surveillance programme should normally include processes for approval of water safety plans (WSPs). This approval will normally involve review of the system assessment, of the identification of appropriate control measures and supporting programmes and of operational monitoring and management plans. It should ensure that the WSP covers normal operating conditions and predictable incidents (deviations) and has contingency plans in case of an emergency or unplanned event.

The surveillance agency may also support or undertake the development of WSPs for community-managed drinking-water supplies and household water treatment and storage. Such plans may be generic for particular technologies rather than specific for individual systems.

5.1 Types of approaches

There are two types of approaches to surveillance of drinking-water quality: audit-based approaches and approaches relying on direct assessment. Implementation of surveillance will generally include a mixture of these approaches according to supply type and may involve using rolling programmes whereby systems are addressed progressively. Often it is not possible to undertake extensive surveillance of all community or household supplies. In these cases, well-designed surveys should be undertaken in order to understand the situation at the national or regional level.

5.1.1 Audit

In the audit approach to surveillance, assessment activities, including verification testing, are undertaken largely by the supplier, with third-party auditing to verify compliance. It is increasingly common that analytical services are procured from accredited external laboratories. Some authorities are also experimenting with the use of such arrangements for services such as sanitary inspection, sampling and audit reviews.

An audit approach requires the existence of a stable source of expertise and capacity within the surveillance agency in order to:

- review and approve new WSPs;
- undertake or oversee auditing of the implementation of individual WSPs as a programmed routine activity;
- respond to, investigate and provide advice on receipt of reports on significant incidents.

Periodic audit of the implementation of WSPs is required:

- at intervals (the frequency of routine audits will be dependent on factors such as the size of the population served and the nature and quality of source water and treatment facilities);
- following substantial changes to the source, the distribution or storage system or treatment processes;
- following significant incidents.

Periodic audit would normally include the following elements:

- examination of records to ensure that system management is being carried out as described in the WSP;
- ensuring that operational monitoring parameters are kept within operational limits and that compliance is being maintained;
- ensuring that verification programmes are operated by the water supplier (either through in-house expertise or through a third-party arrangement);

- assessment of supporting programmes and of strategies for improving and updating the WSP;
- in some circumstances, sanitary inspection, which may cover the whole of the drinking-water system, including sources, transmission infrastructure, treatment plants, storage reservoirs and distribution systems.

In response to reports of significant incidents, it is necessary to ensure that:

- the event is investigated promptly and appropriately;
- the cause of the event is determined and corrected;
- the incident and corrective action are documented and reported to appropriate authorities;
- the WSP is reassessed to avoid the occurrence of a similar situation.

The implementation of an audit-based approach places responsibility on the drinking-water supplier to provide the surveillance agency with information regarding system performance against agreed indicators. In addition, a programme of announced and unannounced visits by auditors to drinking-water suppliers should be implemented to review documentation and records of operational practice in order to ensure that data submitted are reliable. Such an approach does not necessarily imply that water suppliers are likely to falsify records, but it does provide an important means of reassuring consumers that there is true independent verification of the activities of the water supplier. The surveillance agency will normally retain the authority to undertake some analysis of drinking-water quality to verify performance or enter into a third-party arrangement for such analysis.

5.1.2 Direct assessment

It may be appropriate for the drinking-water supply surveillance agency to carry out independent testing of water supplies. Such an approach often implies that the agency has access to analytical facilities with staff trained to carry out sampling, analysis and sanitary inspection.

Direct assessment also implies that surveillance agencies have the capacity to assess findings and to report to and advise suppliers and communities. A surveillance programme based on direct assessment would normally include:

- specified approaches to large municipality/small municipality/community supplies and individual household supplies;
- sanitary inspections to be carried out by qualified personnel;
- sampling to be carried out by qualified personnel;
- tests to be conducted using suitable methods by accredited laboratories or using approved field testing equipment and qualified personnel;
- procedures on reporting findings and follow-up to ensure that they have been acted on.

For community-managed drinking-water supplies and where the development of in-house verification or third-party arrangements is limited, direct assessment may be used as the principal system of surveillance. This may apply to drinking-water supplies

in small towns by small-scale private sector operators or local government. Direct assessment may lead to the identification of requirements to amend or update the WSP, and the process to be followed when undertaking such amendments should be clearly identified.

Where direct assessment is carried out by the surveillance agency, it complements other verification testing of the water supplier. General guidance on verification testing, which is also applicable to surveillance through direct assessment, is provided in section 4.3.

5.2 Adapting approaches to specific circumstances

5.2.1 Urban areas in developing countries

Drinking-water supply arrangements in urban areas of developing countries are typically complex. There can often be one or more large piped supplies with household and public connections, in combination with a range of alternative drinking-water supplies, including point sources and vended water. In these situations, the surveillance programme should take account of the different sources of drinking-water and the potential for deterioration in quality during collection, storage and use. Furthermore, the population will vary in terms of socioeconomic status and vulnerability to water-related disease.

In many situations, zoning the urban area on the basis of vulnerability and drinking-water supply arrangements is required. The zoning system should include all populations within the urban area, including informal and periurban settlements, regardless of their legal status, in order to direct resources to where greatest improvements (or benefits) to public health will be achieved. This provides a mechanism to ensure that non-piped drinking-water sources are also included within drinking-water supply surveillance activities.

Experience has shown that zoning can be developed using qualitative and quantitative methods and is useful in identifying vulnerable groups and priority communities where drinking-water supply improvements are required.

5.2.2 Community drinking-water supplies

Small community-managed drinking-water supplies are found in most countries and may be the predominant form of drinking-water supply for large sections of the population. The precise definition of a "community drinking-water supply" will vary, but administration and management arrangements are often what set community supplies apart, especially in developing countries. Community-managed supplies may include simple piped water systems or a range of point sources, such as boreholes with hand pumps, dug wells and protected springs.

The control of water quality and implementation of surveillance programmes for such supplies often face significant constraints. These typically include:

- limited capacity and skills within the community to undertake process control and verification; this may increase the need both for surveillance to assess the state of drinking-water supplies and for surveillance staff to provide training and support to community members;

- the very large number of widely dispersed supplies, which significantly increases overall costs in undertaking surveillance activities.

Furthermore, it is often small community-managed water supplies that present the greatest water quality problems.

Experience from both developing and developed countries has shown that surveillance of community-managed drinking-water supplies can be effective when well designed and when the objectives are geared more towards a supportive role to enhance community management than towards enforcement of compliance.

Surveillance of community drinking-water supplies requires a systematic programme of surveys that encompass all aspects of the drinking-water supply to the population as a whole, including sanitary inspection (including catchment inspections) and institutional and community aspects. Surveillance should address variability in source water quality, treatment process efficacy and the quality of distributed or household-treated and household-stored water.

Experience has also shown that the role of surveillance may include health education and health promotion activities to improve healthy behaviour towards management of drinking-water supply and sanitation. Participatory activities can include sanitary inspection by communities and, where appropriate, community-based testing of drinking-water quality using affordable field test kits and other accessible testing resources.

In the evaluation of overall strategies, the principal aim should be to derive overall lessons for improving water safety for all community supplies, rather than relying on monitoring the performance of individual supplies.

Frequent visits to every individual supply may be impractical because of the very large numbers of such supplies and the limitations of resources for such visits. However, surveillance of large numbers of community supplies can be achieved through a rolling programme of visits. Commonly, the aim will be to visit each supply periodically (once every 3–5 years at a minimum) using either stratified random sampling or cluster sampling to select specific supplies to be visited. During each visit, sanitary inspection and water quality analysis will normally be done to provide insight on contamination and its causes.

During each visit, testing of water stored in the home may be undertaken in a sample of households. The objective for such testing is to determine whether contamination occurs primarily at the source or within the home. This will allow evaluation of the need for investment in supply improvement or education on good hygiene practices for household treatment and safe storage. Household testing may also be used to evaluate the impact of a specific hygiene education programme.

5.2.3 Household treatment and storage systems

Where water is handled during storage in households, it may be vulnerable to contamination, and sampling of household-stored water is of interest in independent surveillance. It is often undertaken on a "survey" basis to develop insights into the extent and nature of prevailing problems. Surveillance systems managed by public health author-

ities for drinking-water supplies using household treatment and household storage containers are therefore recommended.

The principal focus of surveillance of household-based interventions will be assessment of their acceptance and impact through sample surveys so as to evaluate and inform overall strategy development and refinement. Systematic determination of continued, correct and effective use and management is recommended so that deficiencies in use and management can be identified and corrected by those responsible.

5.3 Adequacy of supply

As the drinking-water supply surveillance agency has an interest in the population at large, its interest extends beyond water quality in isolation to include all aspects of the adequacy of drinking-water supply for the protection of public health.

In undertaking an assessment of the adequacy of the drinking-water supply, the following basic service parameters of a drinking-water supply should normally be taken into consideration:

- *Quality:* whether the supply has regularly verified water quality and an approved WSP (see chapter 4) that has been validated and is subject to periodic audit to demonstrate compliance with relevant regulations (see chapters 3 and 4);
- *Quantity (service level):* the proportion of the population with access to different levels of drinking-water supply (e.g. no access, basic access, intermediate access and optimal access) as a surrogate for health impacts in relation to quantity of water used;
- *Accessibility:* the percentage of the population that has reasonable access to an improved drinking-water supply;
- *Affordability:* the tariff paid by domestic consumers;
- *Continuity:* the percentage of the time during which drinking-water is available (daily, weekly and seasonally).

5.3.1 Quantity (service level)

The quantity of water collected and used by households has an important influence on health. There is a basic human physiological requirement for water to maintain adequate hydration and an additional requirement for food preparation. There is a further requirement for water to support hygiene, which is necessary for health.

Estimates of the volume of water needed for health purposes vary widely. In deriving World Health Organization (WHO) guideline values, it is assumed that the daily per capita consumption of drinking-water is approximately 2 litres for adults, although actual consumption varies according to climate, activity level and diet. Based on currently available data, a minimum volume of 7.5 litres per capita per day will provide sufficient water for hydration and incorporation into food for most people under most conditions. In addition, adequate domestic water is needed for food preparation, laundry and personal and domestic hygiene, which are also important for health. Water may also be important in income generation and amenity uses.

Table 5.1 Service level and quantity of water collected

Service level	Distance/time	Likely volumes of water collected	Public health risk from poor hygiene	Intervention priority and actions
No access	More than 1 km / more than 30 min round-trip	Very low: 5 litres per capita per day	**Very high** Hygiene practice compromised Basic consumption may be compromised	**Very high** Provision of basic level of service Hygiene education Household water treatment and safe storage as interim measure
Basic access	Within 1 km / within 30 min round-trip	Approximately 20 litres per capita per day on average	**High** Hygiene may be compromised Laundry may occur off-plot	**High** Provision of improved level of service Hygiene education Household water treatment and safe storage as interim measure
Intermediate access	Water provided on-plot through at least one tap (yard level)	Approximately 50 litres per capita per day on average	**Low** Hygiene should not be compromised Laundry likely to occur on-plot	**Low** Hygiene promotion still yields health gains Encourage optimal access
Optimal access	Supply of water through multiple taps within the house	100–200 litres per capita per day on average	**Very low** Hygiene should not be compromised Laundry will occur on-plot	**Very low** Hygiene promotion still yields health gains

Source: *Domestic water quantity, service level and health* (supporting document in Annex 1)

The quantities of water collected and used by households are primarily a function of the distance to the water supply or total collection time required. This broadly equates to the level of service. Four levels of service can be defined, as shown in Table 5.1.

Service level is a useful and easily measured indicator that provides a valid surrogate for the quantity of water collected by households and is the preferred indicator for surveillance. Available evidence indicates that health gains accrue from improving service level in two key stages: the delivery of water within 1 km or 30 minutes of total collection time; and when supplied to a yard level of service. Further health gains are likely to occur once water is supplied through multiple taps, as this will increase water availability for diverse hygiene practices. The volume of water collected may also depend on the reliability and cost of the water. Therefore, collection of data on these indicators is important.

5.3.2 Accessibility

From the public health standpoint, the proportion of the population with reliable access to safe drinking-water is the most important single indicator of the overall success of a drinking-water supply programme.

There are a number of definitions of access (or coverage), many with qualifications regarding safety or adequacy. Access to safe drinking-water for the Millennium Development Goals is currently measured by the WHO/United Nations Children's Fund (UNICEF) Joint Monitoring Programme for Water Supply and Sanitation through a proxy that assesses the use of improved drinking-water sources by households. An improved drinking-water source is one that by the nature of its construction and design adequately protects the source from outside contamination, in particular by faecal matter. The underlying assumption is that improved sources are more likely to supply safe drinking-water than unimproved sources. Improved and unimproved water supply technologies are summarized below:

- Improved drinking-water sources:
  - piped water into dwelling, yard or plot
  - public tap or standpipe
  - tubewell or borehole
  - protected dug well
  - protected spring
  - rainwater collection.
- Unimproved drinking-water sources:
  - unprotected dug well
  - unprotected spring
  - cart with small tank or drum provided by water vendor
  - tanker truck provision of water
  - surface water (river, dam, lake, pond, stream, canal, irrigation channel)
  - bottled water.[1]

Determining the proportion of a population with reliable access to drinking-water is an important function of a drinking-water surveillance agency. This task can be facilitated by establishing a common definition for reasonable access, appropriate to a local context, which may describe a minimum quantity of water supplies per person per day together with a maximum tolerable distance/time to a source (e.g. 20 litres, and within 1 km/30 minutes, respectively, for basic access).

5.3.3 Affordability

The affordability of water has a significant influence on the use of water and selection of water sources. Households with the lowest levels of access to safe water supply frequently pay more for their water than do households connected to a piped water system. The high cost of water may force households to use alternative sources of water of poorer quality that represent a greater risk to health. Furthermore, high costs

[1] Bottled water is considered to be improved only when the household uses drinking-water from an improved source for cooking and personal hygiene.

of water may reduce the volumes of water used by households, which in turn may influence hygiene practices and increase risks of disease transmission.

When assessing affordability, it is important to collect data on the price at the point of purchase. Where households are connected to the drinking-water supplier, this will be the tariff applied. Where water is purchased from public standpipes or from neighbours, the price at the point of purchase may be very different from the drinking-water supplier tariff. Many alternative water sources (notably vendors) also involve costs, and these costs should be included in evaluations of affordability. In addition to recurrent costs, the costs for initial acquisition of a connection should also be considered when evaluating affordability.

5.3.4 Continuity

Interruptions to drinking-water supply, either because of intermittent sources or resulting from engineering inefficiencies, are a major determinant of the access to and quality of drinking-water. Analysis of data on continuity of supply requires the consideration of several components. Continuity can be classified as follows:

- year-round service from a reliable source with no interruption of flow at the tap or source;
- year-round service with frequent (daily or weekly) interruptions, of which the most common causes are:
  - restricted pumping regimes in pumped systems, whether planned or due to power failure or sporadic failure;
  - peak demand exceeding the flow capacity of the transmission mains or the capacity of the reservoir;
  - excessive leakage within the distribution system;
  - excessive demands on community-managed point sources;
- seasonal service variation resulting from source fluctuation, which typically has three causes:
  - natural variation in source volume during the year;
  - volume limitation because of competition with other uses, such as irrigation;
  - periods of high turbidity when the source water may be untreatable;
- compounded frequent and seasonal discontinuity.

These classifications reflect broad categories of continuity, which are likely to affect hygiene in different ways. Any interruption of service is likely to result in degradation of water quality, increased risk of exposure to contaminated water and therefore increased risk of waterborne disease. Daily or weekly discontinuity results in low supply pressure and a consequent risk of in-pipe recontamination. Other consequences include reduced availability and lower volume use, which adversely affect hygiene. Household water storage may be necessary, and this may lead to an increase in the risk of contamination during such storage and associated handling. Seasonal discontinuity often forces users to obtain water from inferior and distant sources. As a consequence, in addition to the obvious reduction in quality and quantity, time is lost in water collection.

5.4 Planning and implementation

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

The focus of drinking-water supply-related improvement activities (whether these are establishment of regional or national priorities, hygiene education programmes or enforcement compliance) will depend on the nature of the drinking-water supplies and the types of problems identified. A list of mechanisms for drinking-water supply improvement based on the output of surveillance is given below:

- *Establishing national priorities:* When the most common problems and shortcomings in the drinking-water system 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 subnational/regional priorities:* Regional offices of drinking-water supply agencies can decide in which communities to work and which remedial activities are priorities; public health criteria should be considered when priorities are set.
- *Establishing hygiene education programmes:* Not all of the problems revealed by surveillance are technical in nature, and not all are solved by drinking-water suppliers; surveillance also looks at problems involving community and household 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.
- *Auditing of WSPs and upgrading:* The information generated by surveillance can be used to audit WSPs and to assess whether these are in compliance. Drinking-water systems and their associated WSPs should be upgraded where they are found to be deficient, although feasibility must be considered, and enforcement of upgrading 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 community drinking-water supplies.
- *Establishing public awareness and information channels:* Publication of information on public health aspects of drinking-water supplies, water quality and the performance of suppliers can encourage suppliers to follow good practices, mobilize public opinion and response and reduce the need for regulatory enforcement, which should be an option of last resort.
- *Implementing programmes for household water treatment and safe storage:* If information from surveillance reveals no or only basic access to water service, as defined in Table 5.1, or unsafe supplied water, the implementation of programmes to promote household water treatment and safe storage may be advised to improve water quality and promote hygienic water management at the household level. These may be effective interim measures for provision of safer water supported by appropriate outreach, education and training activities and creating supply

chains for appropriate household water treatment and safe storage technologies. Further information is available in section 7.3.2 and the 1997 volume, *Surveillance and control of community supplies* (WHO, 1997).

In order to make best use of limited resources where surveillance is not yet practised, it is advisable to start with a basic programme that develops in a planned manner. Activities in the early stages should generate enough useful data to demonstrate the value of surveillance. Thereafter, the objective should be to progress to more advanced surveillance as resources and conditions permit.

The activities normally undertaken in the initial, intermediate and advanced stages of development of drinking-water supply surveillance are summarized as follows:

- *Initial phase:*
  - Establish requirements for institutional development.
  - Provide training for staff involved in the programme.
  - Define the role of participants (e.g. quality assurance/quality control by supplier, surveillance by public health authority).
  - Develop methodologies suitable for the area.
  - Commence routine surveillance in priority areas (including inventories).
  - Limit verification to essential parameters and known problem substances.
  - Establish reporting, filing and communication systems.
  - Advocate improvements according to identified priorities.
  - Establish reporting to local suppliers, communities, media and regional authorities.
  - Establish liaison with communities; identify community roles in surveillance and means of promoting community participation.
- *Intermediate phase:*
  - Train staff involved in the programme.
  - Establish and expand systematic routine surveillance.
  - Expand access to analytical capability (often by means of regional laboratories, national laboratories being largely responsible for analytical quality control and training of regional laboratory staff).
  - Undertake surveys for chemical contaminants using a wider range of analytical methods.
  - Evaluate all methodologies (sampling, analysis, etc.).
  - Use appropriate standard methods (e.g. analytical methods, fieldwork procedures).
  - Develop capacity for statistical analysis of data.
  - Establish a national database.
  - Identify common problems and improve activities to address them at regional and national levels.
  - Expand reporting to include interpretation at the national level.
  - Draft or revise health-based targets as part of a framework for safe drinking-water.
  - Use legal enforcement where necessary.
  - Involve communities routinely in surveillance implementation.

- *Advanced phase:*
  - — Provide further or advanced training for staff involved in the programme.
  - — Establish routine surveillance for all health and acceptability parameters at defined frequencies.
  - — Use a full network of national, regional and local laboratories (including analytical quality control).
  - — Use a national framework for drinking-water quality.
  - — Improve water services on the basis of national and local priorities, hygiene education and enforcement of standards.
  - — Establish regional database archives compatible with the national database.
  - — Disseminate data at all levels (local, regional and national).
  - — Involve communities routinely in surveillance implementation.

5.5 Reporting and communicating

An essential element of a successful surveillance programme is the reporting of results to stakeholders. It is important to establish appropriate systems of reporting to all relevant bodies. Proper reporting and feedback will support the development of effective remedial strategies. The ability of the surveillance programme to identify and advocate interventions to improve water supply is highly dependent on the ability to analyse and present information in a meaningful way to different target audiences. The target audiences for surveillance information will typically include:

- public health officials at local, regional and national levels;
- water suppliers;
- local administrations;
- communities and water users;
- local, regional and national authorities responsible for development planning and investment.

5.5.1 Interaction with community and consumers

Community participation is a desirable component of surveillance, particularly for community and household drinking-water supplies. As primary beneficiaries of improved drinking-water supplies, community members have a right to take part in decision-making. The community represents a resource that can be drawn upon for local knowledge and experience. They are the people who are likely to first notice problems in the drinking-water supply and therefore can provide an indication of when immediate remedial action is required. Communication strategies should include:

> The right of consumers to information on the safety of the water supplied to them for domestic purposes is fundamental.

- provision of summary information to consumers (e.g. through annual reports or the Internet);
- establishment and involvement of consumer associations at local, regional and national levels.

In many communities, however, the simple right of access to information will not ensure that individuals are aware of the quality or safety of the water supplied to them. The agencies responsible for surveillance should develop strategies for disseminating and explaining the significance of results obtained.

It may not be feasible for the surveillance agency to provide feedback information directly to the entire community. Thus, it may be appropriate to use community organizations, where these exist, to provide an effective channel for providing feedback information to users. Some local organizations (e.g. local councils and community-based organizations, such as women's groups, religious groups and schools) have regular meetings in the communities that they serve and can therefore provide a mechanism of relaying important information to a large number of people within the community. Furthermore, by using local organizations, it is often easier to initiate a process of discussion and decision-making within the community concerning water quality. The most important element in working with local organizations is to ensure that the organization selected can access the whole community and can initiate discussion on the results of surveillance (see sections 7.6.1 and 8.7).

5.5.2 Regional use of data

Strategies for regional prioritization are typically of a medium-term nature and have specific data requirements. While the management of information at a national level is aimed at highlighting common or recurrent problems, the objective at a regional level is to assign a degree of priority to individual interventions. It is therefore important to derive a relative measure of health risk. Although this information cannot be used on its own to determine which systems should be given immediate attention (which would also require the analysis of economic, social, environmental and cultural factors), it provides an extremely important tool for determining regional priorities. It should be a declared objective to ensure that remedial action is carried out each year on a predetermined proportion of the systems classified as high risk.

At the regional level, it is also important to monitor the improvement in (or deterioration of) both individual drinking-water supplies and the supplies as a whole. In this context, simple measures, such as the mean sanitary inspection score of all systems, the proportion of systems with given degrees of faecal contamination, the population with different levels of service and the mean cost of domestic consumption, should be calculated yearly and changes monitored.

As shown in Table 7.10 in section 7.4, the aim should be to provide drinking-water that contains no faecal indicator organisms, such as *Escherichia coli*. However, in many developing and developed countries, a high proportion of household and small community drinking-water systems, in particular, fail to meet requirements for water safety, including the absence of *E. coli*. In such circumstances, it is important that realistic goals for progressive improvement are agreed upon and implemented. It is practical to classify water quality results in terms of an overall grading for water safety linked to priority for action, as illustrated in Table 5.2.

Grading schemes may be of particular use in community supplies where the frequency of testing is low and reliance on analytical results alone is especially inappropriate. Such schemes will typically take account of both analytical findings

Table 5.2 Example of categorization of drinking-water systems on the basis of population size and quality rating in order to prioritize actions (see also Table 7.10)

Quality of drinking-water system[a]	Proportion (%) of samples negative for *E. coli*		
	< 5000 population	5000–100 000 population	> 100 000 population
A	90	95	99
B	80	90	95
C	70	85	90
D	60	80	85

[a] Quality decreases from A to D.

Table 5.3 Example of assessment of priority of remedial actions of community drinking-water supplies based on a grading system of microbial quality and sanitary inspection rating or score[a]

		Sanitary inspection risk score (susceptibility of supply to contamination from human and animal faeces)			
		0–2	3–5	6–8	9–10
E. coli classification[b]	A				
	B				
	C				
	D				

Low risk: no action required	Intermediate risk: low action priority	High risk: higher action priority	Very high risk: urgent action required

[a] Where there is a potential discrepancy between the results of the microbial water quality assessment and the sanitary inspection, further follow-up or investigation is required.
[b] Classifications based on those shown in Table 5.2. Quality decreases from A to D.
Source: Adapted from Lloyd & Bartram (1991). See also the supporting document *Rapid assessment of drinking-water quality* (Annex 1).

and results of the sanitary inspection through matrices such as the one illustrated in Table 5.3.

Combined analysis of sanitary inspection and water quality data can be used to identify the most important causes of and control measures for contamination. This is important to support effective and rational decision-making. For instance, it will be important to know whether on-site or off-site sanitation could be associated with contamination of drinking-water, as the remedial actions required to address either source of contamination will be very different. This analysis may also identify other factors associated with contamination, such as heavy rainfall. As the data will be non-parametric, suitable methods for analysis include chi-square, odds ratios and logistic regression models.

Combined analysis of sanitary inspection and water quality data is especially useful in assessing household water management systems. Microbial water quality data

Table 5.4 Example of assessment of priority of remedial action for household drinking-water systems based on a grading system of microbial quality and sanitary inspection rating or scores[a]

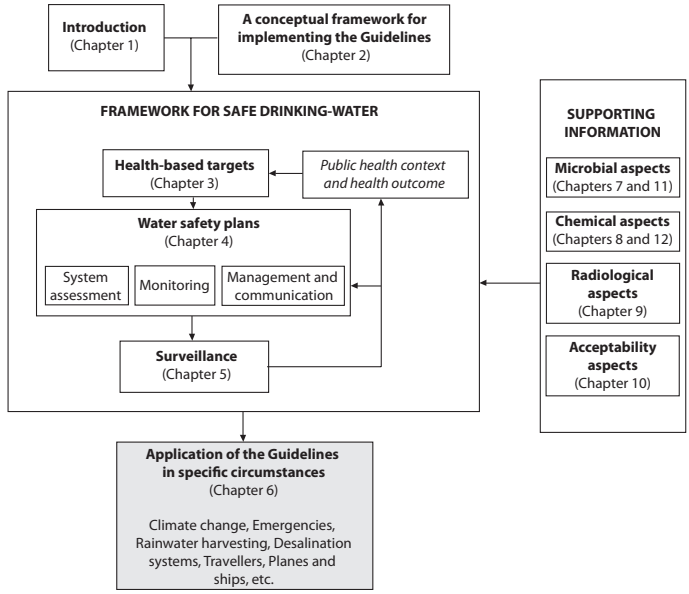
		Sanitary inspection risk score (susceptibility of supply to contamination from human and animal faeces)			
		0–2	3–5	6–8	9–10
***E. coli* classification (as decimal concentration/100)**	< 1				
	1–10				
	11–100				
	> 100				

Low risk: no action required	Intermediate risk: low action priority	High risk: higher action priority	Very high risk: urgent action required

[a] Where there is a potential discrepancy between the results of the microbial water quality assessment and the sanitary inspection, further follow-up or investigation is required.

are often limited, and sanitary inspection risk scoring therefore becomes an important consideration in assessing household water systems, their management and priority for remedial actions. An example of a combined system to assess risk and prioritize remedial actions for household water systems is shown in Table 5.4.

6
Application of the Guidelines in specific circumstances



These Guidelines provide a generally applicable approach to ensuring the safety of drinking-water supplied through piped distribution and community supplies. This chapter describes the application of the Guidelies in some commonly encountered circumstances and specific issues that should be taken into account in each. The sections are not intended to stand alone, and reference is made to more comprehensive supporting documents that provide detailed guidance. In all the specific circumstances described below, the principles enshrined in water safety plans (WSPs) apply. However, the WSP should be tailored to the type of supply in each circumstance; for example, routine chemical and microbiological monitoring of rainwater may not be feasible at a household level, but preventive barriers are both applicable and achievable.

As indicated in chapter 4, WSPs require careful consideration of possible hazards, and forward planning is one of the important requirements in ensuring that both the quantity and quality of water supplies are maintained. One of the significant concerns for the future is climate change, but there remains considerable uncertainty as to its

impact on a local or even subregional level. Nevertheless, it is expected that all types of supply will be affected, including the specific circumstances discussed below.

6.1 Climate change, water scarcity and heavy rainfall

Regional or localized droughts and heavy precipitation events and floods have always occurred, but they appear to be increasing in frequency, and greater extremes of climate should be expected. Anticipating and planning for these events, such that sufficient quantities of safe water can be delivered to consumers without disruptions, are not only key responsibilities of water suppliers, but a growing challenge. The effects of these climate extremes on water quality and quantity will be especially acute in areas with growing populations. In such areas, existing water supplies typically are already stressed, and there is little, if any, water supply margin available to them in the event of a major or extended duration weather event. This is especially true in regions with desert-like climates, such as parts of the Mediterranean, the Middle East, Australia and the south-western United States of America.

Over an extended period of time, climate change may foster greater extremes in weather, including more frequent and longer spells with much higher peak temperatures, droughts, greater frequency of heavy precipitation and violent storms. Changes in sea level from melting ice can affect coastal groundwater, causing salination, which may also occur as a result of over-abstraction. With changes in water quantity come changes in water quality: greater or lesser runoff affects the sediment loading, chemical composition, total organic carbon content and microbial quality. These changes require modifications in water storage capacity and water treatment to ensure safe drinking-water. Changes in groundwater levels may also lead to altered mineral composition, and moves to deeper groundwater may tap into aquifers with high mineral content or high levels of specific constituents of concern for health.

To provide for adequate water quantity and quality in the event of these changes and extremes, natural supplies may need to be augmented in some areas, together with use of more climate-resilient technologies and processes. Water treatment systems may need to be upgraded and obtain greater storage capacity to be able to cope with greater microbial, turbidity and chemical loadings. New sources of water may need to be developed, such as recycled wastewater or desalinated brackish water or seawater, and new strategies may need to be implemented, such as aquifer storage and recovery.

6.2 Rainwater harvesting

Rainwater harvesting is widely practised at a household level but is increasingly being used on a larger community scale. Rainwater can provide an important source of drinking-water in some circumstances as well as a useful source of water for blending with other sources to reduce the levels of contaminants of health concern, such as arsenic and fluoride.

The development of formal WSPs at the household level may not always be practical, but promotion of sanitary inspection with simple good practice is important. Well-designed rainwater harvesting systems with clean catchments, covered cisterns

and storage tanks, and treatment, as appropriate, supported by good hygiene at point of use, can offer drinking-water with very low health risk.

Rainwater is initially relatively free from impurities, except those picked up by the rain from the atmosphere. However, the quality of rainwater may subsequently deteriorate during harvesting, storage and household use. Wind-blown dirt, leaves, faecal droppings from birds and other animals, insects and litter on the catchment areas, such as roofs and in cisterns, can contaminate rainwater, as can particles from the atmosphere, such as soot from burning materials (e.g. old tyres). Regular cleaning of catchment surfaces and gutters should be undertaken to minimize the accumulation of debris. Wire meshes or inlet filters should be placed over the top of downpipes to prevent leaves and other debris from entering storage containers and cleaned regularly to prevent clogging.

Materials used in the catchment and storage tank should be approved for use in contact with drinking-water and should not leach contaminants or cause taste, odour or discoloration. As rainwater is slightly acidic and very low in dissolved minerals, it can dissolve metals and other impurities from materials of the catchment and storage tank, resulting in unacceptably high concentrations of contaminants in the water. Most solid roof materials are suitable for collecting rainwater, but roofs with bitumen-based coatings are generally not recommended, as they may leach hazardous substances or cause taste problems. Care should be taken to ensure that lead-based paints are not used on roof catchments. Thatched roofs can cause discoloration or deposition of particles in collected water.

Poor hygiene in water storage and abstraction from storage containers or at the point of use can also represent a health concern, but risks can be minimized by good design and practice. Faecal contamination is quite common, particularly in samples collected shortly after rainfall, but can be minimized by good practice. Higher microbial concentrations are generally found in the first flush of rainwater, decreasing as the rain continues; therefore, microbial contamination is less in rainy seasons when catchments are frequently washed with fresh rainwater. A system to divert the contaminated first flow of rainwater from roof surfaces is necessary, and automatic devices that prevent the first flush of runoff from being collected in storage are recommended. If diverters are not available, a detachable downpipe can be used manually to provide the same result.

Storage tanks can present breeding sites for mosquitoes, including species that transmit dengue virus (see section 8.6). Covers discourage mosquito breeding and help to prevent faecal contaminants and sunlight, which will promote algal growth, from reaching the water. Covers should be fitted, and openings need to be protected by mosquito-proof mesh. Cracks in the tank can result in contamination of stored water, whereas water withdrawal using contaminated containers is a potential cause of both faecal and chemical contamination. Storage containers should preferably be fitted with a mechanism such as a tap or outlet pipe that enables hygienic abstraction of water.

Further treatment at the point of consumption may be applied to ensure better quality of drinking-water and reduce health risk. Solar water disinfection and point-of-use chlorination are examples of low-cost disinfection options for the treatment

of stored rainwater. These and other household water treatment technologies are discussed in more detail in sections 7.3.2 (microbial) and 8.4.4 (chemical).

6.3 Vended water

Vended water is common in many parts of the world where scarcity of supplies or lack of infrastructure limits access to suitable quantities of safe drinking-water. Although water vending is more common in developing countries, it also occurs in developed countries.

In the context of these Guidelines, water vending implies private vending of drinking-water, but does not include bottled or packaged water (which is considered in section 6.14) or water sold in bottles through vending machines.

Water vending may be undertaken by formal bodies, such as water utilities or registered associations, by contracted suppliers or by informal and independent suppliers. Where formal vending is practised, the water typically comes from treated utility supplies or registered sources and is supplied in tankers or from standpipes and water kiosks. Informal suppliers tend to use a range of sources, including untreated surface water, dug wells and boreholes, and deliver small volumes for domestic use, often in containers loaded onto small carts or tanker trucks.

Both the quality and adequacy of vended supplies can vary significantly, and vended water has been associated with outbreaks of diarrhoeal disease (Hutin, Luby & Paquet, 2003). Water supplied to users should be suitable for drinking and comply with national or regional guidelines and regulatory requirements. The chemical and microbial quality of untreated or private sources of water should be tested to determine their suitability for use and to identify appropriate control measures, including treatment requirements. Surface water and some dug well and borehole waters are not suitable for drinking without treatment; disinfection is the minimum requirement, and filtration is often required when surface water is used.

In many developing countries, consumers purchase water from kiosks and then carry the water home in a variety of containers of varying size. Measures should be taken to protect vended water from contamination during transport as well as storage in the home, including transporting and storing water in containers that are clean, free from both faecal and chemical contamination and either enclosed or with narrow openings, ideally fitted with a dispensing device such as a spigot that prevents hand access and other sources of extraneous contamination. Good hygiene is required and should be supported by educational programmes.

In other cases, particularly in developed countries, vendors transport and deliver the water to users in tanker trucks. If large volumes are being transported, the addition of chlorine to provide a free residual concentration of at least 0.5 mg/l at the point of delivery to users is desirable. Tankers should also be used solely for water or, if this is not possible, should be thoroughly cleaned prior to use.

All components of systems associated with supplying and delivering vended water need to be designed and operated in a manner that protects water quality. Water storage containers, pipework and fittings should not include defects such as structural faults that allow leakage and permit the entry of contaminants. Cleanliness of storage containers, standpipes, taps and hoses needs to be maintained. Hoses used to transfer

water at kiosks or used on carts and tanker trucks should be protected from contamination (e.g. by preventing contact of the ends with the ground) and drained when not in use. The area around standpipes should include drainage or be constructed in a manner to prevent pooling of water. Materials used in all components, including pipework, containers and hoses, need to be suitable for use in contact with drinking-water and should not result in contamination of the water with hazardous chemicals or with substances that could adversely affect its taste.

All components of water vending, including sources, methods of abstraction and transport, should be incorporated into a WSP. Where vendors are registered or have a contract with a water utility, implementation and operation of the WSP should be regularly checked by the utility. WSPs and the operation of water vendors should also be subject to independent surveillance.

6.4 Bulk water supply

Bulk water supplies can be either untreated or treated water, but usually there is limited or no choice in the provision of such supplies. They may be provided where one agency or company controls a large raw water source, usually surface water, and provides water to one or several other water suppliers. Bulk water supplies can be delivered by pipeline or tanker or using ships or fleets of road or rail tankers.

In all cases, it is important that the bulk supply is incorporated into the WSP of the receiving supply and treated as another source. Where bulk supplies of treated water have been used to provide support during a drought or emergency, it is vital that the receiving supplier takes steps to ensure that the water is safe before it is introduced into the receiving distribution system. At all stages, it is important that there is close communication between all parties involved and that the procedures and requirements are documented, understood and carried out with appropriate monitoring and verification.

The potential hazards from bulk water are similar to those from any water supply, but there are additional sources of contamination, such as inappropriate containers and materials and lack of sanitation and hygiene at bulk water filling connections or transfer points. Pipelines may be vulnerable to contamination along the transmission route, particularly if there is the potential for unapproved connections into the system.

Many of the requirements for bulk supply are the same as for any piped supply, such as using approved materials that will not adversely affect water quality. Where tankers are used, these should be of a suitable material and be clean and free from microbial and chemical contamination. To minimize contamination during filling of bulk water containers or water tankers and charging of water transmission pipelines, sanitary inspections and maintenance of sanitary conditions for water filling stations are necessary. These sites should have proper drainage to avoid standing water and flooding, should not be exposed to sources of contamination and should be secure, with access restricted to authorized personnel. At water filling and delivery points, nozzles and couplings should be protected from sources of contamination, including animals. Installation of protective coverings for filling and receiving connectors would help in this respect. Some plastic pipe materials are permeable to organic chemicals,

and transfer of substances such as petroleum hydrocarbons could diminish the structural integrity of the pipe materials or render the water unpalatable to consumers. Such piping is most likely to be found in transfer hoses, so the cleanliness of the transfer points where tankers are used is vital, as is protection of the transfer area from spills of petroleum fuels.

Implementation of security measures to guard against intentional contamination and theft may also be warranted.

6.5 Desalination systems

Desalination is used to remove salts from brackish or saline surface water and groundwater in order to render it acceptable for human consumption or other uses. It is increasingly employed to provide drinking-water because of a growing scarcity of fresh water driven by population growth, overexploitation of water resources and climate change. Desalination facilities exist all over the world, particularly in the eastern Mediterranean region, with use increasing on all continents. Small-scale desalination is used to supply fresh water on ships and to provide additional fresh water in some hot and arid regions.

These Guidelines are fully applicable to desalinated water supply systems; however, desalination presents certain differences in emphasis, as summarized below.

Desalinated water has a very low total organic carbon content and low disinfectant demand, so disinfection by-products are generally of little concern, although brominated organics may occur owing to the presence of bromide in seawater. Membrane and distillation desalination processes are very efficient at removing higher molecular weight organic chemicals and virtually all inorganic chemicals, and volatile organic compounds are vented during thermal desalination processes. Where membranes are used, boron and some lower molecular weight organic substances may not be excluded, so it is important to establish the membrane capability. Because of the apparently high effectiveness of some of the processes used (especially distillation and reverse osmosis) in removing both microorganisms and chemical constituents, these processes may be employed as single-stage treatments or combined with only a low level of residual disinfectant. For further information, see the supporting document *Water treatment and pathogen control* (Annex 1). Pretreatment is largely in place to protect the desalination process, but it will also remove certain hazards present in brackish or saline waters.

Water produced by desalination is low in minerals and usually aggressive towards materials with which it comes into contact, such as materials used for distribution pipes, storage and plumbing. During post-treatment, the water must be stabilized or remineralized prior to distribution to reduce its corrosive nature. Stabilization is commonly achieved by adding chemical constituents such as calcium and magnesium carbonate along with pH adjustment or through blending with small volumes of mineral-rich waters. Seawater and spent seawater that has undergone electrolysis to form hypochlorite have been used for this purpose, but the latter practice has essentially ended because of the formation of bromate in the distributed water. Blending waters should be pretreated to ensure their microbial safety, because the post-desalination residual disinfectant level may be insufficient to control pathogens present in the blending water.

Desalinated water contains lower than usual concentrations of dissolved solids and essential elements such as calcium and magnesium, which are commonly found in water (see the supporting document *Calcium and magnesium in drinking-water*; Annex 1). Drinking-water typically contributes a small proportion to the recommended daily intake of essential elements, with most of the intake occurring through food. Fluoride would also be missing from desalinated water unless it were added prior to distribution, which may be considered by countries in which sugar consumption is high (WHO, 2005b).

High temperatures of distributed water in warm climate areas and difficulty in maintaining disinfectant residuals during transport over long distances may lead to microbial aftergrowth, depending on nutrient availability. Although such growth is likely to be without health significance (see the supporting document *Heterotrophic plate counts and drinking-water safety*; Annex 1), it can contribute to problems of acceptability. The use of chloramines constitutes an advantageous alternative to free chlorine in distribution systems with long residence times and elevated temperatures, although nitrite formation by organisms in biofilms needs to be considered where chloramination is practised and excess ammonia is present.

Extensive information on desalination for safe drinking-water supply is available in the book *Desalination technology: Health and environmental impacts* (Cotruvo et al., 2010) and the supporting document *Safe drinking-water from desalination* (Annex 1).

6.6 Dual piped water supply systems

In some locations, households and buildings served with a piped drinking-water supply may also receive piped water from an alternative source for non-potable purposes, creating a dual piped water supply system. The alternative water source is usually provided to reduce the use of high-quality water resources for non-potable uses (e.g. toilets, washing clothes, irrigation) or simply to conserve scarce water resources.

Non-potable piped supplies can potentially introduce health hazards, commonly through accidental cross-connections between potable and non-potable piped supplies. Measures to control health risks from dual piped supply systems include:

- use of good design practices that prevent cross-connections;
- unambiguous labelling of both systems to ensure that the non-potable supply is not mistaken for the potable supply;
- installation of the non-potable piped system only by qualified plumbers;
- regulation of non-potable piped systems by the authority responsible for drinking-water surveillance;
- public communication about the potential health risks from exposure to non-potable water through cross-connections and the dangers of modifying systems by inexperienced and non-certified individuals.

Increasingly in developed countries, dual systems are being installed at a household level or in public buildings. Guidance should be provided on installation, particularly where this is by non-certified individuals. Potable water supplied into the building should be fitted with a non-return valve in order to prevent backflow into the public water supply.

6.7 Emergencies and disasters

Safe drinking-water is one of the most important public health requirements in most emergencies and disasters, along with adequate sanitation. The greatest waterborne risk to health comes from the transmission of faecal pathogens as a result of inadequate sanitation, hygiene and protection of drinking-water sources. Some disasters, including those caused by or involving damage to chemical or nuclear industrial installations, spillage in transport or volcanic activity, may result in contamination by chemical or radiological hazards of concern. The circumstances of most large-scale emergencies will vary, and each will present its own peculiar problems and challenges.

Where a number of agencies are involved in disaster relief or overseeing an emergency, it is vital that there is good communication between the agencies and coordination of their activities. It is also important that the overall coordinators take advice from the experts in a particular field, such as water supply and sanitation. This section considers primarily large-scale disasters and emergencies, although much of the information will apply to smaller-scale emergencies as well. For microbiological and chemical emergencies on a smaller scale in piped supplies, the relevant sections in chapters 7 and 8 should be consulted.

When people are displaced by conflict and natural disaster, they may move to an area where unprotected water sources are contaminated. When population density is high and sanitation is inadequate, unprotected water sources in and around the temporary settlement are highly likely to become contaminated. A displaced population with low immunity due to malnutrition as a consequence of food shortages or the burden of other diseases is at an increased risk of an outbreak of waterborne disease.

Emergency planning initiatives should include three phases:

1) vulnerability assessments (which should be part of a WSP for any large supply) to identify the critical elements of the existing systems that, if compromised, would result in major disruption of basic services;
2) mitigation plans to identify feasible actions to prevent or reduce the disruptive effects related to the loss of the vulnerable elements or facilities;
3) emergency preparedness plans to facilitate managing the crisis and the restoration of service should disruptions occur.

The key is to anticipate probable events, have plans in place, prepare to respond when needed, have backup materials and facilities and have conducted simulations so that the organization and its staff will be effective in the event of an emergency.

Available sources of water are limited in most emergency situations, and providing a sufficient quantity of water for personal and domestic hygiene as well as for drinking and cooking is important. National drinking-water quality standards should therefore be flexible, taking into consideration the risks and benefits to health in the short and long term, and should not excessively restrict water availability for hygiene, as this would often result in an increased overall risk of disease transmission.

There are a number of factors to take into consideration when providing drinking-water for a population affected by a disaster, including the following:

- *The quantity of water available and the reliability of supply:* These are likely to be the overriding concerns in most emergency situations, as it is usually easier to improve water quality than to increase its availability or to move the affected population closer to another water source.
- *The equitability of access to water:* Even if sufficient water is available to meet minimum needs, additional measures may be needed to ensure that access is equitable. Unless water points are sufficiently close to their dwellings, people will not be able to collect enough water for their needs. Water may need to be rationed to ensure that everyone's basic needs are met.
- *Protecting the water source against contamination:* This should always be a priority in emergencies, whether or not disinfection of the water supply is considered necessary.
- *The need for disinfection:* Disinfection, maintaining an adequate disinfectant residual and, where necessary, pretreatment to reduce turbidity to as low as feasible in order to ensure the efficiency of disinfection are essential components in ensuring a safe drinking-water supply.
- *Longer-term planning for continuing emergency situations:* When the first phase of an emergency or disaster is over and the cleanup is in progress, consideration needs to be given to the longer-term provision of safe water and sanitation. In this case, pre-planning can be invaluable.
- *Acceptability:* It is important to ensure that drinking-water provided in emergencies is acceptable to the consumers in terms of taste, odour and appearance, or the consumers may resort to water from unprotected or untreated supplies.
- *The need for containers to collect and store water:* Containers that are hygienic and appropriate to local needs and habits are needed for the collection and storage of water to be used for washing, cooking and bathing.
- *The availability of bottled or packaged water:* Provision of bottled or packaged water from a reliable source is often an effective way to quickly provide safe, potable water in emergencies and disasters. Brewers and soft drink producers, if they are part of the emergency response plan, are often capable of converting their processes to produce bottled or packaged water in emergencies. This is particularly valuable if they have water treatment plants for ensuring the quality of water used as an ingredient in their processes.

In many emergency situations, water is collected from central water collection points, stored in containers and then transferred to cooking and drinking vessels by the affected people. It is important that people be aware of the risks to health from contamination of water from the point of collection to the moment of consumption and have the means to reduce or eliminate these risks. Detailed information may be found in Wisner & Adams (2003).

Water quality should be monitored during emergencies, including sanitary inspection and microbial water sampling and analysis; monitoring of water treatment processes, including disinfection; monitoring of water quality at all water collection points and in a sample of homes; and water quality assessment in the investigation of disease outbreaks or the evaluation of hygiene promotion activities, as required.

Monitoring and reporting systems should be designed and managed to ensure that action is swiftly taken to protect health. Health information should also be monitored to ensure that water quality can be rapidly investigated when it is suspected of contributing to a health problem and treatment processes, particularly disinfection, can be modified as required.

Where large numbers of water samples need testing or analysis of a broad range of parameters is of interest, laboratory analysis is usually most appropriate. If the drinking-water supplier's laboratories or laboratories at environmental health offices and universities no longer function because of the disaster, a temporary laboratory may need to be set up. Where samples are transported to laboratories, appropriate handling is important to ensure meaningful results. Portable testing kits allow the determination in the field of key water quality parameters, such as thermotolerant coliform count, free residual chlorine, pH, turbidity and filterability.

Workers should be trained in the correct procedures for collecting, labelling, packing and transporting samples and in supplying supporting information from the sanitary survey to help interpret laboratory results. For guidance on methods of water sampling and testing, see Bartram & Ballance (1996), WHO (1997) and APHA, AWWA & WEF (2005).

6.8 Temporary water supplies

A number of waterborne disease outbreaks have occurred as a result of poor management and design of temporary water supplies, which are distributed water supplies for planned seasonal or time-limited events (e.g. festivals, markets and summer camps). Water supplies for holiday towns are not covered, because they are permanent supplies, although substantial seasonal variations in demand bring specific problems.

A systematic approach to drinking-water safety, including adequate quantity and quality, is needed for temporary water supplies. A WSP is an essential requirement in identifying the hazards and risks and developing good management procedures to deal with them. Chapter 4 and other sections in chapter 6 provide additional useful information. Where water is supplied through tankers, the requirements are the same as for vended water (section 6.3) and bulk water supplies (section 6.4).

A temporary water supply may be independent (i.e. not connected to any other water supply system and with its own facilities from source to tap) or dependent (i.e. receiving treated water from an existing water supply system but with independent distribution facilities). The risk of drinking-water contamination is usually lower in dependent systems, provided there is access to the technologies, expertise and management of the permanent system. A contract is often made between the organizer of an event (e.g. a festival) and a water supply entity, which should include the water quantity and quality supplied by the entity, the roles and responsibilities of each party in water quality management, the locations and frequency of water quality monitoring, sanitary inspection and surveillance by a health authority and the provision of adequate and properly sited sanitation. Coordination between an event organizer, a water supply entity and the relevant health authority is very important for ensuring drinking-water safety.

Temporary water supply systems can vary substantially in terms of their scale, period of operation, water use and fluctuations in demand, and these variations should be taken into consideration during the planning and design stages. In the case of an independent system, adequate consideration should also be given to the selection of a water source in terms of quantity, quality and treatment processes, and care should be taken not to adversely affect any other supply or water source. Where a temporary system is directly connected to a mains water supply, it is important to prevent the accidental contamination of the mains water supply through backflow during construction and operation of the temporary system. Water consumption for firefighting, hand washing and toilet flushing should be taken into account in estimating total and predictable variations in water demand where there are no other water sources available for such purposes.

Water quality targets for temporary supplies should be the same as those for permanent water supplies. Disinfection should be considered indispensable in a temporary supply, and it is preferable to maintain a certain level of disinfectant (e.g. chlorine) residual at service taps. If the supply is not for potable uses, appropriate action should be taken to ensure that it is not used for drinking.

If a temporary water supply is used recurrently, it is essential to fully flush the entire system with water containing a higher than normal disinfectant residual before restarting. When planning installation on site, positioning of pipes, hoses and connections should take risks of contamination into account—for example, by avoiding the placement of hosing and fittings on the ground near sites of potential faecal contamination or storage tanks in direct sunlight where rising temperatures support microbial growth. It is also important to ensure that the facility has no defects, including leakage, that could cause the deterioration of water quality and that water quality at every service tap satisfies the required quality target. Important control measures during dismantling and transport of installations include emptying hoses, preferably drying them and storing them so that ingress of contamination is avoided. In all cases, the materials should be approved for use in contact with potable water.

Care should be taken in planning and designing wastewater management and disposal facilities, particularly to ensure that lavatories and disposal facilities are located so as to avoid any risk of adversely affecting source water quality or stored water. It is also important to prevent runoff from other areas, such as livestock pens, from entering the source. The source, treatment facilities and distribution reservoirs should be well protected from access by animals (e.g. bird faeces) and humans by covers or roofs.

A temporary system is usually more vulnerable to accidental and deliberate contamination than an existing permanent water supply system, and attention needs to be paid to security. All water treatment facilities should be thoroughly inspected at least every day. All of these procedures and requirements should be included in the operational management documents that are at the core of the WSP.

Signs are an important part of ensuring that water from taps is used appropriately and the protection of water sources and drinking-water infrastructure. The signs should be easily understood and used in conjunction with other barriers, such as fences.

Water quality and appearance should be routinely monitored at the service taps of a temporary water supply system. At the very least, water temperature and disinfectant residual should be monitored every day as simple rapid tests that act as indicators of possible problems. Other basic parameters that should be regularly monitored, if possible, include pH, conductivity, turbidity, colour and *Escherichia coli* (or, alternatively, thermotolerant coliforms). Routine sanitary inspection of a temporary water supply by the appropriate health authority is very important. If any problem related to water quality arises, remedial actions that are included in the management documents supporting the WSP should be taken promptly. If a temporary water supply system is to be used for a period of more than a few weeks, regular surveillance by the appropriate health authority should be implemented.

6.9 Buildings[1]

Drinking-water systems in buildings can be a significant source of contamination, and poor management of these systems has contributed to outbreaks of disease and illness. One of the challenges in ensuring water safety is that responsibility for many actions essential to the control of drinking-water quality in buildings is often outside the mandate of the drinking-water supplier. Roles and responsibilities of different stakeholders relating to the safe management of drinking-water systems within buildings can be influenced by a number of factors, including ownership of assets and rights of access. WSPs established for management of public water supplies are not typically extended to buildings, although the water supplier WSP may include a number of initiatives to ensure that backflow prevention is in place or to provide information to consumers on protecting their own water quality. In many cases, owners, managers or maintenance personnel are responsible for managing building water supplies, but awareness and application of drinking-water guidelines are often limited, and so educational supporting programmes may be required.

The design of water networks in buildings is variable, as influenced by the diversity of building types (e.g. schools, child-care facilities, residential buildings, hotels, sports facilities, factories, office blocks, museums, transport terminals), designs and water uses. Drinking-water systems in buildings are typically divided into hot and cold water networks and may be connected to water-based devices (e.g. cooling towers, boilers, swimming pools) or point-of-use equipment (e.g. washing machines).

General drinking-water safety is ensured by good management practices, including sound design, routine maintenance protocols, regular cleaning, temperature management and flow management (avoidance of stagnation). These practices should be incorporated in WSPs developed by building owners or managers. WSPs for buildings should address cold and hot drinking-water networks and consider water-based devices and point-of-use equipment. Regulatory or other appropriate authorities may provide guidance on the development and application of WSPs for drinking-water systems in buildings.

[1] Hospitals, nursing care homes and other health-care facilities are discussed in section 6.10.

The regulator can specify compliance requirements for buildings in general or for specific types of buildings based on the level of risk. Schools, hotels and some other large buildings are high-risk environments because of both the complex nature of their drinking-water systems and the vulnerability of some users, occupants and visitors, and heightened vigilance in terms of operational monitoring, validation of control measures and verification is generally justified. Compliance may require that maintenance and monitoring programmes be carried out through a building-specific WSP. It may be appropriate to display maintenance and monitoring programmes and certification of compliance at a conspicuous location within the building. Compliance could be verified and certified by an independent auditor.

The principal hazard that may threaten drinking-water systems of buildings is ingress of contamination from external water supplies or through faults in the distribution system (including storage tanks). Unapproved and inappropriate fittings and materials can lead to the release of chemical substances from tanks, piping, jointing and plumbing materials. The release may vary with the age of the material and the contact period; for example, first-draw water contains higher concentrations of lead or copper. Cross-connections with chemical storage containers, backflow from point-of-use equipment and cross-connections with non-potable supplies can lead to a range of contaminants entering drinking-water.

Where water is supplied directly to equipment in buildings, the potential for backflow into the mains network exists. This may be driven by high pressures generated in equipment connected to mains water supplies or by low pressures in the mains, but it can be prevented by fitting appropriate backflow prevention devices.

An additional problem not directly related to drinking-water is microbial growth (e.g. *Legionella*) on surfaces and in water-based devices that may lead to an inhalation hazard from spray droplets. Growth of such bacteria can be controlled through basic measures (e.g. maintaining water outside the range at which *Legionella* proliferate, i.e. > 50 °C for hot water and < 25 °C for cold water, or maintaining a suitable disinfectant residual). Poor temperature control can occur in cold water systems through inadequate insulation and separation from hot water systems and in hot water systems in heating devices and storage containers, inappropriate location of tempering devices, long branch mains and dead ends (i.e. lengths of pipe, closed at one end, through which no water passes). In large buildings, there is increased potential for growth of *Legionella* in long water distribution systems, and maintenance of these systems needs particular attention. For further information on *Legionella* in drinking-water, see section 11.1 and the supporting document *Legionella and the prevention of legionellosis* (Annex 1).

Effective assessment of potential health hazards and risks requires documentation of the physical structure of water systems in buildings. This should be kept up to date and include hot and cold water networks, including materials used; point-of-entry treatment; point-of-use treatment, equipment and systems (e.g. for firefighting) connected to the drinking-water supply; and water-based devices supplied by the drinking-water system.

In undertaking an assessment of the building's distribution system, a range of specific issues must be taken into consideration that relate to ingress, introduction and proliferation of contaminants, including:

- the quality and management of external supplies;
- use of independent water supplies;
- intermittent supplies;
- pressure of water within the system;
- temperature of water (in both cold and hot water systems);
- integrity of storage tanks;
- areas subject to intermittent or seasonal use (e.g. hotels with seasonal occupancy, schools);
- cross-connections, especially in mixed systems;
- backflow prevention;
- system design to minimize dead/blind ends and other areas of potential stagnation;
- the use of materials and coatings approved for use with drinking-water.

The aim of a distribution system within a large building is to supply safe drinking-water at adequate pressure and flow. The quality of water entering building supplies will be ensured by a water utility or by the installation of point-of-entry devices typically managed by the building owner or operator. To maintain drinking-water quality, it is important to minimize transit times, low flows and low pressures.

Procedures should be established for repairs, renovations or extensions of systems to ensure that water safety is maintained, and all work, including changes to water systems, should be documented. Following work on the system, it would be appropriate to disinfect and flush.

Monitoring should focus on ensuring that control measures are working effectively. Where possible, this should include monitoring by maintenance personnel using field kits for parameters such as temperature, pH and disinfectant residuals. The frequency will vary depending on the size and use of the building, but it should be weekly in large buildings. Monitoring of drinking-water quality will be more frequent when the building is new or recently commissioned.

Independent surveillance is a desirable element in ensuring continued water safety within buildings and should be undertaken by the relevant health agency or other independent authority.

To ensure the safety of drinking-water within buildings, supportive activities of national regulatory agencies include:

- specific attention to application of codes of good practice (e.g. at commissioning and in contracting construction and rehabilitation);
- suitable education and training programmes for building owners and managers, engineers, plumbers and operators of water-based devices (e.g. cooling towers and evaporative condensers);
- regulation of the plumbing community and use of certified professionals;
- effective certification and use of materials and devices in the marketplace;
- codes of practice for design and operation of water-based devices.

For further guidance, see the supporting document *Water safety in buildings* (Annex 1).

6.10 Health-care facilities

Health-care facilities include hospitals, health centres and hospices, residential care, dental surgeries and dialysis units. Drinking-water in such facilities should be suitable for human consumption and for all usual domestic purposes, including personal hygiene. However, it may not be suitable for all uses or for some patients, and further processing or treatment or other safeguards may be required.

Although microorganisms such as *Pseudomonas aeruginosa* and mycobacteria, *Acinetobacter*, *Aeromonas* and *Aspergillus* species do not appear to represent a health concern through water consumption by the general population, including most patients in health-care facilities, they may be of concern for severely immunosuppressed persons, such as those with neutrophil counts below 500 per microlitre (see the supporting document *Heterotrophic plate counts and drinking-water safety*; Annex 1). Some of these microorganisms also have the potential to cause infections if drinking-water is used to wash burns or medical devices such as endoscopes and catheters. Water used for such purposes may require additional processing, such as microfiltration or sterilization, depending on use.

Health-care facilities may include environments that support the proliferation and dissemination of *Legionella* (see section 11.1 and the supporting document *Legionella and the prevention of legionellosis*; Annex 1). Some equipment, such as water-cooled high-speed drills in dental surgeries, is of particular concern for both inhalation of droplets and infection of wounds.

Renal dialysis requires large volumes of water that is of higher quality than drinking-water. Water used for dialysis requires special processing to minimize the presence of microorganisms, endotoxins, toxins and chemical contaminants. There are special requirements regarding aluminium, which, in the past, has caused dialysis dementia, and dialysis patients are also sensitive to chloramines, which needs to be considered when chloramination is used to disinfect drinking-water supplies, particularly in areas where there are home dialysis patients.

All health-care facilities should have specific WSPs as part of their infection control programme. These plans should address issues such as water quality and treatment requirements, cleaning of specialized equipment and control of microbial growth in water systems and ancillary equipment.

6.11 Safe drinking-water for travellers

The most common sources of exposure to disease-causing organisms for travellers are contaminated drinking-water and food that has been washed with contaminated water. Diarrhoea is the most common symptom of waterborne infection, affecting 20–50% of all travellers or about 10 million people per year. Cases can occur even among people staying in high-quality resorts and hotels. In some parts of the world, tap or bottled water that has not been produced under proper conditions may not be safe, even if it is clear and colourless.

No vaccine is capable of conferring general protection against infectious diarrhoea, which is caused by many different pathogens. It is important that travellers be aware of the possibility of illness and take appropriate steps to minimize the risks. Preventive measures while living or travelling in areas with questionable drinking-water quality include the following:

- Drink only bottled water or other beverages (carbonated beverages, pasteurized juices and milk) provided in sealed tamper-proof containers and bottled/canned by known manufacturers (preferably certified by responsible authorities). Hotel personnel or local hosts are often good sources of information about which local brands are safe.
- Drink water that has been treated effectively at point of use (e.g. through boiling, filtration or chemical disinfection) and stored in clean containers.
- Drink hot beverages such as coffee and tea that are made with boiled water and are kept hot and stored in clean containers.
- Avoid brushing teeth with unsafe water.
- Do not use ice unless it has been made from safe water.
- Avoid salads or other uncooked foods that may have been washed or prepared with unsafe water.

Water can be treated in small quantities by travellers to significantly improve its safety. Numerous simple treatment approaches and commercially available technologies are available to travellers to disinfect drinking-water for single-person or family use. Travellers should select a water treatment approach that removes or inactivates all classes of pathogens. Technologies should be certified by a credible organization, and manufacturers' instructions should be followed carefully.

Bringing water to a rolling boil is the simplest and most effective way to kill all disease-causing pathogens, even in turbid water and at high altitudes. The hot water should be allowed to cool without the addition of ice. If the water is turbid and needs to be clarified for aesthetic reasons, this should be done before boiling.

If it is not possible to boil water, chemical disinfection of clear, non-turbid water is effective for killing bacteria and most viruses and some protozoa (but not, for example, *Cryptosporidium* oocysts). Certain chlorine-based or iodine-based compounds are most widely used for disinfection of drinking-water by travellers. Following chlorination or iodination, an activated carbon (charcoal) filter may be used to remove excess taste and odour from the water. The use of iodine is not recommended for long-term use by infants, pregnant women, those with a history of thyroid disease and those with known hypersensitivity to iodine unless treatment includes an effective post-disinfection iodine removal device (e.g. activated carbon). Travellers intending to use iodine treatment daily for all water consumed for more than 3–4 weeks should consult a physician beforehand and not use it in excessive amounts. Silver is sometimes promoted as a disinfectant, but it is not recommended, as its efficacy is uncertain and it requires lengthy contact periods.

Suspended particles in water can reduce the effectiveness of disinfectants, and turbid water should be clarified or filtered before disinfection. Chemical products that

combine clarification (coagulation and flocculation to remove particles) with chlorine disinfection are available.

Portable point-of-use filtration devices tested and rated to remove protozoa and some bacteria, such as ceramic, membrane (mainly reverse osmosis) and activated carbon block filters, are also available. A pore size rating of 1 μm or less is recommended to ensure the removal of *Cryptosporidium* oocysts. These filters may require a pre-filter to remove suspended particles in order to avoid clogging the final filter.

Unless water is boiled, a combination of techniques (e.g. clarification and/or filtration followed by chemical disinfection) is recommended. This combination provides a multiple treatment barrier that removes significant numbers of protozoa in addition to killing bacteria and viruses.

For people with weakened immune systems, pregnant women and infants, extra precautions are recommended to reduce the risk of infection from water contaminated with *Cryptosporidium*, for example. Boiling and storing water in a protected container are recommended, although internationally or nationally certified bottled or mineral water may also be acceptable.

The treatment methods described here, with the exception of carbon filtration and reverse osmosis, will generally not reduce levels of most chemical contaminants in drinking-water. However, these are not usually of health concern in the short term.

Further information on household water treatment of microbial and chemical contaminants of water can be found in sections 7.3.2 and 8.4.4, respectively. Table 6.1 provides a summary of drinking-water disinfection methods that can be used by travellers.

6.12 Aircraft and airports

The importance of water as a potential vehicle for infectious disease transmission on aircraft has been well documented. In general terms, the greatest microbial risks are those associated with ingestion of water that is contaminated with human and animal excreta. If the source of water used to replenish aircraft supplies is contaminated and adequate precautions are not taken, disease can be spread through the aircraft water if it is used for drinking or tooth cleaning. It is thus imperative that airports comply with the International Health Regulations (2005) and be provided with potable drinking-water from a source approved by the appropriate regulatory agency (WHO, 2005a). Airports usually have special arrangements for managing water after it has entered the airport.

A potable water source is not a safeguard if the water is subsequently contaminated during transfer, storage or distribution in aircraft. A WSP covering water management within airports from receipt of the water through to its transfer to the aircraft (e.g. by water servicing vehicles or water bowsers), complemented by measures to ensure that water quality is maintained on the aircraft (e.g. safe materials and good practices in design, construction, operation and maintenance of aircraft systems), provides a framework for water safety in aviation.

In undertaking an assessment of the general airport/aircraft water distribution system, a range of specific issues must be taken into consideration, including:

Table 6.1 Drinking-water disinfection methods for use by travellers

Method	Recommendation	What it does	What it does *not* do
Boiling	Bring water to a rolling boil and allow to cool	Kills all pathogens	Does not remove turbidity/cloudiness Does not provide residual chemical disinfectant, such as chlorine, to protect against contamination
Chlorine compounds: 1. Unscented household bleach (sodium hypochlorite) 2. Sodium dichloroisocyanurate tablet 3. Calcium hypochlorite	For typical room temperature and water temperature of 25 °C, minimum contact time should be 30 min; increase contact time for colder water—e.g. double time for each 10 °C less than 25 °C Prepare according to instructions Should be added to clear water or after settling or clarification to be most effective Type and typical dosage: 1. Household bleach (5%)—4 drops per litre 2. Sodium dichloroisocyanurate—1 tablet (per package directions) 3. Calcium hypochlorite (1% stock solution)[a]—4 drops per litre	Effective for killing most bacteria and viruses Longer contact time required to kill *Giardia* cysts, especially when water is cold	Not effective against *Cryptosporidium*; not as effective as iodine when using turbid water
Flocculant-chlorine tablet or sachet	Dose per package directions	Effective for killing or removing most waterborne pathogens (coagulant-flocculants partially remove *Cryptosporidium*)	Flocculated water must be decanted into a clean container, preferably through a clean fabric filter

Table 6.1 (continued)

Method	Recommendation	What it does	What it does *not* do
Iodine: 1. Tincture of iodine (2% solution) 2. Iodine (10% solution) 3. Iodine tablet 4. Iodinated (triiodide or pentaiodide) resin	25 °C—minimum contact for 30 min; increase contact time for colder water Prepare according to package instructions Type and typical dosage: 1. Tincture of iodine (2% solution)—5 drops per litre 2. Iodine (10% solution)—8 drops per litre 3. Iodine tablet—1 or 2 tablets per litre 4. Iodinated (triiodide or pentaiodide) resin—room temperature according to directions and stay within rated capacity *Caution:* Not recommended for pregnant women, for people with thyroid problems or for more than a few months' time. Excess iodine may be removed after iodine treatment through use of a carbon filter or other effective process.	Kills most pathogens Longer contact time is required to kill *Giardia* cysts, especially when water is cold Carbon filtration after an iodine resin will remove excess iodine from the water; replace the carbon filter regularly	Not effective against *Cryptosporidium*
Portable filtering devices: 1. Ceramic filters 2. Carbon filters; some carbon block filters will remove *Cryptosporidium*—only if tested and certified for oocyst removal 3. Membrane filter (microfilter, ultrafilter, nanofilter and reverse osmosis) type devices	Check pore size rating and reported removal efficiencies for different pathogens (viruses, bacteria and protozoa) provided by manufacturer and certified by a national or international certification agency. Filter media pore size must be rated at 1 µm (absolute) or less. Note that water must be clear to prevent clogging of pores. Filtration or settling of turbid water to clarify it is recommended before disinfection with chlorine or iodine if water is not boiled	1 µm or less filter pore size will remove *Giardia*, *Cryptosporidium* and other protozoa Approved reverse osmosis device can remove almost all pathogens Some filters include a chemical disinfectant such as iodine or chlorine to kill microbes; check for manufacturer's claim and documentation from an independent national or international certification agency	Most bacteria and viruses will not be removed by filters with a pore size larger than 1 µm Microfilters may not remove viruses, especially from clear waters; additional treatment such as chemical disinfection or boiling/pasteurization may be needed to reduce viruses Most carbon block filters do not remove pathogens, other than possibly protozoa, even if carbon is impregnated with silver, because pore size is too large (> 1 µm)

[a] To make a 1% stock solution of calcium hypochlorite, add (to 1 litre of water) 28 g if chlorine content is 35%, 15.4 g if chlorine content is 65% or 14.3 g if chlorine content is 70%.

- quality of source water and the need for additional treatment;
- design and construction of airport storage tanks and pipes;
- design and construction of water servicing vehicles;
- use of materials and fittings approved for contact with drinking-water at all stages;
- water loading techniques;
- any treatment systems on aircraft (e.g. ultraviolet disinfection);
- maintenance of on-board plumbing;
- prevention of cross-connections, including backflow prevention.

The airport authority has responsibility for safe drinking-water supply, including operational monitoring, until water is transferred to the aircraft operator. The primary emphasis of monitoring is to ensure that management processes are operating efficiently—for example, the source water quality is not compromised; all parts of the system, including hydrants, hoses and bowsers, are clean and in good repair; backflow prevention is in place; and any filters are clean. In addition, the system should be disinfected and flushed after maintenance or repairs, and the microbiological quality of the water should be checked, preferably before the system is returned to service.

Transfer of water into the aircraft and the aircraft drinking-water system also has the potential to introduce hazards, even if the water is of good quality up to this point. It is therefore important that staff involved be properly trained and understand the reasons for the precautions to be taken and the care required in preventing contamination. The precautions described in previous sections regarding transfer of drinking-water from a piped supply or from bowsers and tankers are essential, including maintaining the cleanliness of vehicles and transfer points. There is a significant potential for aviation fuel to contaminate the system, and only small quantities of low molecular weight hydrocarbons can cause the water to be unacceptable. In addition, staff employed in drinking-water supply must not be engaged in activities related to aircraft toilet servicing without first taking all necessary precautions (e.g. thorough hand washing, change of outer garments). All of these requirements and procedures should be properly documented as part of the WSP for the airport water transfer system and should be made clear to airlines using the airport to ensure that they play their part as key stakeholders.

Independent surveillance is an important part of the WSP, because circumstances and equipment or staff may change, and the weakening of barriers or the introduction of new risks may not be noticed. This would include initial review and approval of the WSP, periodic review and direct assessment of the provisions and operation of the WSP, paying specific attention to the aircraft industry's codes of practice, the supporting document *Guide to hygiene and sanitation in aviation* (Annex 1) and airport health or airline regulations. It is also important that the response to any incident is recorded and reviewed and any lessons learnt incorporated into the WSP.

6.13 Ships

The importance of water as a vehicle for infectious disease transmission on ships has been clearly documented. In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with human and animal excreta. However,

chemical contamination could also occur on ships as a result of contaminated bulk water being brought aboard in port, cross-connections on board or improper on-board treatment. The supporting document *Guide to ship sanitation* (Annex 1) describes the factors that can be encountered during water treatment, transfer, production, storage or distribution in ships and specific features of the organization of the supply and the regulatory framework. To this end, it is vital that all staff responsible for working with the potable water system are properly trained.

The organization of water supply systems covering shore facilities and ships differs considerably from conventional water transfer on land but is similar to that for airports. The port authority has responsibility for providing safe potable water for loading onto vessels. If water is suspected to have come from an unsafe source, the ship's master may have to decide if any additional treatment (e.g. hyperchlorination or filtration) is necessary. When treatment on board or prior to boarding is necessary, the treatment selected should be that which is best suited to the water and which is most easily operated and maintained by the ship's officers and crew.

Water is delivered to ships by hoses or transferred to the ship via water boats or barges. The transfer from shore to ship is a potential source of microbial or chemical contamination. In addition to shore-to-ship transfer of water and bulk storage on board ship, many ships use desalination (see section 6.4) to produce their own drinking-water.

In contrast to a shore facility, plumbing aboard ships consists of numerous piping systems carrying potable water, seawater, sewage and fuel and fitted into a relatively confined space. Piping systems are normally extensive and complex, making them difficult to inspect, repair and maintain. A number of waterborne outbreaks on ships have been caused by contamination of potable water after it had been loaded onto the ship—for example, by sewage or bilge water when the water storage systems were not adequately designed and constructed. Potable water should be stored in one or more tanks that are constructed, located and protected so as to be safe against contamination. Potable water lines should be protected and located so that they will not be submerged in bilge water or pass through tanks storing non-potable liquids. It is important to design the system to prevent deterioration of water quality during distribution by minimizing stagnation and dead ends and to take into account ship movement, which increases the possibility of surge and backflow.

An overall assessment of the operation of the ship's water supply should be made, for which the final responsibility lies with the ship's master, who must ensure that all of the management processes in place are functioning efficiently. An important part of this process is ensuring that those crew who are responsible for the fresh drinking-water supply are properly trained and receive refresher training as appropriate. In developing a WSP and ensuring that the system is capable of supplying safe water, the following need to be considered:

- quality of source water if this is from a shore-based source along with the equipment and method of transfer from shore to ship;
- desalination equipment and processes where these are used, taking into consideration the points raised in section 6.5;

- design and construction of storage tanks and pipework, including the use of approved materials and chemicals and clear colour coding of pipes for different purposes;
- minimization of dead ends and areas of stagnation, which may be managed by periodic flushing;
- filtration systems and other treatment systems on board the ship, including disinfection and delivery of residual disinfection;
- prevention of cross-connections and presence of working backflow prevention devices;
- maintenance of adequate water pressure within the system;
- presence of a disinfectant residual throughout the system.

The system needs to be checked regularly for cleanliness and repair, and parameters such as pH and disinfectant residual need to be checked daily. Where possible, checks on microbiological quality such as plate counts and faecal coliforms, even if only in port, help to ensure that the supply continues to deliver safe water. There also need to be suitable procedures in place to ensure safety after maintenance or repair, including specific disinfection of the system or the affected zone. Any indication of a problem, such as illness or taste or odour problems, should be immediately investigated and the system corrected if it is shown to be the source. In confined communities such as on ships, person-to-person spread of infectious disease is a major issue. Someone who has been working on the latrines and sanitation system on ships should not transfer to work on the drinking-water system without thorough hand washing and a change of outer clothing.

Independent surveillance is a desirable element in ensuring drinking-water safety on ships. This implies that there will be periodic audit and direct assessment and the review and approval of the WSP. Specific attention should be given to the shipping industry's codes of practice, the supporting document *Guide to ship sanitation* (Annex 1) and port health and shipping regulations. Independent surveillance should also include ensuring that any specific incidents that affect or might have affected water quality have been properly investigated and the lessons to be learnt are incorporated in the WSP.

6.14 Packaged drinking-water

Bottled water and water in containers are widely available in both industrialized and developing countries. Consumers purchase packaged drinking-water for reasons such as taste, convenience or fashion, but safety and potential health benefits are also important considerations.

Water is packaged for consumption in a range of vessels, including cans, laminated boxes and plastic bags, but it is most commonly supplied in glass or plastic bottles. Bottled water also comes in various sizes, from single servings to large carbuoys holding up to 80 litres. Control of the quality of materials, containers and closures for bottled water is of special concern. Ozone is sometimes used for final disinfection prior to bottling because it does not impart a taste to the water. If the water contains naturally occurring bromide, this can lead to the formation of bromate unless care is taken to minimize its formation.

The Guidelines provide a basis for derivation of standards for all packaged waters. As with other sources of drinking-water, safety is pursued through a combination of safety management and end product quality standards and testing and is more readily achievable because batches can be held until results are available. The international framework for packaged water regulation is provided by the Codex Alimentarius Commission of the World Health Organization and the Food and Agriculture Organization of the United Nations.

The Codex Alimentarius Commission has developed a *Standard for natural mineral waters*—which describes the product and its compositional and quality factors, including prescribed treatments, limits for certain chemicals, hygiene, packaging and labelling—and an associated Code of Practice. It has also developed a *Standard for bottled/packaged waters* to cover packaged drinking-water other than natural mineral waters. Both relevant Codex standards refer directly to these Guidelines; the Codex standards for bottled/packaged water are directly equivalent to the guideline values established in these Guidelines. Under the Codex *Standard for natural mineral waters* and associated Code of Practice, natural mineral waters must conform to strict requirements, including collection and bottling without further treatment from a natural source, such as a spring or well. In comparison, the Codex *Standard for bottled/packaged waters* includes waters from other sources, in addition to springs and wells, and treatment to improve their safety and quality. The distinctions between these standards are especially relevant in regions where natural mineral waters have a long cultural history. For further information on the Codex *Standard for natural mineral waters* and its companion Code of Practice and the Codex *Standard for bottled/packaged waters*, readers are referred to the Codex web site (http://www.codexalimentarius.net/).

The Codex Alimentarius Commission's *Code of practice for collecting, processing and marketing of natural mineral waters* provides guidance on a range of good manufacturing practices and provides a generic WSP applied to packaged drinking-water.

Some consumers believe that certain natural mineral waters have medicinal properties or offer other health benefits. Some such waters have higher mineral content, sometimes significantly higher than concentrations normally accepted in drinking-water. They often have a long tradition of use and are often accepted on the basis that they are considered foods rather than drinking-water per se. Although certain mineral waters may be useful in providing essential micronutrients, such as calcium and magnesium, these Guidelines do not make recommendations regarding minimum concentrations of essential elements because of the uncertainties surrounding mineral nutrition from drinking-water. Packaged waters with very low mineral content, such as distilled or demineralized waters, are also consumed. There is insufficient scientific information on the benefits or hazards of long-term consumption of very low mineral waters to allow any recommendations to be made (WHO, 2005b; see also the supporting document *Calcium and magnesium in drinking-water*; Annex 1).

Another form of packaged water is ice that is intended for adding to drinks and which may come into contact with food to be eaten without cooking. Ice prepared and sold in this manner should be treated the same as any packaged water for potable use.

6.15 Food production and processing

The quality of water defined by the Guidelines is such that it is suitable for all normal uses in the food industry. Some processes have special water quality requirements in order to secure the desired characteristics of the product, and the Guidelines do not necessarily guarantee that such special requirements are met.

Poor quality drinking-water may have a severe impact in food processing and potentially on public health. The consequences of a failure to use water of suitable quality in food processing will depend on the use of the water and the subsequent processing of potentially contaminated materials. Variations in water quality that may be tolerated occasionally in drinking-water supply may be unacceptable for some uses in the food industry. These variations may result in a significant financial impact on food production—for example, through product recalls.

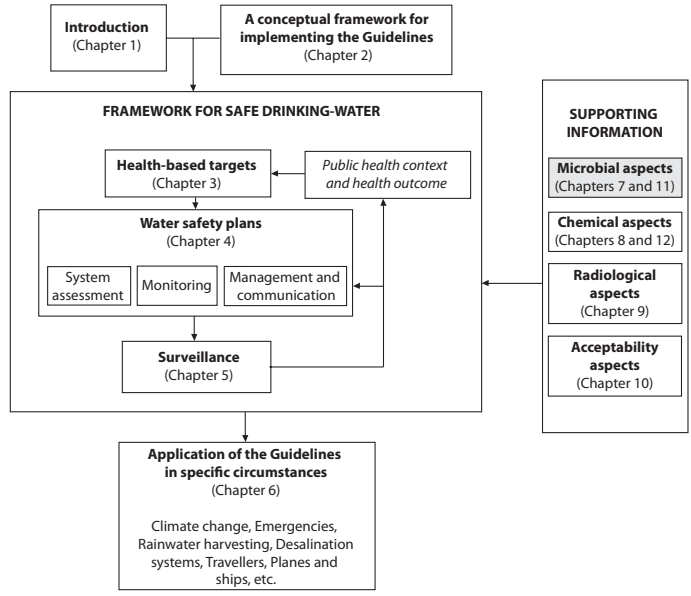
The diverse uses of water in food production and processing have different water quality requirements. Uses include irrigation and livestock watering; as an ingredient or where used in washing or "refreshing" of foods, such as misting of salad vegetables in grocery stores; and those in which contact between the water and foodstuff should be minimal (as in heating or cooling and cleaning water).

To reduce microbial contamination, specific treatments (e.g. heat) capable of removing a range of pathogenic organisms of public health concern may be used in food processing. The effect of these treatments should be taken into account when assessing the impacts of deterioration in drinking-water quality on a food production or processing facility. For example, water that is used in canning will usually be heated to a temperature that is at least equivalent to pasteurization.

Information on deterioration of the microbial or chemical quality of a drinking-water supply should be promptly communicated to food and beverage production facilities.

For further information on disinfection of water for use in food production and processing, see FAO/WHO (2009).

7
Microbial aspects



The greatest risk to public health from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant.

This chapter focuses on organisms for which there is evidence, from outbreak studies or from prospective studies in non-outbreak situations, of diseases being caused by ingestion of drinking-water, inhalation of water droplets or dermal contact with drinking-water and their prevention and control. For the purpose of the Guidelines, these routes are considered waterborne.

Chapter 11 (Microbial fact sheets) provides additional detailed information on individual waterborne pathogens, as well as on indicator microorganisms.

7.1 Microbial hazards associated with drinking-water

Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g. protozoa and helminths) are the most common and widespread health risk associated with drinking-water. The public health burden is determined by the severity and incidence of the illnesses associated with pathogens, their infectivity and the population exposed. In vulnerable subpopulations, disease outcome may be more severe.

Breakdown in water supply safety (source, treatment and distribution) may lead to large-scale contamination and potentially to detectable disease outbreaks. In some cases, low-level, potentially repeated contamination may lead to significant sporadic disease, but public health surveillance is unlikely to identify contaminated drinking-water as the source.

Infectious diseases caused by pathogenic bacteria, viruses, protozoa and helminths are the most common and widespread health risk associated with drinking-water.

Waterborne pathogens have several properties that distinguish them from other drinking-water contaminants:

- Pathogens can cause acute and also chronic health effects.
- Some pathogens can grow in the environment.
- Pathogens are discrete.
- Pathogens are often aggregated or adherent to suspended solids in water, and pathogen concentrations vary in time, so that the likelihood of acquiring an infective dose cannot be predicted from their average concentration in water.
- Exposure to a pathogen resulting in disease depends upon the dose, invasiveness and virulence of the pathogen, as well as the immune status of the individual.
- If infection is established, pathogens multiply in their host.
- Certain waterborne pathogens are also able to multiply in food, beverages or warm water systems, perpetuating or even increasing the likelihood of infection.
- Unlike many chemical agents, pathogens do not exhibit a cumulative effect.

Quantitative microbial risk assessment (QMRA), a mathematical framework for evaluating infectious risks from human pathogens, can assist in understanding and managing waterborne microbial hazards, especially those associated with sporadic disease.

7.1.1 Waterborne infections

The pathogens that may be transmitted through contaminated drinking-water are diverse in characteristics, behaviour and resistance. Table 7.1 provides general information on pathogens that are of relevance for drinking-water supply management. Waterborne transmission of the pathogens listed has been confirmed by epidemiological studies and case histories. Part of the demonstration of pathogenicity involves reproducing the disease in suitable hosts. Experimental studies in which healthy adult volunteers are exposed to known numbers of pathogens provide information, but these data are applicable to only a part of the exposed population; extrapolation to more vulnerable subpopulations is an issue that remains to be studied in more detail. Table 7.2 provides information on organisms that have been suggested as possible causes of waterborne disease but where evidence either is limited or indicates that transmission through drinking-water supplies is unlikely. The spectrum of pathogens may change as a result of host, pathogen and environmental changes such as fluctuations in human and animal populations, reuse of wastewater, changes in lifestyles and medical interventions, population movement and travel, selective pressures for new pathogens and mutants or recombinations of existing pathogens. The immunity of

Table 7.1 Pathogens transmitted through drinking-water[a]

Pathogen	Health significance[b]	Persistence in water supplies[c]	Resistance to chlorine[d]	Relative infectivity[e]	Important animal source
Bacteria					
Burkholderia pseudomallei	High	May multiply	Low	Low	No
Campylobacter jejuni, *C. coli*	High	Moderate	Low	Moderate	Yes
Escherichia coli – Pathogenic[f]	High	Moderate	Low	Low	Yes
E. coli – Enterohaemorrhagic	High	Moderate	Low	High	Yes
Francisella tularensis	High	Long	Moderate	High	Yes
Legionella spp.	High	May multiply	Low	Moderate	No
Leptospira	High	Long	Low	High	Yes
Mycobacteria (non-tuberculous)	Low	May multiply	High	Low	No
Salmonella Typhi	High	Moderate	Low	Low	No
Other salmonellae	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	High	No
Vibrio cholerae	High	Short to long[g]	Low	Low	No
Viruses					
Adenoviruses	Moderate	Long	Moderate	High	No
Astroviruses	Moderate	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Hepatitis A virus	High	Long	Moderate	High	No
Hepatitis E virus	High	Long	Moderate	High	Potentially
Noroviruses	High	Long	Moderate	High	Potentially
Rotaviruses	High	Long	Moderate	High	No
Sapoviruses	High	Long	Moderate	High	Potentially
Protozoa					
Acanthamoeba spp.	High	May multiply	High	High	No
Cryptosporidium hominis/ parvum	High	Long	High	High	Yes
Cyclospora cayetanensis	High	Long	High	High	No
Entamoeba histolytica	High	Moderate	High	High	No
Giardia intestinalis	High	Moderate	High	High	Yes
Naegleria fowleri	High	May multiply[h]	Low	Moderate	No
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	High	No
Schistosoma spp.	High	Short	Moderate	High	Yes

[a] This table contains pathogens for which there is some evidence of health significance related to their occurrence in drinking-water supplies. More information on these and other pathogens is presented in chapter 11.

[b] Health significance relates to the incidence and severity of disease, including association with outbreaks.

[c] Detection period for infective stage in water at 20 °C: short, up to 1 week; moderate, 1 week to 1 month; long, over 1 month.

[d] When the infective stage is freely suspended in water treated at conventional doses and contact times and pH between 7 and 8. Low means 99% inactivation at 20 °C generally in < 1 min, moderate 1–30 min and high > 30 min. It should be noted that organisms that survive and grow in biofilms, such as *Legionella* and mycobacteria, will be protected from chlorination.

[e] From experiments with human volunteers, from epidemiological evidence and from experimental animal studies. High means infective doses can be 1–10^2 organisms or particles, moderate 10^2–10^4 and low > 10^4.

[f] Includes enteropathogenic, enterotoxigenic, enteroinvasive, diffusely adherent and enteroaggregative.

[g] *Vibrio cholerae* may persist for long periods in association with copepods and other aquatic organisms.

[h] In warm water.

individuals also varies considerably, whether acquired by contact with a pathogen or influenced by such factors as age, sex, state of health and living conditions.

For pathogens transmitted by the faecal–oral route, drinking-water is only one vehicle of transmission. Contamination of food, hands, utensils and clothing can also play a role, particularly when domestic sanitation and hygiene are poor. Improvements in the quality and availability of water, excreta disposal and general hygiene are all important in reducing faecal–oral disease transmission.

Microbial drinking-water safety is not related only to faecal contamination. Some organisms grow in piped water distribution systems (e.g. *Legionella*), whereas others occur in source waters (e.g. guinea worm [*Dracunculus medinensis*]) and may cause outbreaks and individual cases. Some other microbes (e.g. toxic cyanobacteria) require specific management approaches, which are covered elsewhere in these Guidelines (see section 11.5).

Although consumption of contaminated drinking-water represents the greatest risk, other routes of transmission can also lead to disease, with some pathogens transmitted by multiple routes (e.g. adenovirus) (Figure 7.1). Certain serious illnesses result from inhalation of water droplets (aerosols) in which the causative organisms have multiplied because of warm waters and the presence of nutrients. These include legionellosis, caused by *Legionella* spp., and illnesses caused by the amoebae *Naegleria fowleri* (primary amoebic meningoencephalitis) and *Acanthamoeba* spp. (amoebic meningitis, pulmonary infections).

Schistosomiasis (bilharziasis) is a major parasitic disease of tropical and subtropical regions that is transmitted when the larval stage (cercariae), which is released by infected aquatic snails, penetrates the skin. It is primarily spread by contact with water. Ready availability of safe drinking-water contributes to disease prevention by reducing the need for contact with contaminated water resources—for example, when collecting water to carry to the home or when using water for bathing or laundry.

It is conceivable that unsafe drinking-water contaminated with soil or faeces could act as a carrier of other infectious parasites, such as *Balantidium coli* (balantidiasis) and certain helminths (species of *Fasciola*, *Fasciolopsis*, *Echinococcus*, *Spirometra*, *Ascaris*, *Trichuris*, *Toxocara*, *Necator*, *Ancylostoma*, *Strongyloides* and *Taenia solium*). However, in most of these, the normal mode of transmission is ingestion of the eggs in food contaminated with faeces or faecally contaminated soil (in the case of *Taenia solium*, ingestion of the larval cysticercus stage in uncooked pork) rather than ingestion of contaminated drinking-water.

Other pathogens that may be naturally present in the environment may be able to cause disease in vulnerable subpopulations: the elderly or the very young, patients with burns or extensive wounds, those undergoing immunosuppressive therapy or those with acquired immunodeficiency syndrome (AIDS). If water used by such persons for drinking or bathing contains sufficient numbers of these organisms, they can produce various infections of the skin and the mucous membranes of the eye, ear, nose and throat. Examples of such agents are *Pseudomonas aeruginosa* and species of *Flavobacterium*, *Acinetobacter*, *Klebsiella*, *Serratia*, *Aeromonas* and certain "slow-growing" (non-tuberculous) mycobacteria (see the supporting document *Pathogenic*

Table 7.2 Organisms for which transmission through drinking-water has been suggested but for which evidence is inconclusive[a]

Pathogen	Level of evidence	Presence in water supplies	Resistance to chlorine[b]
Bacteria			
Acinetobacter	Possible issue in health-care facilities (non-gastrointestinal)	Common and can multiply	Low
Aeromonas	Clinical isolates do not match environmental isolates	Common and can multiply	Low
Enterobacter sakazakii	Infection associated with infant formula; no evidence of waterborne transmission	Unlikely	Low
Helicobacter pylori	Suggested but no direct evidence; familial transmission primary route	Detected, survives for limited time	Low
Klebsiella	Possible issue in health-care facilities (non-gastrointestinal)	Can multiply	Low
Pseudomonas aeruginosa	Possible issue in health-care facilities (non-gastrointestinal)	Common and can multiply	Moderate
Staphylococcus aureus	No evidence of transmission through drinking-water; hands are the most important source	Common and can multiply	Moderate
Tsukamurella	Possible issue in health-care facilities (non-gastrointestinal)	Common and can multiply	Unknown
Yersinia enterocolitica	Species detected in water probably non-pathogenic; food primary source	Common and can multiply	Low
Viruses			
Influenza viruses	No evidence for waterborne transmission	Unlikely	Low
Severe acute respiratory syndrome coronaviruses	Some evidence for transmission via inhalation of droplets	Unlikely	Unknown
Protozoa			
Balantidium coli	One outbreak reported in 1971	Detected	High
Blastocystis hominis	Plausible but limited evidence	Unknown, persistence[c] likely	High
Isospora belli	Plausible but no evidence	Unknown	High
Microsporidia	Plausible but limited evidence; infections predominantly in persons with acquired immunodeficiency syndrome	Detected, persistence[c] likely	Moderate
Toxoplasma gondii	One outbreak reported in 1995	Long	High

Table 7.2 (continued)

Pathogen	Level of evidence	Presence in water supplies	Resistance to chlorine[b]
Helminths			
Fasciola spp.	Plausible, detected in water in hyperendemic regions	Detected	High
Free-living nematodes other than *Dracunculus medinensis*	Plausible, but transmission primarily associated with food or soil	Detected and can multiply	High

[a] More information on these and other pathogens is presented in chapter 11.
[b] When the infective stage is freely suspended in water treated at conventional doses and contact times and pH between 7 and 8. Low means 99% inactivation at 20 °C generally in < 1 min, moderate 1–30 min and high > 30 min. It should be noted that organisms that survive and grow in biofilms, such as *Pseudomonas aeruginosa*, will be protected from chlorination.
[c] Persistence means survival for 1 month or more.

mycobacteria in water; Annex 1). A number of these organisms are listed in Table 7.2 (and described in more detail in chapter 11).

Most of the human pathogens listed in Table 7.1 (which are also described in more detail in chapter 11) are distributed worldwide; some, however, such as those causing outbreaks of cholera or guinea worm disease, are regional. Eradication of *Dracunculus medinensis* is a recognized target of the World Health Assembly (1991).

It is likely that there are pathogens not shown in Table 7.1 that are also transmitted by water. This is because the number of known pathogens for which water is a transmission route continues to increase as new or previously unrecognized pathogens continue to be discovered (WHO, 2003).

7.1.2 Emerging issues

A number of developments are subsumed under the concept of "emerging issues" in drinking-water. Global changes, such as human development, population growth and movement and climate change (see section 6.1), exert pressures on the quality and quantity of water resources that may influence waterborne disease risks. Between 1972 and 1999, 35 new agents of disease were discovered, and many more have re-emerged after long periods of inactivity or are expanding into areas where they have not previously been reported (WHO, 2003). In 2003, a coronavirus was identified as the causative agent of severe acute respiratory syndrome, causing a multinational outbreak. Even more recently, influenza viruses originating from animal reservoirs have been transmitted to humans on several occasions, causing flu pandemics and seasonal epidemic influenza episodes (see the supporting document *Review of latest available evidence on potential transmission of avian influenza (H5N1) through water and sewage and ways to reduce the risks to human health*; Annex 1). Zoonotic pathogens make up 75% of the emerging pathogens and are of increasing concern for human health, along with pathogens with strictly human-to-human transmission. Zoonotic pathogens pose the greatest challenges to ensuring the safety of drinking-water and ambient water, now and in the future (see the supporting document *Waterborne zoonoses*; Annex 1). For each emerging pathogen, whether zoonotic or not, it should be considered whether it

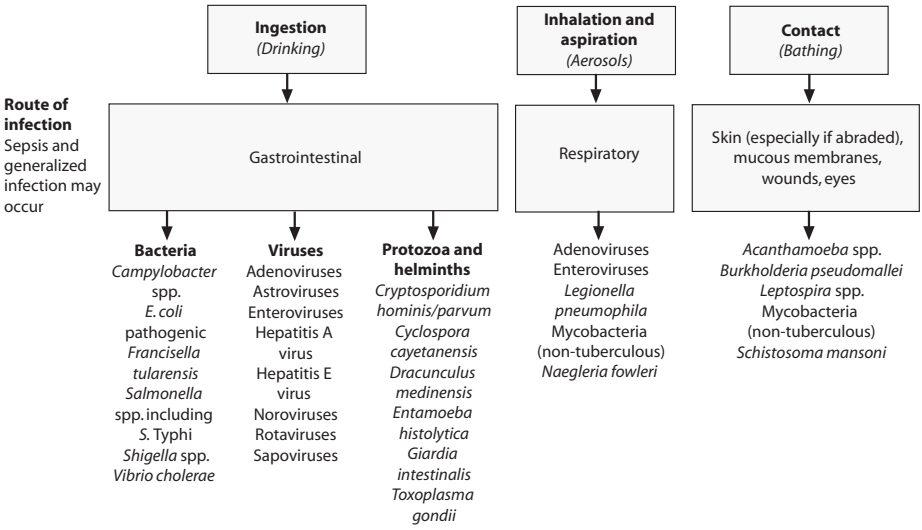


Figure 7.1 Transmission pathways for and examples of water-related pathogens

can be transmitted through water and, if so, which prevention and control measures can be suggested to minimize this risk.

7.1.3 Persistence and growth in water

Waterborne pathogens, such as *Legionella*, may grow in water, whereas other host-dependent waterborne pathogens, such as noroviruses and *Cryptosporidium*, cannot grow in water, but are able to persist.

Host-dependent waterborne pathogens, after leaving the body of their host, gradually lose viability and the ability to infect. The rate of decay is usually exponential, and a pathogen will become undetectable after a certain period. Pathogens with low persistence must rapidly find new hosts and are more likely to be spread by person-to-person contact or poor personal hygiene than by drinking-water. Persistence is affected by several factors, of which temperature is the most important. Decay is usually faster at higher temperatures and may be mediated by the lethal effects of ultraviolet (UV) radiation in sunlight acting near the water surface.

Relatively high amounts of biodegradable organic carbon, together with warm waters and low residual concentrations of chlorine, can permit growth of *Legionella*, *Vibrio cholerae*, *Naegleria fowleri*, *Acanthamoeba* and nuisance organisms in some surface waters and during water distribution (see also the supporting documents *Heterotrophic plate counts and drinking-water safety* and *Legionella and the prevention of legionellosis*; Annex 1).

Microbial water quality may vary rapidly and widely. Short-term peaks in pathogen concentration may increase disease risks considerably and may also trigger outbreaks of waterborne disease. Microorganisms can accumulate in sediments and are mobilized when water flow increases. Results of water quality testing for microbes are not normally available in time to inform management action and prevent the supply of unsafe water.

7.1.4 Public health aspects

Outbreaks of waterborne disease may affect large numbers of persons, and the first priority in developing and applying controls on drinking-water quality should be the control of such outbreaks. Available evidence also suggests that drinking-water can contribute to background rates of disease in non-outbreak situations, and control of drinking-water quality should therefore also address waterborne disease in the general community.

Experience has shown that systems for the detection of waterborne disease outbreaks are typically inefficient in countries at all levels of socioeconomic development, and failure to detect outbreaks is not a guarantee that they do not occur; nor does it suggest that drinking-water should necessarily be considered safe.

Some of the pathogens that are known to be transmitted through contaminated drinking-water lead to severe and sometimes life-threatening disease. Examples include typhoid, cholera, infectious hepatitis (caused by hepatitis A virus or hepatitis E virus) and disease caused by *Shigella* spp. and *E. coli* O157. Others are typically associated with less severe outcomes, such as self-limiting diarrhoeal disease (e.g. noroviruses, *Cryptosporidium*).

The effects of exposure to pathogens are not the same for all individuals or, as a consequence, for all populations. Repeated exposure to a pathogen may be associated with a lower probability or severity of illness because of the effects of acquired immunity. For some pathogens (e.g. hepatitis A virus), immunity is lifelong, whereas for others (e.g. *Campylobacter*), the protective effects may be restricted to a few months to years. In contrast, vulnerable subpopulations (e.g. the young, the elderly, pregnant women, the immunocompromised) may have a greater probability of illness or the illness may be more severe, including mortality. Not all pathogens have greater effects in all vulnerable subpopulations.

Not all infected individuals will develop symptomatic disease. The proportion of the infected population that is asymptomatic (including carriers) differs between pathogens and also depends on population characteristics, such as prevalence of immunity. Those with asymptomatic infections as well as patients during and after illness may all contribute to secondary spread of pathogens.

7.2 Health-based target setting

7.2.1 Health-based targets applied to microbial hazards

General approaches to health-based target setting are described in section 2.1 and chapter 3.

Sources of information on health risks may be from both epidemiology and QMRA, and typically both are employed as complementary sources. Development of health-based targets for many pathogens may be constrained by limitations in the data. Additional data, derived from both epidemiology and QMRA, are becoming progressively more available. Locally generated data will always be of great value in setting national targets.

Health-based targets may be set using a direct health outcome approach, where the waterborne disease burden is believed to be sufficiently high to allow measurement

of the impact of interventions—that is, epidemiological measurement of reductions in disease that can be attributed to improvements in drinking-water quality.

Interpreting and applying information from analytical epidemiological studies to derive health-based targets for application at a national or local level require consideration of a number of factors, including the following questions:

- Are specific estimates of disease reduction or indicative ranges of expected reductions to be provided?
- How representative of the target population was the study sample in order to assure confidence in the reliability of the results across a wider group?
- To what extent will minor differences in demographic or socioeconomic conditions affect expected outcomes?

More commonly, QMRA is used as the basis for setting microbial health-based targets, particularly where the fraction of disease that can be attributed to drinking-water is low or difficult to measure directly through public health surveillance or analytical epidemiological studies.

For the control of microbial hazards, the most frequent form of health-based target applied is performance targets (see section 3.3.3), which are anchored to a predetermined tolerable burden of disease and established by applying QMRA taking into account raw water quality. Water quality targets (see section 3.3.2) are typically not developed for pathogens; monitoring finished water for pathogens is not considered a feasible or cost-effective option because pathogen concentrations equivalent to tolerable levels of risk are typically less than 1 organism per 10^4–10^5 litres.

7.2.2 Reference pathogens

It is not practical, and there are insufficient data, to set performance targets for all potentially waterborne pathogens, including bacteria, viruses, protozoa and helminths. A more practical approach is to identify reference pathogens that represent groups of pathogens, taking into account variations in characteristics, behaviours and susceptibilities of each group to different treatment processes. Typically, different reference pathogens will be identified to represent bacteria, viruses, protozoa and helminths.

Selection criteria for reference pathogens include all of the following elements:

- waterborne transmission established as a route of infection;
- sufficient data available to enable a QMRA to be performed, including data on dose–response relationships in humans and disease burden;
- occurrence in source waters;
- persistence in the environment;
- sensitivity to removal or inactivation by treatment processes;
- infectivity, incidence and severity of disease.

Some of the criteria, such as environmental persistence and sensitivity to treatment processes, relate to the specific characteristics of the reference pathogens. Other criteria can be subject to local circumstances and conditions. These can include waterborne disease

burden, which can be influenced by the prevalence of the organism from other sources, levels of immunity and nutrition (e.g. rotavirus infections have different outcomes in high- and low-income regions); and occurrence of the organism in source waters (e.g. presence of toxigenic *Vibrio cholerae* and *Entamoeba histolytica* is more common in defined geographical regions, whereas *Naegleria fowleri* is associated with warmer waters).

Selection of reference pathogens

The selection of reference pathogens may vary between different countries and regions and should take account of local conditions, including incidence and severity of waterborne disease and source water characteristics (see section 7.3.1). Evidence of disease prevalence and significance should be used in selecting reference pathogens. However, the range of potential reference pathogens is limited by data availability, particularly in regard to human dose–response models for QMRA.

Decision-making regarding selection of reference pathogens should be informed by all available data sources, including infectious disease surveillance and targeted studies, outbreak investigations and registries of laboratory-confirmed clinical cases. Such data can help identify the pathogens that are likely to be the biggest contributors to the burden of waterborne disease. It is these pathogens that may be suitable choices as reference pathogens and to consider when establishing health-based targets.

Viruses

Viruses are the smallest pathogens and hence are more difficult to remove by physical processes such as filtration. Specific viruses may be less sensitive to disinfection than bacteria and parasites (e.g. adenovirus is less sensitive to UV light). Viruses can persist for long periods in water. Infective doses are typically low. Viruses typically have a limited host range, and many are species specific. Most human enteric viruses are not carried by animals, although there are some exceptions, including specific strains of hepatitis E virus (Table 7.1).

Rotaviruses, enteroviruses and noroviruses have been identified as potential reference pathogens. Rotaviruses are the most important cause of gastrointestinal infection in children and can have severe consequences, including hospitalization and death, with the latter being far more frequent in low-income regions. There is a dose–response model for rotaviruses, but there is no routine culture-based method for quantifying infectious units. Typically, rotaviruses are excreted in very large numbers by infected patients, and waters contaminated by human waste could contain high concentrations. Occasional outbreaks of waterborne disease have been recorded. In low-income countries, sources other than water are likely to dominate.

Enteroviruses, including polioviruses and the more recently recognized parechoviruses, can cause mild febrile illness, but are also important causative agents of severe diseases, such as paralysis, meningitis and encephalitis, in children. There is a dose–response model for enteroviruses, and there is a routine culture-based analysis for measuring infective particles. Enteroviruses are excreted in very large numbers by infected patients, and waters contaminated by human waste could contain high concentrations.

Noroviruses are a major cause of acute gastroenteritis in all age groups. Symptoms of illness are generally mild and rarely last longer than 3 days; however, infection does not yield lasting protective immunity. Hence, the burden of disease per case is lower than for rotaviruses. Numerous outbreaks have been attributed to drinking-water. A dose–response model has been developed to estimate infectivity for several norovirus strains, but no culture-based method is available.

Bacteria

Bacteria are generally the group of pathogens that is most sensitive to inactivation by disinfection. Some free-living pathogens, such as *Legionella* and non-tuberculous mycobacteria, can grow in water environments, but enteric bacteria typically do not grow in water and survive for shorter periods than viruses or protozoa. Many bacterial species that are infective to humans are carried by animals.

There are a number of potentially waterborne bacterial pathogens with known dose–response models, including *Vibrio*, *Campylobacter*, *E. coli* O157, *Salmonella* and *Shigella.*

Toxigenic *Vibrio cholerae* can cause watery diarrhoea. When it is left untreated, as may be the case when people are displaced by conflict and natural disaster, case fatality rates are very high. The infective dose is relatively high. Large waterborne outbreaks have been described and keep occurring.

Campylobacter is an important cause of diarrhoea worldwide. Illness can produce a wide range of symptoms, but mortality is low. Compared with other bacterial pathogens, the infective dose is relatively low and can be below 1000 organisms. It is relatively common in the environment, and waterborne outbreaks have been recorded.

Waterborne infection by *E. coli* O157 and other enterohaemorrhagic strains of *E. coli* is far less common than infection by *Campylobacter*, but the symptoms of infection are more severe, including haemolytic uraemic syndrome and death. The infective dose can be very low (fewer than 100 organisms).

Shigella causes over 2 million infections each year, including about 60 000 deaths, mainly in developing countries. The infective dose is low and can be as few as 10–100 organisms. Waterborne outbreaks have been recorded.

Although non-typhoidal *Salmonella* rarely causes waterborne outbreaks, *S.* Typhi causes large and devastating outbreaks of waterborne typhoid.

Protozoa

Protozoa are the group of pathogens that is least sensitive to inactivation by chemical disinfection. UV light irradiation is effective against *Cryptosporidium*, but *Cryptosporidium* is highly resistant to oxidizing disinfectants such as chlorine. Protozoa are of a moderate size (> 2 μm) and can be removed by physical processes. They can survive for long periods in water. They are moderately species specific. Livestock and humans can be sources of protozoa such as *Cryptosporidium* and *Balantidium*, whereas humans are the sole reservoirs of pathogenic *Cyclospora* and *Entamoeba*. Infective doses are typically low.

There are dose–response models available for *Giardia* and *Cryptosporidium*. *Giardia* infections are generally more common than *Cryptosporidium* infections, and

symptoms can be longer lasting. However, *Cryptosporidium* is smaller than *Giardia* and hence more difficult to remove by physical processes; it is also more resistant to oxidizing disinfectants, and there is some evidence that it survives longer in water environments.

7.2.3 Quantitative microbial risk assessment

QMRA systematically combines available information on exposure (i.e. the number of pathogens ingested) and dose–response models to produce estimates of the probability of infection associated with exposure to pathogens in drinking-water. Epidemiological data on frequency of asymptomatic infections, duration and severity of illness can then be used to estimate disease burdens.

QMRA can be used to determine performance targets and as the basis for assessing the effects of improved water quality on health in the population and subpopulations. Mathematical modelling can be used to estimate the effects of low doses of pathogens in drinking-water on health.

Risk assessment, including QMRA, commences with problem formulation to identify all possible hazards and their pathways from sources to recipients. Human exposure to the pathogens (environmental concentrations and volumes ingested) and dose–response relationships for selected (or reference) organisms are then combined to characterize the risks. With the use of additional information (social, cultural, political, economic, environmental, etc.), management options can be prioritized. To encourage stakeholder support and participation, a transparent procedure and active risk communication at each stage of the process are important. An example of a risk assessment approach is outlined in Table 7.3 and described below.

Problem formulation and hazard identification

All potential hazards, sources and events that can lead to the presence of microbial pathogens (i.e. what can happen and how) should be identified and documented for each component of the drinking-water system, regardless of whether or not the component is under the direct control of the drinking-water supplier. This includes point sources of pollution (e.g. human and industrial waste discharges) as well as diffuse sources (e.g. those arising from agricultural and animal husbandry activities). Continuous, intermittent or seasonal pollution patterns should also be considered, as well as extreme and infrequent events, such as droughts and floods.

The broader sense of hazards includes hazardous scenarios, which are events that may lead to exposure of consumers to specific pathogenic microorganisms. In this, the hazardous event (e.g. peak contamination of source water with domestic wastewater) may be referred to as the hazard.

As a QMRA cannot be performed for each of the hazards identified, representative (or reference) organisms are selected that, if controlled, would ensure control of all pathogens of concern. Typically, this implies inclusion of at least one bacterium, virus, protozoan or helminth. In this section, *Campylobacter*, rotavirus and *Cryptosporidium* have been used as example reference pathogens to illustrate application of risk assessment and calculation of performance targets.

Table 7.3 Risk assessment paradigm for pathogen health risks

Step	Aim
1. Problem formulation and hazard identification	To identify all possible hazards associated with drinking-water that would have an adverse public health consequence, as well as their pathways from source(s) to consumer(s)
2. Exposure assessment	To determine the size and nature of the population exposed and the route, amount and duration of the exposure
3. Dose–response assessment	To characterize the relationship between exposure and the incidence of the health effect
4. Risk characterization	To integrate the information from exposure, dose–response and health interventions in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty

Source: Adapted from Haas, Rose & Gerba (1999)

Exposure assessment

Exposure assessment in the context of drinking-water consumption involves estimation of the number of pathogens to which an individual is exposed, principally through ingestion. Exposure assessment inevitably contains uncertainty and must account for variability of such factors as concentrations of pathogens over time and volumes ingested.

Exposure can be considered as a single dose of pathogens that a consumer ingests at a certain point in time or the total amount over several exposures (e.g. over a year). Exposure is determined by the concentration of pathogens in drinking-water and the volume of water consumed.

It is rarely possible or appropriate to directly measure pathogens in drinking-water on a regular basis. More often, concentrations in raw waters are assumed or measured, and estimated reductions—for example, through treatment—are applied to estimate the concentration in the water consumed. Pathogen measurement, when performed, is generally best carried out at the location where the pathogens are at highest concentration (generally raw waters). Estimation of their removal by sequential control measures is generally achieved by the use of indicator organisms such as *E. coli* for enteric bacterial pathogens (see section 7.4; see also the supporting document *Water treatment and pathogen control* in Annex 1).

The other component of exposure assessment, which is common to all pathogens, is the volume of unboiled water consumed by the population, including person-to-person variation in consumption behaviour and especially consumption behaviour of vulnerable subpopulations. For microbial hazards, it is important that the unboiled volume of drinking-water, both consumed directly and used in food preparation, is used in the risk assessment, as heating will rapidly inactivate pathogens. This amount is lower than that used for deriving water quality targets, such as chemical guideline values.

The daily exposure of a consumer to pathogens in drinking-water can be assessed by multiplying the concentration of pathogens in drinking-water by the volume of drinking-water consumed (i.e. dose). For the purposes of the example model calculations, drinking-water consumption was assumed to be 1 litre of unboiled water per day, but location-specific data on drinking-water consumption are preferred.

Dose–response assessment

The probability of an adverse health effect following exposure to one or more pathogenic organisms is derived from a dose–response model. Available dose–response data have been obtained mainly from studies using healthy adult volunteers. However, adequate data are lacking for vulnerable subpopulations, such as children, the elderly and the immunocompromised, who may suffer more severe disease outcomes.

The conceptual basis for the dose–response model is the observation that exposure to the described dose leads to the probability of infection as a conditional event: for infection to occur, one or more viable pathogens must have been ingested. Furthermore, one or more of these ingested pathogens must have survived in the host's body. An important concept is the single-hit principle (i.e. that even a single pathogen may be able to cause infection and disease). This concept supersedes the concept of (minimum) infectious dose that is frequently used in older literature (see the supporting document *Hazard characterization for pathogens in food and water*; Annex 1).

In general, well-dispersed pathogens in water are considered to be Poisson distributed. When the individual probability of any organism surviving and starting infection is the same, the dose–response relationship simplifies to an exponential function. If, however, there is heterogeneity in this individual probability, this leads to the beta-Poisson dose–response relationship, where the "beta" stands for the distribution of the individual probabilities among pathogens (and hosts). At low exposures, such as would typically occur in drinking-water, the dose–response model is approximately linear and can be represented simply as the probability of infection resulting from exposure to a single organism (see the supporting document *Hazard characterization for pathogens in food and water*; Annex 1).

Risk characterization

Risk characterization brings together the data collected on exposure, dose–response and the incidence and severity of disease.

The probability of infection can be estimated as the product of the exposure by drinking-water and the probability that exposure to one organism would result in infection. The probability of infection per day is multiplied by 365 to calculate the probability of infection per year. In doing so, it is assumed that different exposure events are independent, in that no protective immunity is built up. This simplification is justified for low risks only, such as those discussed here.

Not all infected individuals will develop clinical illness; asymptomatic infection is common for most pathogens. The percentage of infected persons who will develop clinical illness depends on the pathogen, but also on other factors, such as the immune status of the host. Risk of illness per year is obtained by multiplying the probability of infection by the probability of illness given infection.

The low numbers in Table 7.4 can be interpreted to represent the probability that a single individual will develop illness in a given year. For example, a risk of illness for *Campylobacter* of 2.2×10^{-4} per year indicates that, on average, 1 out of 4600 consumers would contract campylobacteriosis from consumption of drinking-water.

To translate the risk of developing a specific illness to disease burden per case, the metric disability-adjusted life year, or DALY, is used (see Box 3.1 in chapter 3). This

metric reflects not only the effects of acute end-points (e.g. diarrhoeal illness) but also mortality and the effects of more serious end-points (e.g. Guillain-Barré syndrome associated with *Campylobacter*). The disease burden per case varies widely. For example, the disease burden per 1000 cases of rotavirus diarrhoea is 480 DALYs in low-income regions, where child mortality frequently occurs. However, it is 14 DALYs per 1000 cases in high-income regions, where hospital facilities are accessible to the great majority of the population (see the supporting document *Quantifying public health risk in the WHO Guidelines for drinking-water quality*; Annex 1). This considerable difference in disease burden results in far stricter treatment requirements in low-income regions for the same raw water quality in order to obtain the same risk (expressed as DALYs per person per year). Ideally, the health outcome target of 10^{-6} DALY per person per year in Table 7.4 should be adapted to specific national situations. In Table 7.4, no accounting is made for effects on immunocompromised persons (e.g. cryptosporidiosis in patients with human immunodeficiency virus or AIDS), which is significant in some countries. Section 3.2 gives more information on the DALY metric and how it is applied to derive a reference level of risk.

Only a proportion of the population may be susceptible to some pathogens, because immunity developed after an initial episode of infection or illness may provide lifelong protection. Examples include hepatitis A virus and rotaviruses. It is estimated that in developing countries, all children above the age of 5 years are immune to rotaviruses because of repeated exposure in the first years of life. This translates to an average of 17% of the population being susceptible to rotavirus illness. In developed countries, rotavirus infection is also common in the first years of life, and the illness is diagnosed mainly in young children, but the percentage of young children as part of the total population is lower. This translates to an average of 6% of the population in developed countries being susceptible.

The uncertainty of the risk outcome is the result of the uncertainty and variability of the data collected in the various steps of the risk assessment. Risk assessment models should ideally account for this variability and uncertainty, although here we present only point estimates (see below).

It is important to choose the most appropriate point estimate for each of the variables. Theoretical considerations show that risks are directly proportional to the arithmetic mean of the ingested dose. Hence, arithmetic means of variables such as concentration in raw water, removal by treatment and consumption of drinking-water are recommended. This recommendation is different from the usual practice among microbiologists and engineers of converting concentrations and treatment effects to log values and making calculations or specifications on the log scale. Such calculations result in estimates of the geometric mean rather than the arithmetic mean, and these may significantly underestimate risk. Analysing site-specific data may therefore require going back to the raw data (i.e. counts and tested volumes) rather than relying on reported log-transformed values, as these introduce ambiguity.

7.2.4 Risk-based performance target setting

The process outlined above enables estimation of risk on a population level, taking account of raw water quality and impact of control. This can be compared with the

Table 7.4 Linking tolerable disease burden and raw water quality for reference pathogens: example calculation

River water (human and livestock pollution)	Units	*Cryptosporidium*	*Campylobacter*	Rotavirus[a]
Raw water quality (C_R)	Organisms per litre	10	100	10
Treatment effect needed to reach tolerable risk (PT)	Log_{10} reduction value	5.89	5.98	5.96
Drinking-water quality (C_D)	Organisms per litre	1.3×10^{-5}	1.05×10^{-4}	1.1×10^{-5}
Consumption of unheated drinking-water (V)	Litres per day	1	1	1
Exposure by drinking-water (E)	Organisms per day	1.3×10^{-5}	1.05×10^{-4}	1.1×10^{-5}
Dose–response (r)[b]	Probability of infection per organism	2.0×10^{-1}	1.9×10^{-2}	5.9×10^{-1}
Risk of infection ($P_{inf,d}$)	Per day	2.6×10^{-6}	2.0×10^{-6}	6.5×10^{-6}
Risk of infection ($P_{inf,y}$)	Per year	9.5×10^{-4}	7.3×10^{-4}	2.4×10^{-3}
Risk of (diarrhoeal) illness given infection ($P_{ill\|inf}$)	Probability of illness per infection	0.7	0.3	0.5
Risk of (diarrhoeal) illness (P_{ill})	Per year	6.7×10^{-4}	2.2×10^{-4}	1.2×10^{-3}
Disease burden (db)	DALY per case	1.5×10^{-3}	4.6×10^{-3}	1.4×10^{-2}
Susceptible fraction (f_s)	Percentage of population	100	100	6
Health outcome target (HT)	DALY per year[c]	1×10^{-6}	1×10^{-6}	1×10^{-6}
Formulas:	$C_D = C_R \div 10^{PT}$	$P_{inf,d} = E \times r$	$HT = P_{ill} \times db \times f_s \div 100$	
	$E = C_D \times V$	$P_{ill} = P_{inf,y} \times P_{ill\|inf}$		

DALY, disability-adjusted life year

[a] Data from high-income regions. In low-income regions, severity is typically higher (see the supporting document *Quantifying public health risk in the WHO Guidelines for drinking-water quality*; Annex 1).

[b] Dose–response for *Campylobacter* and rotavirus from Haas, Rose & Gerba (1999) and for *Cryptosporidium* from the supporting document *Risk assessment of Cryptosporidium in drinking water* (Annex 1).

[c] For a person drinking 1 litre per day (V).

reference level of risk (see section 3.2) or a locally developed tolerable risk. The calculations enable quantification of the degree of source protection or treatment that is needed to achieve a specified level of tolerable risk and analysis of the estimated impact of changes in control measures.

Performance targets are most frequently applied to treatment performance—that is, to determine the microbial reduction necessary to ensure water safety. A performance target may be applied to a specific system (i.e. formulated in response to local raw water characteristics) or generalized (e.g. formulated in response to raw water quality assumptions based on a certain type of source) (see also the supporting document *Water treatment and pathogen control*; Annex 1).

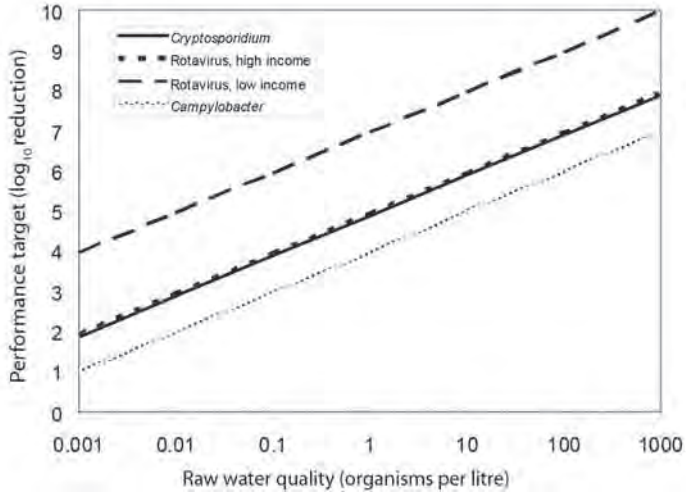


Figure 7.2 Performance targets for example bacterial, viral and protozoan pathogens in relation to raw water quality (to achieve 10^{-6} DALY per person per year)

Figure 7.2 illustrates the targets for treatment performance for a range of pathogens occurring in raw water. For example, 10 microorganisms per litre of raw water will lead to a performance target of 5.89 logs (or 99.999 87% reduction) for *Cryptosporidium* or of 5.96 logs (99.999 89% reduction) for rotaviruses in high-income regions to achieve 10^{-6} DALY per person per year (see also Table 7.5 below). The difference in performance targets for rotaviruses in high- and low-income countries (5.96 and 7.96 logs; Figure 7.2) is related to the difference in disease severity caused by this organism. In low-income countries, the child case fatality rate is relatively high, and, as a consequence, the disease burden is higher. Also, a larger proportion of the population in low-income countries is under the age of 5 and at risk for rotavirus infection.

The derivation of these performance targets is described in Table 7.5, which provides an example of the data and calculations that would normally be used to construct a risk assessment model for waterborne pathogens. The table presents data for representatives of the three major groups of pathogens (bacteria, viruses and protozoa) from a range of sources. These example calculations aim at achieving the reference level of risk of 10^{-6} DALY per person per year, as described in section 3.2. The data in the table illustrate the calculations needed to arrive at a risk estimate and are not guideline values.

7.2.5 Presenting the outcome of performance target development

Table 7.5 presents some data from Table 7.4 in a format that is more meaningful to risk managers. The average concentration of pathogens in drinking-water is included for information. It is not a water quality target, nor is it intended to encourage pathogen monitoring in finished water. As an example, a concentration of 1.3×10^{-5} *Cryptosporidium* per litre (see Table 7.4) corresponds to 1 oocyst per 79 000 litres (see Table 7.5). The performance target (in the row "Treatment effect" in Table 7.4), expressed as a

Table 7.5 Health-based targets derived from example calculation in Table 7.4

	Cryptosporidium	*Campylobacter*	Rotavirus[a]
Organisms per litre in raw water	10	100	10
Health outcome target	10^{-6} DALY per person per year	10^{-6} DALY per person per year	10^{-6} DALY per person per year
Risk of diarrhoeal illness[b]	1 per 1500 per year	1 per 4600 per year	1 per 14 000 per year
Drinking-water quality	1 per 79 000 litres	1 per 9500 litres	1 per 90 000 litres
Performance target[c]	5.89.0 $\log_{10}$ units	5.98 $\log_{10}$ units	5.96 $\log_{10}$ units

[a] Data from high-income regions. In low-income regions, severity is typically higher, but drinking-water transmission is unlikely to dominate.
[b] For the susceptible population.
[c] Performance target is a measure of log reduction of pathogens based on raw water quality.

$\log_{10}$ reduction value, is the most important management information in the risk assessment table. It can also be expressed as a per cent reduction. For example, a 5.96 $\log_{10}$ unit reduction for rotaviruses corresponds to a 99.999 89% reduction.

7.2.6 Adapting risk-based performance target setting to local circumstances

The reference pathogens illustrated in the previous sections will not be priority pathogens in all regions of the world. Wherever possible, country- or site-specific information should be used in assessments of this type. If no specific data are available, an approximate risk estimate can be based on default values (see Table 7.6 below).

Table 7.5 accounts only for changes in water quality derived from treatment and not from source protection measures, which are often important contributors to overall safety, affecting pathogen concentration and/or variability. The risk estimates presented in Table 7.4 also assume that there is no degradation of water quality in the distribution network. These may not be realistic assumptions under all circumstances, and it is advisable to take these factors into account wherever possible.

Table 7.5 presents point estimates only and does not account for variability and uncertainty. Full risk assessment models would incorporate such factors by representing the input variables by statistical distributions rather than by point estimates. However, such models are currently beyond the means of many countries, and data to define such distributions are scarce. Producing such data may involve considerable efforts in terms of time and resources, but will lead to much improved insight into the actual raw water quality and treatment performance.

The necessary degree of treatment also depends on the values assumed for variables that can be taken into account in the risk assessment model. One such variable is drinking-water consumption. Figure 7.3 shows the effect of variation in the consumption of unboiled drinking-water on the performance targets for *Cryptosporidium*. If the raw water concentration is 1 oocyst per litre, the performance target varies between 4.3 and 5.2 $\log_{10}$ units if consumption values vary between 0.25 and 2 litres per day. Another variable is the fraction of the population that is susceptible. Some outbreak data suggest that in developed countries, a significant proportion of the population above 5 years of age may not be immune to rotavirus illness. Figure 7.4

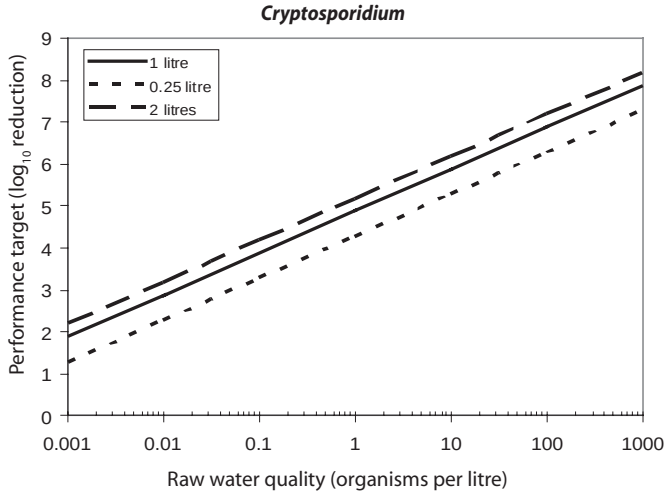


Figure 7.3 Performance targets for *Cryptosporidium* in relation to the daily consumption of unboiled drinking-water (to achieve 10^{-6} DALY per person per year)

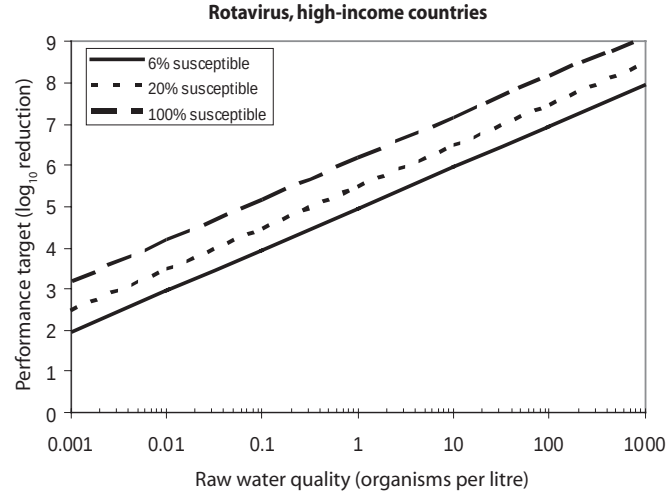


Figure 7.4 Performance targets for rotaviruses in relation to the fraction of the population that is susceptible to illness (to achieve 10^{-6} DALY per person per year)

shows the effect of variation in the susceptible fraction of the population. If the raw water concentration is 10 rotavirus particles per litre, the performance target increases from 5.96 to 7.18 as the susceptible fraction increases from 6% to 100%.

7.2.7 Health outcome targets

Health outcome targets that identify disease reductions in a community should be responded to by the control measures set out in water safety plans and associated

Table 7.6 Example occurrence of selected indicators and pathogens in faeces, wastewater and raw water (local data will vary)

Microbe	Number per gram of faeces	Number per litre in untreated wastewater	Number per litre in raw water
Faecal coliforms (*E. coli* and *Klebsiella*)	10^7 (mostly non-pathogenic)	10^6–10^{10}	100–100 000
Campylobacter spp.	10^6	100–10^6	100–10 000
Vibrio cholerae[a]	10^6	100–10^6	100–10^8
Enteroviruses	10^6	1–1000	0.01–10
Rotaviruses	10^9	50–5000	0.01–100
Cryptosporidium	10^7	1–10 000	0–1000
Giardia intestinalis	10^7	1–10 000	0–1000

[a] *Vibrio* can grow in the aquatic environment.

Sources: Feachem et al. (1983); Stelzer (1988); Jones, Betaieb & Telford (1990); Stampi et al. (1992); Koenraad et al. (1994); Gerba et al. (1996); AWWA (1999); Maier, Pepper & Gerba (2000); Metcalf & Eddy, Inc. (2003); Bitton (2005); Lodder & de Roda Husman (2005); Schijven & de Roda Husman (2006); Masini et al. (2007); Rutjes et al. (2009); Lodder et al. (2010)

water quality interventions at community and household levels. These targets would identify expected disease reductions in communities receiving the interventions.

The prioritization of water quality interventions should focus on those aspects that are estimated to contribute more than, for example, 5% of the burden of a given disease (e.g. 5% of total diarrhoea). In many parts of the world, the implementation of a water quality intervention that results in an estimated health gain of more than 5% would be considered extremely worthwhile. Directly demonstrating the health gains arising from improving water quality—as assessed, for example, by reduced *E. coli* counts at the point of consumption—may be possible where disease burden is high and effective interventions are applied and can be a powerful tool to demonstrate a first step in incremental drinking-water safety improvement.

Where a specified quantified disease reduction is identified as a health outcome target, it is advisable to undertake ongoing proactive public health surveillance among representative communities to measure the effectiveness of water quality interventions.

7.3 Occurrence and treatment of pathogens

As discussed in section 4.1, system assessment involves determining whether the drinking-water supply chain as a whole can deliver drinking-water quality that meets identified targets. This requires an understanding of the quality of source water and the efficacy of control measures, such as treatment.

7.3.1 Occurrence

An understanding of pathogen occurrence in source waters is essential, because it facilitates selection of the highest-quality source for drinking-water supply, determines pathogen concentrations in source waters and provides a basis for establishing treatment requirements to meet health-based targets within a water safety plan.

By far the most accurate way of determining pathogen concentrations in specific catchments and other water sources is by analysing pathogen concentrations in water

over a period of time, taking care to include consideration of seasonal variation and peak events such as storms. Direct measurement of pathogens and indicator organisms in the specific source waters for which a water safety plan and its target pathogens are being established is recommended wherever possible, because this provides the best estimates of microbial concentrations. However, resource limitations in many settings preclude this. In the absence of measured pathogen concentrations, an alternative interim approach is to make estimations based on available data, such as the results of sanitary surveys combined with indicator testing.

In the case of absence of data on the occurrence and distribution of human pathogens in water for the community or area of implementation, concentrations in raw waters can be inferred from observational data on numbers of pathogens per gram of faeces representing direct faecal contamination or from numbers of pathogens per litre of untreated wastewater (Table 7.6). Data from sanitary surveys can be used to estimate the impact of raw or treated wastewater discharged into source waters. In treated wastewater, the concentrations of pathogens may be reduced 10- to 100-fold or more, depending on the efficiency of the treatment process. The concentrations of pathogens in raw waters can be estimated from concentrations of pathogens in wastewater and the fraction of wastewater present in source waters. In addition, some indicative concentrations of pathogens in source waters are given that were measured at specific locations, but these concentrations may differ widely between locations.

From Table 7.6, it may be clear that faecal indicator bacteria, such as *E. coli*, are always present at high concentrations in wastewater. Everybody sheds *E. coli*; nevertheless, concentrations vary widely. Only infected persons shed pathogens; therefore, the concentrations of pathogens in wastewater vary even more. Such variations are due to shedding patterns, but they also depend on other factors, such as the size of the population discharging into wastewater and dilution with other types of wastewater, such as industrial wastewater. Conventional wastewater treatment commonly reduces microbial concentrations by one or two orders of magnitude before the wastewater is discharged into surface waters. At other locations, raw wastewater may be discharged directly, or discharges may occur occasionally during combined sewer overflows. Discharged wastewater is diluted in receiving surface waters, leading to reduced pathogen numbers, with the dilution factor being very location specific. Pathogen inactivation, die-off or partitioning to sediments may also play a role in pathogen reduction. These factors differ with the surface water body and climate. This variability suggests that concentrations of faecal indicators and pathogens vary even more in surface water than in wastewater.

Because of differences in survival, the ratio of pathogen to *E. coli* at the point of discharge will not be the same as farther downstream. A comparison of data on *E. coli* with pathogen concentrations in surface waters indicates that, overall, there is a positive relationship between the presence of pathogens in surface water and *E. coli* concentration, but that pathogen concentrations may vary widely from low to high at any *E. coli* concentration. Even the absence of *E. coli* is not a guarantee for the absence of pathogens or for pathogen concentrations to be below those of significance for public health.

The estimates based on field data in Table 7.6 provide a useful guide to the concentrations of enteric pathogens in a variety of sources affected by faecal contamination.

However, there are a number of limitations and sources of uncertainty in these data, including the following:

- Although data on pathogens and *E. coli* were derived from different regions in the world, they are by far mostly from high-income countries.
- There are concerns about the sensitivity and robustness of analytical techniques, particularly for viruses and protozoa, largely associated with the recoveries achieved by techniques used to process and concentrate large sample volumes typically used in testing for these organisms.
- Numbers of pathogens were derived using a variety of methods, including culture-based methods using media or cells, molecular-based tests (such as polymerase chain reaction) and microscopy, and should be interpreted with care.
- The lack of knowledge about the infectivity of the pathogens for humans has implications in risk assessment and should be addressed.

7.3.2 Treatment

Understanding the efficacy of control measures includes validation (see sections 2.2 and 4.1.7). Validation is important both in ensuring that treatment will achieve the desired goals (performance targets) and in assessing areas in which efficacy may be improved (e.g. by comparing performance achieved with that shown to be achievable through well-run processes). Water treatment could be applied in a drinking-water treatment plant (central treatment) to piped systems or in the home or at the point of use in settings other than piped supplies.

Central treatment

Waters of very high quality, such as groundwater from confined aquifers, may rely on protection of the source water and the distribution system as the principal control measures for provision of safe water. More typically, water treatment is required to remove or destroy pathogenic microorganisms. In many cases (e.g. poor quality surface water), multiple treatment stages are required, including, for example, coagulation, flocculation, sedimentation, filtration and disinfection. Table 7.7 provides a summary of treatment processes that are commonly used individually or in combination to achieve microbial reductions (see also Annex 5). The minimum and maximum removals are indicated as $\log_{10}$ reduction values and may occur under failing and optimal treatment conditions, respectively.

The microbial reductions presented in Table 7.7 are for broad groups or categories of microbes: bacteria, viruses and protozoa. This is because it is generally the case that treatment efficacy for microbial reduction differs among these microbial groups as a result of the inherently different properties of the microbes (e.g. size, nature of protective outer layers, physicochemical surface properties). Within these microbial groups, differences in treatment process efficiencies are smaller among the specific species, types or strains of microbes. Such differences do occur, however, and the table presents conservative estimates of microbial reductions based on the more resistant or persistent pathogenic members of that microbial group. Where differences in removal by treatment between specific members of a microbial group are great, the results for the individual microbes are presented separately in the table.

Table 7.7 Reductions of bacteria, viruses and protozoa achieved by water treatment technologies at drinking-water treatment plants for large communities

Treatment process	Enteric pathogen group	Minimum removal (LRV)	Maximum removal (LRV)	Notes
Pretreatment				
Roughing filters	Bacteria	0.2	2.3	Depends on filter medium, coagulant
Storage reservoirs	Bacteria	0.7	2.2	Residence time > 40 days
	Protozoa	1.4	2.3	Residence time 160 days
Bank filtration	Viruses	> 2.1	8.3	Depends on travel distance, soil type, pumping rate, pH, ionic strength
	Bacteria	2	> 6	
	Protozoa	> 1	> 2	
Coagulation, flocculation and sedimentation				
Conventional clarification	Viruses	0.1	3.4	Depends on coagulation conditions
	Bacteria	0.2	2	
	Protozoa	1	2	
High-rate clarification	Protozoa	> 2	2.8	Depends on use of appropriate blanket polymer
Dissolved air flotation	Protozoa	0.6	2.6	Depends on coagulant dose
Lime softening	Viruses	2	4	Depends on pH and settling time
	Bacteria	1	4	
	Protozoa	0	2	
Filtration				
Granular high-rate filtration	Viruses	0	3.5	Depends on filter media and coagulation pretreatment
	Bacteria	0.2	4.4	
	Protozoa	0.4	3.3	
Slow sand filtration	Viruses	0.25	4	Depends on presence of schmutzdecke, grain size, flow rate, operating conditions (mainly temperature, pH)
	Bacteria	2	6	
	Protozoa	0.3	> 5	
Precoat filtration	Viruses	1	1.7	If filter cake is present
	Bacteria	0.2	2.3	Depends on chemical pretreatment
	Protozoa	3	6.7	Depends on media grade and filtration rate
Membrane filtration: microfiltration, ultrafiltration, nanofiltration reverse osmosis	Viruses	< 1	> 6.5	Varies with membrane pore size (microfilters, ultrafilters, nanofilters and reverse osmosis filters), integrity of filter medium and filter seals, and resistance to chemical and biological ("grow-through") degradation
	Bacteria	1	> 7	
	Protozoa	2.3	> 7	

Table 7.7 (continued)

Treatment process	Enteric pathogen group	Minimum removal (LRV)	Maximum removal (LRV)	Notes
Primary disinfection[a,b]				
Chlorine	Viruses	2 (Ct_{99} 2–30 min·mg/l; 0–10 °C; pH 7–9)		Turbidity and chlorine-demanding solutes inhibit this process; free chlorine × time product predicts efficacy; not effective against *Cryptosporidium* oocysts. In addition to initial disinfection, the benefits of maintaining free chlorine residuals throughout distribution systems at or above 0.2 mg/l should be considered
	Bacteria	2 (Ct_{99} 0.04–0.08 min·mg/l; 5 °C; pH 6-7)		
	Protozoa	2 (Ct_{99} 25–245 min·mg/l; 0–25 °C; pH 7–8; mainly *Giardia*)		
Chlorine dioxide	Viruses	2 (Ct_{99} 2–30 min·mg/l; 0–10 °C; pH 7–9)		
	Bacteria	2 (Ct_{99} 0.02–0.3 min·mg/l; 15–25 °C; pH 6.5–7)		
	Protozoa	2 (Ct_{99} 100 min·mg/l)		
Ozone	Viruses	2 (Ct_{99} 0.006–0.2 min·mg/l)		Viruses generally more resistant than bacteria
	Bacteria	2 (Ct_{99} 0.02 min·mg/l)		
	Protozoa	2 (Ct_{99} 0.5–40 min·mg/l)		Depends on temperature; *Cryptosporidium* varies widely
UV	Viruses	4 (7–186 mJ/cm^2)		Excessive turbidity and certain dissolved species inhibit process; effectiveness depends on fluence (dose), which varies with intensity, exposure time, UV wavelength
	Bacteria	4 (0.65–230 mJ/cm^2)		
	Protozoa	4 (< 1–60 mJ/cm^2)		

Ct, product of disinfectant concentration and contact time; LRV, log_{10} reduction value

[a] Chemical disinfection: Ct values are given that achieve 2 LRV.

[b] UV irradiation: UV dose range is given that achieves 4 LRV.

Sources: Chevrefils et al. (2006); Dullemont et al. (2006); Hijnen, Beerendonk & Medema (2006); see also the supporting document *Water treatment and pathogen control* (Annex 1).

Further information about these water treatment processes, their operations and their performance for pathogen reduction in piped water supplies is provided in more detail in the supporting document *Water treatment and pathogen control* (Annex 1).

Household treatment

Household water treatment technologies are any of a range of devices or methods employed for the purposes of treating water in the home or at the point of use in other settings. These are also known as point-of-use or point-of-entry water treatment technologies (Cotruvo & Sobsey, 2006; Nath, Bloomfield & Jones, 2006; see also the supporting document *Managing water in the home*, Annex 1). Household water treatment technologies comprise a range of options that enable individuals and communities to treat collected water or contaminated piped water to remove or inactivate microbial

pathogens. Many of these methods are coupled with safe storage of the treated water to preclude or minimize contamination after household treatment (Wright, Gundry & Conroy, 2003).

Household water treatment and safe storage have been shown to significantly improve water quality and reduce waterborne infectious disease risks (Fewtrell & Colford, 2004; Clasen et al., 2006). Household water treatment approaches have the potential to have rapid and significant positive health impacts in situations where piped water systems are not possible and where people rely on source water that may be contaminated or where stored water becomes contaminated because of unhygienic handling during transport or in the home. Household water treatment can also be used to overcome the widespread problem of microbially unsafe piped water supplies. Similar small technologies can also be used by travellers in areas where the drinking-water quality is uncertain (see also section 6.11).

Not all household water treatment technologies are highly effective in reducing all classes of waterborne pathogens (bacteria, viruses, protozoa and helminths). For example, chlorine is ineffective for inactivating oocysts of the waterborne protozoan *Cryptosporidium*, whereas some filtration methods, such as ceramic and cloth or fibre filters, are ineffective in removing enteric viruses. Therefore, careful consideration of the health-based target microbes to control in a drinking-water source is needed when choosing among these technologies.

Definitions and descriptions of the various household water treatment technologies for microbial contamination follow:

- *Chemical disinfection:* Chemical disinfection of drinking-water includes any chlorine-based technology, such as chlorine dioxide, as well as ozone, some other oxidants and some strong acids and bases. Except for ozone, proper dosing of chemical disinfectants is intended to maintain a residual concentration in the water to provide some protection from post-treatment contamination during storage. Disinfection of household drinking-water in developing countries is done primarily with free chlorine, either in liquid form as hypochlorous acid (commercial household bleach or more dilute sodium hypochlorite solution between 0.5% and 1% hypochlorite marketed for household water treatment use) or in dry form as calcium hypochlorite or sodium dichloroisocyanurate. This is because these forms of free chlorine are convenient, relatively safe to handle, inexpensive and easy to dose. However, sodium trichloroisocyanurate and chlorine dioxide are also used in some household water treatment technologies. Proper dosing of chlorine for household water treatment is critical in order to provide enough free chlorine to maintain a residual during storage and use. Recommendations are to dose with free chlorine at about 2 mg/l to clear water (< 10 nephelometric turbidity units [NTU]) and twice that (4 mg/l) to turbid water (> 10 NTU). Although these free chlorine doses may lead to chlorine residuals that exceed the recommended chlorine residual for water that is centrally treated at the point of delivery, 0.2–0.5 mg/l, these doses are considered suitable for household water treatment to maintain a free chlorine residual of 0.2 mg/l in stored household water treated by chlorination. Further information on point-of-use chlorination can be found

in the document *Preventing travellers' diarrhoea: How to make drinking water safe* (WHO, 2005).

Disinfection of drinking-water with iodine, which is also a strong oxidant, is generally not recommended for extended use unless the residual concentrations are controlled, because of concerns about adverse effects of excess intake on the thyroid gland; however, this issue is being re-examined, because dietary iodine deficiency is a serious health problem in many parts of the world (see also section 6.11 and Table 6.1). As for central treatment, ozone for household water treatment must be generated on site, typically by corona discharge or electrolytically, both of which require electricity. As a result, ozone is not recommended for household water treatment because of the need for a reliable source of electricity to generate it, its complexity of generation and proper dosing in a small application, and its relatively high cost. Strong acids or bases are not recommended as chemical disinfectants for drinking-water, as they are hazardous chemicals that can alter the pH of the water to dangerously low or high levels. However, as an emergency or short-term intervention, the juices of some citrus fruits, such as limes and lemons, can be added to water to inactivate *Vibrio cholerae*, if enough is added to sufficiently lower the pH of the water (probably to pH less than 4.5).

- *Membrane, porous ceramic or composite filters:* These are filters with defined pore sizes and include carbon block filters, porous ceramics containing colloidal silver, reactive membranes, polymeric membranes and fibre/cloth filters. They rely on physical straining through a single porous surface or multiple surfaces having structured pores to physically remove and retain microbes by size exclusion. Some of these filters may also employ chemical antimicrobial or bacteriostatic surfaces or chemical modifications to cause microbes to become adsorbed to filter media surfaces, to be inactivated or at least to not multiply. Cloth filters, such as those of sari cloth, have been recommended for reducing *Vibrio cholerae* in water. However, these filters reduce only vibrios associated with copepods, other large crustaceans or other large eukaryotes retained by the cloth. These cloths will not retain dispersed vibrios or other bacteria not associated with copepods, other crustaceans, suspended sediment or large eukaryotes, because the pores of the cloth fabric are much larger than the bacteria, allowing them to pass through. Most household filter technologies operate by gravity flow or by water pressure provided from a piped supply. However, some forms of ultrafiltration, nanofiltration and reverse osmosis filtration may require a reliable supply of electricity to operate.
- *Granular media filters:* Granular media filters include those containing sand or diatomaceous earth or others using discrete particles as packed beds or layers of surfaces over or through which water is passed. These filters retain microbes by a combination of physical and chemical processes, including physical straining, sedimentation and adsorption. Some may also employ chemically active antimicrobial or bacteriostatic surfaces or other chemical modifications. Other granular media filters are biologically active because they develop layers of microbes and their associated exopolymers on the surface of or within the granular medium matrix. This biologically active layer, called the *schmutzdecke* in conventional slow sand filters, retains microbes and often leads to their inactivation and

biodegradation. A household-scale filter with a biologically active surface layer that can be dosed intermittently with water has been developed.

- *Solar disinfection:* There are a number of technologies using solar irradiation to disinfect water. Some use solar radiation to inactivate microbes in either dark or opaque containers by relying on heat from sunlight energy. Others, such as the solar water disinfection or SODIS system, use clear plastic containers penetrated by UV radiation from sunlight and rely on the combined action of the UV radiation, oxidative activity associated with dissolved oxygen and heat. Other physical forms of solar radiation exposure systems also employ combinations of these solar radiation effects in other types of containers, such as UV-penetrable plastic bags (e.g. the "solar puddle") and panels.
- *UV light technologies using lamps:* A number of drinking-water treatment technologies employ UV light radiation from UV lamps to inactivate microbes. For household- or small-scale water treatment, most employ low-pressure mercury arc lamps producing monochromatic UV radiation at a germicidal wavelength of 254 nm. Typically, these technologies allow water in a vessel or in flow-through reactors to be exposed to the UV radiation from the UV lamps at sufficient dose (fluence) to inactivate waterborne pathogens. These may have limited application in developing countries because of the need for a reliable supply of electricity, cost and maintenance requirements.
- *Thermal (heat) technologies:* Thermal technologies are those whose primary mechanism for the destruction of microbes in water is heat produced by burning fuel. These include boiling and heating to pasteurization temperatures (typically > 63 °C for 30 minutes when applied to milk). The recommended procedure for water treatment is to raise the temperature so that a rolling boil is achieved, removing the water from the heat and allowing it to cool naturally, and then protecting it from post-treatment contamination during storage. The above-mentioned solar technologies using solar radiation for heat or for a combination of heat and UV radiation from sunlight are distinguished from this category.
- *Coagulation, precipitation and/or sedimentation:* Coagulation or precipitation is any device or method employing a natural or chemical coagulant or precipitant to coagulate or precipitate suspended particles, including microbes, to enhance their sedimentation. Sedimentation is any method for water treatment using the settling of suspended particles, including microbes, to remove them from the water. These methods may be used along with cloth or fibre media for a straining step to remove the floc (the large coagulated or precipitated particles that form in the water). This category includes simple sedimentation (i.e. that achieved without the use of a chemical coagulant). This method often employs a series of three pots or other water storage vessels in series, in which sedimented (settled) water is carefully transferred by decanting daily; by the third vessel, the water has been sequentially settled and stored a total of at least 2 days to reduce microbes.
- *Combination (multiple-barrier) treatment approaches:* These are any of the above technologies used together, either simultaneously or sequentially, for water treatment. These combination treatments include coagulation plus disinfection, media filtration plus disinfection or media filtration plus membrane filtration. Some are

commercial single-use chemical products in the form of granules, powders or tablets containing a chemical coagulant, such as an iron or aluminium salt, and a disinfectant, such as chlorine. When added to water, these chemicals coagulate and flocculate impurities to promote rapid and efficient sedimentation and also deliver the chemical disinfectant (e.g. free chlorine) to inactivate microbes. Other combined treatment technologies are physical devices that include two or more stages of treatment, such as media or membrane filters or adsorbents to physically remove microbes and either chemical disinfectants or another physical treatment process (e.g. UV radiation) to kill any remaining microbes not physically removed by filtration or adsorption. Many of these combined household water treatment technologies are commercial products that can be purchased for household or other local use. It is important to choose commercial combination devices based on consideration of the treatment technologies that have been included in the device. It is also desirable to require that they meet specific microbial reduction performance criteria and preferably be certified for such performance by a credible national or international authority, such as government or an independent organization representing the private sector that certifies good practice and documented performance.

Estimated reductions of waterborne bacteria, viruses and protozoan parasites by several of the above-mentioned household water treatment technologies are summarized in Table 7.8. These reductions are based on the results of studies reported in the scientific literature. Two categories of effectiveness are reported: baseline removals and maximum removals. Baseline removals are those typically expected in actual field practice when done by relatively unskilled persons who apply the treatment to raw waters of average and varying quality and where there are minimum facilities or supporting instruments to optimize treatment conditions and practices. Maximum removals are those possible when treatment is optimized by skilled operators who are supported with instrumentation and other tools to maintain the highest level of performance in waters of predictable and unchanging quality (e.g. a test water seeded with known concentrations of specific microbes). It should be noted that there are differences in the $\log_{10}$ reduction value performance of certain water treatment processes as specified for household water treatment in Table 7.8 and for central treatment in Table 7.7. These differences in performance by the same treatment technologies are to be expected, because central treatment is often applied to water that is of desirable quality for the treatment process, and treatment is applied by trained operators using properly engineered and operationally controlled processes. In contrast, household water treatment is often applied to waters having a range of water qualities, some of which are suboptimal for best technology performance, and the treatment is often applied without the use of specialized operational controls by people who are relatively untrained and unskilled in treatment operations, compared with people managing central water treatment facilities. Further details on these treatment processes, including the factors that influence their performance and the basis for the $\log_{10}$ reduction value performance levels provided in Table 7.8, can be found in the supporting documents *Managing water in the home* and *Evaluating household water treatment options* (Annex 1).

Table 7.8 Reductions of bacteria, viruses and protozoa achieved by household water treatment technologies

Treatment process	Enteric pathogen group	Baseline removal (LRV)	Maximum removal (LRV)	Notes
Chemical disinfection				
Free chlorine disinfection	Bacteria	3	6	Turbidity and chlorine-demanding solutes inhibit this process; free chlorine × time product predicts efficacy; not effective against *Cryptosporidium* oocysts
	Viruses	3	6	
	Protozoa, non-*Cryptosporidium*	3	5	
	Cryptosporidium	0	1	
Membrane, porous ceramic or composite filtration				
Porous ceramic and carbon block filtration	Bacteria	2	6	Varies with pore size, flow rate, filter medium and inclusion of augmentation with silver or other chemical agents
	Viruses	1	4	
	Protozoa	4	6	
Membrane filtration (microfiltration, ultrafiltration, nanofiltration, reverse osmosis)	Bacteria	2 MF; 3 UF, NF or RO	4 MF; 6 UF, NF or RO	Varies with membrane pore size, integrity of filter medium and filter seals, and resistance to chemical and biological ("grow-through") degradation
	Viruses	0 MF; 3 UF, NF or RO	4 MF; 6 UF, NF or RO	
	Protozoa	2 MF; 3 UF, NF or RO	6 MF; 6 UF, NF or RO	
Fibre and fabric filtration (e.g. sari cloth filtration)	Bacteria	1	2	Particle or plankton association increases removal of microbes, notably copepod-associated guinea worm (*Dracunculus medinensis*) and plankton-associated *Vibrio cholerae*; larger protozoa (> 20 µm) may be removed; ineffective for viruses, dispersed bacteria and small protozoa (e.g. *Giardia intestinalis*, 8–12 µm, and *Cryptosporidium*, 4–6 µm)
	Viruses	0	0	
	Protozoa	0	1	
Granular media filtration				
Rapid granular, diatomaceous earth, biomass and fossil fuel–based (granular and powdered activated carbon, wood and charcoal ash, burnt rice hulls, etc.) filters	Bacteria	1	4+	Varies considerably with media size and properties, flow rate and operating conditions; some options are more practical than others for use in developing countries
	Viruses	1	4+	
	Protozoa	1	4+	
Household-level intermittently operated slow sand filtration	Bacteria	1	3	Varies with filter maturity, operating conditions, flow rate, grain size and filter bed contact time
	Viruses	0.5	2	
	Protozoa	2	4	

Table 7.8 (continued)

Treatment process	Enteric pathogen group	Baseline removal (LRV)	Maximum removal (LRV)	Notes
Solar disinfection				
Solar disinfection (solar UV radiation + thermal effects)	Bacteria	3	5+	Varies depending on oxygenation, sunlight intensity, exposure time, temperature, turbidity and size of water vessel (depth of water)
	Viruses	2	4+	
	Protozoa	2	4+	
UV light technologies using lamps				
UV irradiation	Bacteria	3	5+	Excessive turbidity and certain dissolved species inhibit process; effectiveness depends on fluence (dose), which varies with intensity, exposure time, UV wavelength
	Viruses	2	5+	
	Protozoa	3	5+	
Thermal (heat) technologies				
Thermal (e.g. boiling)	Bacteria	6	9+	Values are based on vegetative cells; spores are more resistant to thermal inactivation than are vegetative cells; treatment to reduce spores by boiling must ensure sufficient temperature and time
	Viruses	6	9+	
	Protozoa	6	9+	
Sedimentation				
Simple sedimentation	Bacteria	0	0.5	Effective due to settling of particle-associated and large (sedimentable) microbes; varies with storage time and particulates in the water
	Viruses	0	0.5	
	Protozoa	0	1	
Combination treatment approaches				
Flocculation plus disinfection systems (e.g. commercial powder sachets or tablets)	Bacteria	7	9	Some removal of *Cryptosporidium* possible by coagulation
	Viruses	4.5	6	
	Protozoa	3	5	

LRV, $\log_{10}$ reduction value; MF, microfilter; NF, nanofilter; RO, reverse osmosis; UF, ultrafilter

The values in Table 7.8 do not account for post-treatment contamination of stored water, which may limit the effectiveness of some technologies where safe storage methods are not practised. The best options for water treatment at the household level will also employ means for safe storage, such as covered, narrow-mouthed vessels with a tap system or spout for dispensing stored water.

Validation, surveillance and certification of household water treatment and storage are recommended, just as they are for central water supplies and systems. The entities responsible for these activities for household water treatment systems may differ from those of central supplies. In addition, separate entities may be responsible for validation, independent surveillance and certification. Nevertheless, validation and surveillance as well as certification are critical for effective management of household

and other point-of-use and point-of-entry drinking-water supplies and their treatment and storage technologies, just as they are for central systems (see sections 2.3 and 5.2.3).

Non-piped water treatment technologies manufactured by or obtained from commercial or other external sources should be certified to meet performance or effectiveness requirements or guidelines, preferably by an independent, accredited certification body. If the treatment technologies are locally made and managed by the household itself, efforts to document effective construction and use and to monitor performance during use are recommended and encouraged.

7.4 Microbial monitoring

Microbial monitoring can be undertaken for a range of purposes, including:

- validation (see also section 4.1.7);
- operational monitoring (see also sections 2.2.2 and 4.2);
- verification (see also sections 2.3.1 and 4.3);
- surveillance (see chapter 5);
- source water monitoring for identifying performance targets (see sections 7.2 and 7.3.1);
- collecting data for QMRA (see also section 7.2.3).

Owing to issues relating to complexity, sensitivity of detection, cost and timeliness of obtaining results, testing for specific pathogens is generally limited to assessing raw water quality as a basis for identifying performance targets and validation, where monitoring is used to determine whether a treatment or other process is effective in removing target organisms. Very occasionally, pathogen testing may be performed to verify that a specific treatment or process has been effective. However, microbial testing included in verification, operational and surveillance monitoring is usually limited to testing for indicator organisms.

It is important to recognize that different methods for pathogen detection measure different properties. Culture methods, such as broth cultures or agar-based bacterial media and cell cultures for viruses and phages, detect living organisms based on infection or growth. Pathogen detection by microscopy, nucleic acid presence or amplification (e.g. polymerase chain reaction) and immunological assays (e.g. enzyme-linked immunosorbent assay) measure the physical presence of the pathogen or components of them and do not necessarily determine if what is detected is alive or infectious. This creates greater uncertainty regarding the human health risk significance compared with detection by culture-based methods. When using non-culture methods that do not measure in units indicative of culturability or infectivity, assumptions are often made about the fraction of pathogens or components detected that represent viable and infectious organisms.

The concept of using organisms such as *E. coli* as indicators of faecal pollution is a well-established practice in the assessment of drinking-water quality. The criteria determined for such faecal indicators are that they should not be pathogens themselves and they should:

Table 7.9 Use of indicator organisms in monitoring

	Type of monitoring		
Microorganism(s)	**Validation of process**	**Operational**	**Verification and surveillance**
E. coli (or thermotolerant coliforms)	Not applicable	Not applicable	Faecal indicator
Total coliforms	Not applicable	Indicator for cleanliness and integrity of distribution systems	Not applicable
Heterotrophic plate counts	Indicator for effectiveness of disinfection of bacteria	Indicator for effectiveness of disinfection processes and cleanliness and integrity of distribution systems	Not applicable
Clostridium perfringens[a]	Indicator for effectiveness of disinfection and physical removal processes for viruses and protozoa	Not applicable	Not applicable[b]
Coliphages *Bacteroides fragilis* phages Enteric viruses	Indicator for effectiveness of disinfection and physical removal processes for viruses	Not applicable	Not applicable[b]

[a] Use of *Clostridium perfringens* for validation will depend on the treatment process being assessed.
[b] Could be used for verification where source waters are known to be contaminated with enteric viruses and protozoa or where such contamination is suspected as a result of impacts of human faecal waste.

- be universally present in faeces of humans and animals in large numbers;
- not multiply in natural waters;
- persist in water in a similar manner to faecal pathogens;
- be present in higher numbers than faecal pathogens;
- respond to treatment processes in a similar fashion to faecal pathogens;
- be readily detected by simple, inexpensive culture methods.

These criteria reflect an assumption that the same organism could be used as an indicator of both faecal pollution and treatment/process efficacy. However, it has become clear that one indicator cannot fulfil these two roles and that a range of organisms should be considered for different purposes (Table 7.9). For example, heterotrophic bacteria can be used as operational indicators of disinfection effectiveness and distribution system cleanliness; *Clostridium perfringens* and coliphage can be used to validate the effectiveness of treatment systems.

Escherichia coli has traditionally been used to monitor drinking-water quality, and it remains an important parameter in monitoring undertaken as part of verification or surveillance. Thermotolerant coliforms can be used as an alternative to the test for *E. coli* in many circumstances. Water intended for human consumption should contain no faecal indicator organisms. In the majority of cases, monitoring for *E. coli* or thermotolerant coliforms provides a high degree of assurance because of their large numbers in polluted waters.

Table 7.10 Guideline values for verification of microbial quality[a] (see also Table 5.2)

Organisms	Guideline value
All water directly intended for drinking	
E. coli or thermotolerant coliform bacteria[b,c]	Must not be detectable in any 100 ml sample
Treated water entering the distribution system	
E. coli or thermotolerant coliform bacteria[b]	Must not be detectable in any 100 ml sample
Treated water in the distribution system	
E. coli or thermotolerant coliform bacteria[b]	Must not be detectable in any 100 ml sample

[a] Immediate investigative action must be taken if *E. coli* are detected.

[b] 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 as an indicator of the sanitary quality of water supplies, particularly in tropical areas, where many bacteria of no sanitary significance occur in almost all untreated supplies.

[c] It is recognized that in the great majority of rural water supplies, especially in developing countries, faecal contamination is widespread. Especially under these conditions, medium-term targets for the progressive improvement of water supplies should be set.

However, increased attention has focused on the shortcomings of traditional indicators, such as *E. coli*, as indicator organisms for enteric viruses and protozoa. Viruses and protozoa more resistant to conventional environmental conditions or treatment technologies, including filtration and disinfection, may be present in treated drinking-water in the absence of *E. coli*. Retrospective studies of waterborne disease outbreaks have shown that complete reliance on assumptions surrounding the absence or presence of *E. coli* may not ensure safety. Under certain circumstances, it may be desirable to include more resistant microorganisms, such as bacteriophages and/or bacterial spores, as indicators of persistent microbial hazards. Their inclusion in monitoring programmes, including control and surveillance programmes, should be evaluated in relation to local circumstances and scientific understanding. Such circumstances could include the use of source water known to be contaminated with enteric viruses and parasites or where such contamination is suspected as a result of the impacts of human and livestock waste.

Further discussion on indicator organisms is contained in the supporting document *Assessing microbial safety of drinking water* (Annex 1).

Table 7.10 presents guideline values for verification of the microbial quality of drinking-water. Individual values should not be used directly from the table. The guideline values should be used and interpreted in conjunction with the information contained in these Guidelines and other supporting documentation.

A consequence of variable susceptibility to pathogens is that exposure to drinking-water of a particular quality may lead to different health effects in different populations. For derivation of national standards, it is necessary to define reference populations or, in some cases, to focus on specific vulnerable subpopulations. National or local authorities may wish to apply specific characteristics of their populations in deriving national standards.

Table 7.11 International Organization for Standardization (ISO) standards for detection and enumeration of faecal indicator organisms in water

ISO standard	Title (water quality)
6461-1:1986	Detection and enumeration of the spores of sulfite-reducing anaerobes (clostridia)—Part 1: Method by enrichment in a liquid medium
6461-2:1986	Detection and enumeration of the spores of sulfite-reducing anaerobes (clostridia)—Part 2: Method by membrane filtration
7704:1985	Evaluation of membrane filters used for microbiological analyses
9308-1:2000	Detection and enumeration of *Escherichia coli* and coliform bacteria—Part 1: Membrane filtration method
9308-2:1990	Detection and enumeration of coliform organisms, thermotolerant coliform organisms and presumptive *Escherichia coli*—Part 2: Multiple tube (most probable number) method
9308-3:1998	Detection and enumeration of *Escherichia coli* and coliform bacteria—Part 3: Miniaturized method (most probable number) for the detection and enumeration of *E. coli* in surface and waste water
10705-1:1995	Detection and enumeration of bacteriophages—Part 1: Enumeration of F-specific RNA bacteriophages
10705-2:2000	Detection and enumeration of bacteriophages—Part 2: Enumeration of somatic coliphages
10705-3:2003	Detection and enumeration of bacteriophages—Part 3: Validation of methods for concentration of bacteriophages from water
10705-4:2001	Detection and enumeration of bacteriophages—Part 4: Enumeration of bacteriophages infecting *Bacteroides fragilis*

7.5 Methods of detection of faecal indicator organisms

Analysis for faecal indicator organisms provides a sensitive, although not the most rapid, indication of pollution of drinking-water supplies. Because the growth medium and the conditions of incubation, as well as the nature and age of the water sample, can influence the species isolated and the count, microbiological examinations may have variable accuracy. This means that the standardization of methods and of laboratory procedures is of great importance if criteria for the microbial quality of water are to be uniform in different laboratories and internationally.

International standard methods should be evaluated under local circumstances before being adopted. Established standard methods are available, such as those of the International Organization for Standardization (ISO) (Table 7.11) or methods of equivalent efficacy and reliability. It is desirable that established standard methods be used for routine examinations. Whatever method is chosen for detection of *E. coli* or thermotolerant coliforms, the importance of "resuscitating" or recovering environmentally damaged or disinfectant-damaged strains must be considered.

7.6 Identifying local actions in response to microbial water quality problems and emergencies

During an emergency in which there is evidence of faecal contamination of the drinking-water supply, it may be necessary either to modify the treatment of existing

sources or to temporarily use alternative sources of drinking-water. It may be necessary to increase disinfection at source, following treatment or during distribution.

If microbial quality cannot be maintained, it may be necessary to advise consumers to boil the water during the emergency (see section 7.6.1). Initiating superchlorination and undertaking immediate corrective measures may be preferable where the speed of response is sufficient to prevent significant quantities of contaminated water from reaching consumers.

During outbreaks of potentially waterborne disease or when faecal contamination of a drinking-water supply is detected, the concentration of free chlorine should be increased to greater than 0.5 mg/l throughout the system as a minimum immediate response. It is most important that decisions are taken in consultation with public health authorities and, where appropriate, civil authorities (see also sections 4.4.3, 6.2 and 8.7).

7.6.1 Boil water advisories

Boil water advisories share many features with water avoidance advisories used in the event of serious chemical contamination (see section 8.7). Water suppliers in conjunction with public health authorities should develop protocols for boil water orders. Protocols should be prepared prior to the occurrence of incidents and incorporated within management plans. Decisions to issue advisories are often made within a short period of time, and developing responses during an event can complicate decision-making, compromise communication and undermine public confidence. In addition to the information discussed in section 4.4.3, the protocols should deal with:

- criteria for issuing and rescinding advisories;
- information to be provided to the general public and specific groups;
- activities affected by the advisory.

Protocols should identify mechanisms for the communication of boil water advisories. The mechanisms may vary, depending on the nature of the supply and the size of the community affected, and could include:

- media releases through television, radio and newspapers;
- telephone, e-mail and fax contact of specific facilities, community groups and local authorities;
- posting of notices in conspicuous locations;
- personal delivery;
- mail delivery.

The methods chosen should provide a reasonable surety that all of those affected by the advisory, including residents, workers and travellers, are notified as soon as possible.

Boil water advisories should indicate that the water can be made safe by bringing it to a rolling boil. After boiling, the water should be allowed to cool down on its own without the addition of ice. This procedure is effective at all altitudes and with turbid water. The types of event that should lead to consideration of boil water advisories include:

- substantial deterioration in source water quality;

- major failures associated with treatment processes or the integrity of distribution systems;
- inadequate disinfection;
- detection of pathogens or faecal indicator organisms in drinking-water;
- epidemiological evidence suggesting that drinking-water is responsible for an outbreak of illness.

Boil water advisories are a serious measure that can have substantial adverse consequences. Advice to boil water can have negative public health consequences through scalding and increased anxiety, even after the advice is rescinded. In addition, not all consumers will follow the advice issued, even at the outset; if boil water advisories are issued frequently or are left in place for long periods, compliance will decrease. Hence, advisories should be issued only after careful consideration of all available information by the public health authority and the incident response team and conclusion that there is an ongoing risk to public health that outweighs any risk from the advice to boil water. For example, where microbial contamination is detected in samples of drinking-water, factors that should be considered in evaluating the need for an advisory include:

- reliability and accuracy of results;
- vulnerability of source water to contamination;
- evidence of deterioration in source water quality;
- source water monitoring results;
- results from operational monitoring of treatment and disinfection processes;
- disinfectant residuals;
- physical integrity of the distribution system.

The available information should be reviewed to determine the likely source of the contamination and the likelihood of recurrence or persistence.

When issued, a boil water advisory should be clear and easily understood by recipients, or it may be ignored. Advisories should normally include a description of the problem, potential health risks and symptoms, activities that are affected, investigative actions and corrective measures that have been initiated, as well as the expected time to resolve the problem. If the advisory is related to an outbreak of illness, specific information should be provided on the nature of the outbreak, the illness and the public health response.

Boil water advisories should identify both affected and unaffected uses of drinking-water supplies. Generally, the advisory will indicate that unboiled water should not be used for drinking, preparing cold drinks, making ice, preparing or washing food or brushing teeth. Unless heavily contaminated, unboiled water will generally be safe for bathing (providing swallowing of water is avoided) and washing clothes. A boil water advisory could include specific advice for vulnerable subpopulations, such as pregnant women and others who might be immunocompromised. Specific advice should also be provided to facilities such as dental clinics, dialysis centres, doctors' offices, hospitals and other health-care facilities, child-care facilities, schools, food suppliers and manufacturers, hotels, restaurants and operators of public swimming pools and spas.

Provision of alternative supplies of drinking-water, such as bottled water or bulk water, should be considered when temporary boil water advisories are in place. The protocols should identify sources of alternative supplies and mechanisms for delivery.

Protocols should include criteria for rescinding boil water advisories. Depending on the reason for issuing the advisory, the criteria could include one or more of the following:

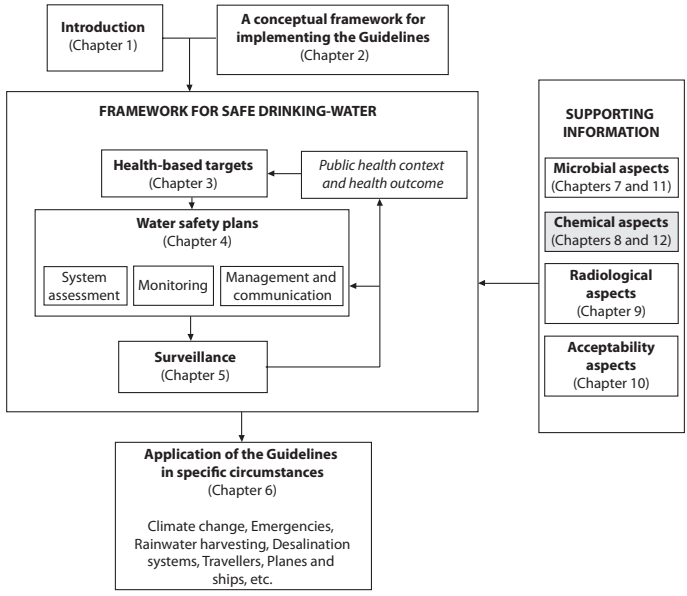
- evidence that source water quality has returned to normal;
- correction of failures associated with treatment processes or distribution systems;
- correction of faults in disinfection processes and restoration of normal disinfectant residuals;
- where detection of microbial contamination in drinking-water initiated the advisory, evidence that this contamination has been removed or inactivated;
- evidence that sufficient mains flushing or water displacement has removed potentially contaminated water and biofilms;
- epidemiological evidence indicating that an outbreak has concluded.

When boil water advisories are rescinded, information should be provided through similar channels and to the same groups that received the original advice. In addition, operators/managers or occupants of large buildings and buildings with storage tanks should be advised of the need to ensure that storages and extensive internal distribution systems are thoroughly flushed before normal uses are restored.

7.6.2 Actions following an incident

It is important that any incident be properly investigated and remedial action instigated to prevent its recurrence. The water safety plan will require revision to take into account the experience gained, and the findings may also be of importance in informing actions regarding other water supplies to prevent a similar event from occurring elsewhere. Where appropriate, epidemiological investigations by the health authority will also help to inform actions for the future.

8
Chemical aspects



Most chemicals arising in drinking-water are of health concern only after extended exposure of years, rather than months. The principal exception is nitrate. Typically, changes in water quality occur progressively, except for those substances that are discharged or leach intermittently to flowing surface waters or groundwater supplies from, for example, contaminated landfill sites.

In some cases, there are groups of chemicals that arise from related sources—for example, disinfection by-products (DBPs)—and it may not be necessary to set standards for all of the DBPs for which there are guideline values. If chlorination is practised, the trihalomethanes (THMs) and haloacetic acids (HAAs) will be the main DBPs. If bromide is present, brominated as well as chlorinated DBPs will be produced. Maintaining THM and HAA concentrations below the guideline values by controlling precursor compounds will provide adequate control over other chlorination by-products.

Several of the inorganic elements for which guideline values have been established are recognized to be essential elements in human nutrition. No attempt has been made here at this time to define a minimum desirable concentration of such substances in drinking-water, although the issue of nutritional essentiality is considered during the guideline development process.

Fact sheets for individual chemical contaminants are provided in chapter 12. For those contaminants for which a guideline value has been established, the fact sheets include a brief toxicological overview of the chemical, the basis for guideline derivation, treatment performance and analytical limit of detection. More detailed chemical reviews are available (http://www.who.int/water_sanitation_health/dwq/chemicals/en/index.html).

8.1 Chemical hazards in drinking-water

A few chemical contaminants have been shown to cause adverse health effects in humans as a consequence of prolonged exposure through drinking-water. However, this is only a very small proportion of the chemicals that may reach drinking-water from various sources.

> The lists of chemicals addressed in these Guidelines do not imply that all of these chemicals will always be present or that other chemicals not addressed will be absent.

The substances considered here have been assessed for possible health effects, and guideline values have been established only on the basis of health concerns. Additional consideration of the potential effects of chemical contaminants on the acceptability (i.e. taste, odour and appearance) of drinking-water to consumers is included in chapter 10. Some substances of health concern have effects on the acceptability of drinking-water that would normally lead to rejection of the water at concentrations significantly lower than those of health concern. For such substances, no formal guideline value is usually proposed, but a health-based value (see section 8.2) may be needed, for instance, in order to assist in judging the response required when problems are encountered and in some cases to provide reassurance to health authorities and consumers with regard to possible health risks.

Regulators are required to establish health-based targets that must be met through water safety plans. In the case of chemical contaminants, these are normally based on the guideline value, which is, in turn, based on health-related end-points. In this case, the guideline value and the local water quality target are similar, but not necessarily identical, because the latter value may need to be adjusted to take into account local sociocultural, economic and environmental/geological circumstances, as indicated in section 2.6. Guideline values provide a benchmark for the development of local water quality targets for chemicals (usually a national standard expressing a maximum allowable concentration). Guideline values may not directly reflect the target of 10^{-6} disability-adjusted life year (DALY), as these are frequently derived based on evidence indicating a no-adverse-effect or negligible risk level. Some guideline values are based on extrapolation of the risk of cancer from exposures at which this can be measured to low exposures where measurement is currently not possible.

In section 2.6, it is stated that "In developing national drinking-water standards based on these Guidelines, it will be necessary to take account of a variety of environmental, social, cultural, economic, dietary and other conditions affecting potential exposure. This may lead to national standards that differ appreciably from these Guidelines." This is particularly applicable to chemical contaminants, for which there

is a long list, and setting standards for, or including, all of them in monitoring programmes is neither feasible nor desirable.

It is important that chemical contaminants be prioritized so that the most important in the country or local region are considered for inclusion in national standards and monitoring programmes.

The probability that any particular chemical may occur in significant concentrations in any particular setting must be assessed on a case-by-case basis. The presence of certain chemicals may already be known within a particular country, but others may be more difficult to assess.

In most countries, whether developing or industrialized, water sector professionals are likely to be aware of a number of chemicals that are present in significant concentrations in some drinking-water supplies. A body of local knowledge that has been built up by practical experience over a period of time is invaluable. Hence, the presence of a limited number of chemical contaminants in drinking-water is usually already known in many countries and in many local systems. Significant problems, even crises, can occur, however, when chemicals posing high health risk are widespread but their presence is unknown, because their long-term health effect is caused by chronic exposure as opposed to acute exposure. Such has been the case of arsenic in groundwater in Bangladesh and West Bengal, India, for example.

For many contaminants, there will be exposure from sources other than drinking-water, and this may need to be taken into account when setting, and considering the need for, standards. It may also be important when considering the need for monitoring. In some cases, drinking-water will be a minor source of exposure, and controlling levels in water will have little impact on overall exposure. In other cases, controlling a contaminant in water may be the most cost-effective way of reducing exposure. Drinking-water monitoring strategies should therefore not be considered in isolation from other potential routes of exposure to chemicals in the environment.

The scientific basis for each of the guideline values is summarized in chapter 12. This information is important in helping to adapt guideline values to suit national requirements or for assessing the health significance of a contaminant that is of a higher concentration than the guideline value.

Chemical contaminants in drinking-water may be categorized in various ways; however, the most appropriate is to consider the primary source of the contaminant—that is, to group chemicals according to where control may be effectively exercised. This aids in the development of approaches that are designed to prevent or minimize contamination, rather than those that rely primarily on the measurement of contaminant levels in final waters.

In general, approaches to the management of chemical hazards in drinking-water vary between those where the source water is a significant contributor (with control effected, for example, through source water selection, pollution control, treatment or blending) and those from materials and chemicals used in the production and distribution of drinking-water (controlled by process optimization or product specification). In these Guidelines, chemicals are therefore divided into five major source groups, as shown in Table 8.1.

Table 8.1 Categorization of source of chemical constituents

Source of chemical constituents	Examples of sources
Naturally occurring	Rocks, soils and the effects of the geological setting and climate; eutrophic water bodies (also influenced by sewage inputs and agricultural runoff)
Industrial sources and human dwellings	Mining (extractive industries) and manufacturing and processing industries, sewage (including a number of contaminants of emerging concern), solid wastes, urban runoff, fuel leakages
Agricultural activities	Manures, fertilizers, intensive animal practices and pesticides
Water treatment or materials in contact with drinking-water	Coagulants, DBPs, piping materials
Pesticides used in water for public health	Larvicides used in the control of insect vectors of disease

Categories may not always be clear-cut. The group of naturally occurring contaminants, for example, includes many inorganic chemicals that are found in drinking-water as a consequence of release from rocks and soils by rainfall, some of which may become problematical where there is environmental disturbance, such as in mining areas.

8.2 Derivation of chemical guideline values

One of the following criteria must be satisfied in order for a guideline value to be established for a particular chemical constituent:

- There is credible evidence of occurrence of the chemical in drinking-water, combined with evidence of actual or potential toxicity.
- The chemical is of significant international concern.
- The chemical is being considered for inclusion or is included in the World Health Organization Pesticide Evaluation Scheme (WHOPES), which coordinates the testing and evaluation of pesticides for public health, including those applied directly to drinking-water for control of insect vectors of disease.

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 at concentrations that are reasonably achievable through practical treatment approaches or in analytical laboratories; in these cases, the guideline value is above the concentration that would normally represent the calculated health-based value. Guideline values are also designated as provisional when there is a high degree of uncertainty in the toxicological and health data (see also section 8.2.5). For some chemicals, no formal guideline value is proposed on the grounds that occurrence is only at concentrations well below those that would be of concern for health. In order to provide guidance for Member States should the chemical be found in drinking-water or in source water in the hazard identification

phase of developing a water safety plan, a "health-based value" has been determined. Establishing a formal guideline value for such substances could encourage some Member States to incorporate a value into their national standards when this is neither necessary nor appropriate.

There are two principal sources of information on health effects resulting from exposure to chemicals that can be used in deriving guideline values. The first and preferred source is studies on human populations. However, the availability of such studies for most substances is limited, owing to the ethical barriers to conducting human toxicological studies and the lack of quantitative information on the concentration to which people have been exposed or on simultaneous exposure to other agents. However, for a few substances, such studies are the primary basis on which guideline values are developed. The second and most frequently used source of information is toxicological studies using laboratory animals. The limitations of toxicological studies include the relatively small number of experimental animals used and the relatively high doses administered, which create uncertainty as to the relevance of particular findings to human health. This uncertainty stems from the need to extrapolate the results from experimental animals to humans and to the low doses to which human populations are usually exposed. In most cases, the study used to derive the guideline value is supported by a range of other studies, including human data, and these are also considered in carrying out a health risk assessment.

In order to derive a guideline value to protect human health, it is necessary to select the most suitable study or studies. Data from well-conducted studies, where a clear dose–response relationship has been demonstrated, are preferred. Expert judgement, applied against criteria described in section 8.2.4, is exercised in the selection of the most appropriate studies from the range of information available. Safety or uncertainty factors using standard risk assessment principles are included to provide conservative guideline values that are considered to be protective.

8.2.1 Approaches taken

Two approaches to the derivation of guideline values are used: one for "threshold chemicals" and the other for "non-threshold chemicals" (mostly genotoxic carcinogens).

It is generally considered that the initiating event in the process of genotoxic chemical carcinogenesis is the induction of a mutation in the genetic material (deoxyribonucleic acid [DNA]) of somatic cells (i.e. cells other than ova or sperm) and that there is a theoretical risk at any level of exposure (i.e. no threshold). In contrast, there are carcinogens that are capable of producing tumours in experimental animals or humans without exerting a genotoxic activity, but acting through an indirect mechanism. It is generally believed that a demonstrable threshold dose exists for non-genotoxic carcinogens.

In deriving guideline values for carcinogens, consideration is given to the potential mechanisms by which the substance may cause cancer, in order to decide whether a threshold or non-threshold approach should be used (see sections 8.2.2 and 8.2.3).

The evaluation of the potential carcinogenicity of chemical substances is usually based on long-term laboratory animal studies. Sometimes data are available on carcinogenicity in humans, mostly from occupational exposure.

On the basis of the available evidence, the International Agency for Research on Cancer (IARC) categorizes chemical substances with respect to their potential carcinogenic risk into the following groups:

Group 1:	the agent is carcinogenic to humans
Group 2A:	the agent is probably carcinogenic to humans
Group 2B:	the agent is possibly carcinogenic to humans
Group 3:	the agent is not classifiable as to its carcinogenicity to humans
Group 4:	the agent is probably not carcinogenic to humans

According to IARC, these classifications represent a first step in carcinogenic risk assessment, which leads to a second step of quantitative risk assessment where possible. In establishing guideline values for drinking-water, the IARC evaluation of carcinogenic compounds, where available, is taken into consideration.

8.2.2 Threshold chemicals

For most kinds of toxicity, it is believed that there is a dose below which no adverse effect will occur. For chemicals that give rise to such toxic effects, a tolerable daily intake (TDI) should be derived as follows, using the most sensitive end-point in the most relevant study, preferably involving administration in drinking-water:

$$\text{TDI} = \frac{\text{NOAEL or LOAEL or BMDL}}{\text{UF and/or CSAF}}$$

where:

NOAEL	=	no-observed-adverse-effect level
LOAEL	=	lowest-observed-adverse-effect level
BMDL	=	lower confidence limit on the benchmark dose
UF	=	uncertainty factor
CSAF	=	chemical-specific adjustment factor

The guideline value (GV) is then derived from the TDI as follows:

$$\text{GV} = \frac{\text{TDI} \times \text{bw} \times \text{P}}{\text{C}}$$

where:

bw	=	body weight (see below)
P	=	fraction of the TDI allocated to drinking-water
C	=	daily drinking-water consumption (see below)

Tolerable daily intake

The TDI is an estimate of the amount of a substance in food and drinking-water, expressed on a body weight basis (milligram or microgram per kilogram of body weight), that can be ingested over a lifetime without appreciable health risk, and with a margin of safety.

Acceptable daily intakes (ADIs) are established for food additives and pesticide residues that occur in food for necessary technological purposes or plant protection reasons. For chemical contaminants, which usually have no intended function in drinking-water, the term "tolerable daily intake" is more appropriate than "acceptable daily intake", as it signifies permissibility rather than acceptability.

Over many years, the Joint Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Expert Committee on Food Additives (JECFA) and the Joint FAO/WHO Meeting on Pesticide Residues (JMPR) have developed certain principles in the derivation of ADIs (FAO/WHO, 2009). These principles have been adopted, where appropriate, in the derivation of TDIs used in developing guideline values for drinking-water quality.

As TDIs are regarded as representing a tolerable intake for a lifetime, they are not so precise that they cannot be exceeded for short periods of time. Short-term exposure to levels exceeding the TDI is not a cause for concern, provided the individual's intake averaged over longer periods of time does not appreciably exceed the level set. The large uncertainty factors generally involved in establishing a TDI (see below) serve to provide assurance that exposure exceeding the TDI for short periods is unlikely to have any deleterious effects upon health. However, consideration should be given to any potential acute effects that may occur if the TDI is substantially exceeded for short periods of time.

No-observed-adverse-effect level and lowest-observed-adverse-effect level

The NOAEL is defined as the highest dose or concentration of a chemical in a single study, found by experiment or observation, that causes no detectable adverse health effect. Wherever possible, the NOAEL is based on long-term studies, preferably of ingestion in drinking-water. However, NOAELs obtained from short-term studies and studies using other sources of exposure (e.g. food, air) may also be used.

If a NOAEL is not available, a LOAEL may be used, which is the lowest observed dose or concentration of a substance at which there is a detectable adverse health effect. When a LOAEL is used instead of a NOAEL, an additional uncertainty factor is normally applied (see below).

Benchmark dose

Increasingly, the preferred approaches for the derivation of TDIs/ADIs for threshold effects include the benchmark dose (BMD) or the lower confidence limit on the benchmark dose (BMDL) (IPCS, 1994). When appropriate data for mathematical modelling of dose–response relationships are available, BMDLs are used as alternatives to NOAELs in the calculation of health-based guideline values. In such a case, use of the BMDL could eliminate the need for application of an additional uncertainty factor to the LOAEL. The BMDL is the lower confidence limit of the dose that

Table 8.2 Source of uncertainty in derivation of guideline values

Source of uncertainty	Uncertainty factor
Interspecies variation (extrapolating from experimental animals to humans)	1–10
Intraspecies variation (accounting for individual variations within humans)	1–10
Adequacy of studies or database	1–10
Nature and severity of effect	1–10

produces a small increase (e.g. 5% or 10%) in the level of adverse effects. The BMDL is derived on a quantitative basis using data from the entire dose–response curve for the critical effect rather than from a single dose at the NOAEL or LOAEL and accounts for the statistical power and quality of the data (IPCS, 2009).

Uncertainty factors

The application of uncertainty or safety factors has been traditionally and successfully used in the derivation of ADIs and TDIs for food additives, pesticides and environmental contaminants. The derivation of these factors requires expert judgement and careful consideration of the available scientific evidence.

In the derivation of guideline values, uncertainty factors are applied to the NOAEL, LOAEL or BMD/BMDL for the response considered to be the most biologically significant.

In relation to exposure of the general population, the NOAEL or BMD/BMDL for the critical effect in experimental animals is normally divided by an uncertainty factor of 100. This comprises two 10-fold factors, one for interspecies differences and one for interindividual variability in humans (Table 8.2). Extra uncertainty factors may be incorporated to allow for database deficiencies and for the severity or irreversibility of effects.

Factors lower than 10 are used, for example, for interspecies variation when humans are known to be less sensitive than the experimental animal species studied. Inadequate studies or databases include those where a LOAEL is used instead of a NOAEL and studies considered to be shorter in duration than desirable. Situations in which the nature or severity of effect might warrant an additional uncertainty factor include studies in which the end-point is malformation of a fetus or in which the end-point determining the NOAEL is directly related to possible carcinogenicity. In the latter case, an additional uncertainty factor is usually applied for carcinogenic compounds for which the guideline value is derived using a TDI approach rather than a theoretical risk extrapolation approach.

For substances for which the uncertainty factors are greater than 1000, guideline values are designated as provisional in order to emphasize the higher level of uncertainty inherent in these values. A high uncertainty factor indicates that the guideline value may be considerably lower than the concentration at which health effects would actually occur in a real human population. Guideline values with high uncertainty are more likely to be modified as new information becomes available.

The selection and application of uncertainty factors are important in the derivation of guideline values for chemicals, as they can make a considerable difference in the

values set. For contaminants for which there is sufficient confidence in the database, the guideline value is derived using a small uncertainty factor. For most contaminants, however, there is greater scientific uncertainty, and a relatively large uncertainty factor is used. The use of uncertainty factors enables the particular attributes of the chemical and the data available to be considered in the derivation of guideline values.

Use of chemical-specific adjustment factors instead of uncertainty factors

Approaches to the derivation of TDIs are increasingly being based on understanding of a chemical's mode of action in order to reduce reliance on default assumptions. This approach provides a departure from the use of default uncertainty factors (such as a simple 10 for interspecies variation and 10 for intraspecies variation) and relies on the use of quantitative toxicokinetic and toxicodynamic data to derive CSAFs for use in interspecies and intraspecies extrapolations (IPCS, 2005). Previously, CSAFs were called "data-derived uncertainty factors". The part of the CSAF approach that is at present best developed is the use of physiologically based pharmacokinetic models to replace the default values for extrapolation between species and between differing routes of exposure (e.g. inhalation to oral).

Relative source allocation

Drinking-water is usually not the only source of human exposure to the chemicals for which guideline values have been derived. In many cases, the exposure to or intake of chemical contaminants from drinking-water is much lower than that from other sources, such as food, air and consumer products. Some consideration of the proportion of the ADI or TDI that may be attributed to different sources is therefore needed in developing guideline values and risk management strategies. This approach ensures that total daily intake from all sources (including drinking-water containing concentrations of the chemical at or near the guideline value) does not exceed the ADI or TDI.

Wherever possible, data on the proportion of total daily intake normally ingested in drinking-water (based on mean levels in food, drinking-water and air) or intakes estimated on the basis of physical and chemical properties of the substances of concern are used in the derivation of guideline values. As the primary sources of exposure to chemicals are generally food (e.g. pesticide residues) and water, it is important to quantify the exposures from both sources. To inform this process, it is desirable to collect as many high-quality data on food intake in different parts of the world as possible. The data collected can then be used to estimate the proportion of the intake that comes from food and the proportion that comes from drinking-water.

Where appropriate information on exposure from food and water is not available, allocation factors are applied that reflect the likely contribution of water to total daily intake for various chemicals. In the absence of adequate exposure data, the normal allocation of the total daily intake to drinking-water is 20%, which reflects a reasonable level of exposure based on broad experience, while still being protective. This value reflects a change from the previous allocation of 10%, which was found to be excessively conservative. As chemicals are progressively reassessed, overall exposure will be reconsidered, and a change in the default allocation factor

from 10% to 20% will be made, if appropriate. Therefore, not all older guideline values in this edition will reflect this change. In some circumstances, there is clear evidence that exposure from food is very low, such as for some of the DBPs; the allocation in such cases may be as high as 80%, which still allows for some exposure from other sources. In the case of some pesticides, which are likely to be found as residues in food from which there will be significant exposure, the allocation for water may be as low as 1%.

A detailed explanation of the reasoning behind the choice of allocation factor is an essential component of the evaluation. This assists Member States in making appropriate decisions about incorporating or adapting guideline values into national standards where local circumstances need to be taken into account. It also provides assistance in making decisions regarding potential risks when a guideline value is exceeded. As a general principle, efforts should be made to keep contaminant concentrations as low as possible and not allow increases up to the guideline value.

Although the values chosen are, in most cases, sufficient to account for additional routes of intake (i.e. inhalation and dermal absorption) of contaminants in water, under certain circumstances (e.g. limited ventilation), authorities may wish to take inhalation and dermal exposure into account in adapting the guideline values to local conditions (see section 8.2.9).

Some elements are essential for human nutrition. In developing guideline values and in considering allocation factors, it is necessary to take into account the recommended minimum daily intake and exposures from food and to ensure that the allocation does not result in an apparent conflict with essentiality.

Default assumptions

There is variation in both the volume of water consumed daily and the body weight of consumers. It is therefore necessary to apply some assumptions in order to determine a guideline value. The default assumption for consumption by an adult is 2 litres of water per day, whereas the default assumption for body weight is 60 kg.

In some cases, the guideline value is based on children, where they are considered to be particularly vulnerable to a particular substance. In this event, a default intake of 1 litre is assumed for a body weight of 10 kg; where the most vulnerable group is considered to be bottle-fed infants, an intake of 0.75 litre is assumed for a body weight of 5 kg.

Significant figures

The calculated TDI is used to derive the guideline value, which is usually rounded to one significant figure. In some instances, ADI values with only one significant figure set by JECFA or JMPR were used to calculate the guideline value. The guideline value was generally rounded to one significant figure to reflect the uncertainty in, for example, experimental animal toxicity data, exposure assumptions made and the uncertainty factors selected. In a few cases, rounding to two significant figures was found to be appropriate, as the impact of rounding depends on the units; for example, rounding from 1.5 to 2.0 µg/l has less influence on exposure than rounding from 1.5 to 2.0 mg/l. These are considered on a case-by-case basis.

The general rounding rule for mid-way values (x.5) is to round up, in line with common convention. Examples for rounding to one significant figure are as follows: 1.25 becomes 1, 0.73 becomes 0.7 and 1.5 becomes 2.

8.2.3 Non-threshold chemicals

In the case of compounds considered to be genotoxic carcinogens, guideline values are normally determined using a mathematical model. Although several models exist, the linearized multistage model is generally adopted. Other models are considered more appropriate in certain cases. These models compute an estimate of risk at a particular level of exposure, along with upper and lower bounds of confidence on the calculation, which may include zero at the lower bound. Guideline values are conservatively presented as the concentrations in drinking-water associated with an estimated upper-bound excess lifetime cancer risk of 10^{-5} (or one additional case of cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). This value does not equate to the number of cases of cancer that will be caused by exposure to the substance at this level. It is the maximum potential risk, taking into account large uncertainties. It is highly probable that the actual level of risk is less than this, even approaching zero, but risks at low levels of exposure cannot be experimentally verified. The recognition that the cancer risk may approach zero or be indistinguishable from zero stems from the uncertainties associated with mechanisms of carcinogenesis, including the role of the chemical in the cancer process and the possibility of detoxification and repair mechanisms. Member States may consider that a different level of hypothetical risk is more appropriate to their circumstances, and values relating to risks of 10^{-4} or 10^{-6} additional cancer cases over a lifetime of exposure may be determined by respectively multiplying or dividing the guideline value by 10.

The mathematical models used for deriving guideline values for non-threshold chemicals cannot be verified experimentally, and they do not usually take into account a number of biologically important considerations, such as pharmacokinetics, pre-systemic and metabolic detoxification, DNA repair or protection by the immune system. They also assume the validity of a linear extrapolation of very high dose exposures in test animals to very low dose exposures in humans. As a consequence, the models used are conservative (i.e. err on the side of caution). The guideline values derived using these models should be interpreted differently from TDI-derived values because of the lack of precision of the models. Moderate short-term exposure to levels exceeding the guideline value for non-threshold chemicals does not significantly affect the risk.

8.2.4 Data quality

The following factors were taken into account in assessing the quality and reliability of available information:

- Oral studies are preferred (in particular, drinking-water studies), using the pure substance with appropriate dosing regime and a good quality clinical biochemistry and histopathology.

- The database should be sufficiently broad that all potential toxicological end-points of concern have been identified.
- The quality of the studies is such that they are considered reliable; for example, there has been adequate consideration of confounding factors in epidemiological studies.
- There is reasonable consistency between studies; the end-point and study used to derive a guideline value do not contradict the overall weight of evidence.
- For inorganic substances, there is some consideration of speciation in drinking-water.
- There is appropriate consideration of multimedia exposure in the case of epidemiological studies.

In the development of guideline values, existing international approaches are carefully considered. In particular, previous risk assessments developed by the International Programme on Chemical Safety (IPCS) in Environmental Health Criteria monographs and Concise International Chemical Assessment Documents, IARC, JMPR and JECFA are reviewed. These assessments are relied upon except where new information justifies a reassessment, but the quality of new data is critically evaluated before it is used in any risk assessment. Where international reviews are not available, other sources of data are used in the derivation of guideline values, including published reports from peer-reviewed open literature, national reviews recognized to be of high quality, information submitted by governments and other interested parties and, to a limited extent, unpublished proprietary data (primarily for the evaluation of pesticides).

8.2.5 Provisional guideline values

The use and designation of provisional guideline values are outlined in Table 8.3.

For non-threshold substances, in cases in which the concentration associated with an upper-bound excess lifetime cancer risk of 10^{-5} is not feasible as a result of inadequate analytical or treatment technology, a provisional guideline value (designated A or T, respectively) is recommended at a practicable level.

Table 8.3 Use and designation of provisional guideline values

Situations where a provisional guideline applies	Designation	
Significant scientific uncertainties regarding derivation of health-based guideline value	P	
Calculated guideline value is below the achievable analytical quantification level	A	*(Guideline value is set at the achievable quantification level)*
Calculated guideline value is below the level that can be achieved through practical treatment methods	T	*(Guideline value is set at the practical treatment level)*
Calculated guideline value is likely to be exceeded as a result of disinfection procedures	D	*(Guideline value is set on the basis of health, but disinfection of drinking-water remains paramount)*

8.2.6 Chemicals with effects on acceptability

Some substances of health concern have effects on the taste, odour or appearance of drinking-water that would normally lead to rejection of water at concentrations significantly lower than those of concern for health. Such substances are not normally appropriate for routine monitoring. However, guideline values have been established for some substances that may cause taste or odour in drinking-water at concentrations much lower than the guideline values because there is such a wide range in the ability of consumers to detect them by taste or odour. For such substances, a fact sheet and health-based guideline value (see chapter 12) are presented in the usual way. In the fact sheet, the relationship between concentrations relevant to health and those relevant to the acceptability of the drinking-water is explained. In tables of guideline values, the health-based guideline values are designated with a "C". For other substances, health-based guideline values may be needed, for instance, in order to assist in judging the response that is required when problems are encountered and in some cases to provide reassurance to health authorities and consumers with regard to possible health risks.

8.2.7 Chemicals not included in the Guidelines

Additional information on many chemicals not included in these Guidelines is available from several credible sources, including WHO Environmental Health Criteria monographs and Concise International Chemical Assessment Documents (http://www.who.int/ipcs/en/), chemical risk assessment reports from JMPR, JECFA and IARC and published documents from a number of national sources, such as the United States Environmental Protection Agency. Although these information sources may not have been reviewed for these Guidelines, they have been peer reviewed and provide readily accessible information on the toxicology of many additional chemicals. They can help drinking-water suppliers and health officials decide upon the significance (if any) of a detected chemical and on the response that might be appropriate.

8.2.8 Mixtures

Chemical contaminants of drinking-water supplies are present with numerous other inorganic and organic constituents. The guideline values are calculated separately for individual substances, without specific consideration of the potential for interaction of each substance with other compounds present. Synergistic interactions between substances are usually selective and very limited, especially at the very low levels usually encountered in drinking-water. The large margin of uncertainty incorporated in the majority of the guideline values is considered to be sufficient to account for potential interactions. In addition, the majority of contaminants will not be continuously present at concentrations at or near their guideline value.

For many chemical contaminants, mechanisms of toxicity are different; consequently, there is no reason to assume that there are interactions. There may, however, be occasions when a number of contaminants with similar toxicological mechanisms are present at levels near their respective guideline values. In such cases, decisions concerning appropriate action should be made, taking into consideration local

circumstances. Unless there is evidence to the contrary, it is appropriate to assume that the toxic effects of these compounds are additive.

8.2.9 Adapting guideline values to local circumstances

In order to account for the variations in exposure from different sources in different parts of the world, default values, generally between 20% and 80%, are used to make an allocation of the TDI to drinking-water in setting guideline values for many chemicals. Where relevant exposure data are available, authorities are encouraged to develop context-specific guideline values that are tailored to local circumstances and conditions. For example, in areas where the intake of a particular contaminant in drinking-water is known to be much greater than that from other sources (e.g. air and food), it may be appropriate to allocate a greater proportion of the TDI to drinking-water to derive a guideline value more suited to the local conditions.

Daily water intake can vary significantly in different parts of the world, seasonally and particularly where consumers are involved in manual labour in hot climates. Local adjustments to the daily water consumption value may be needed in setting local standards, as in the case of fluoride, for example. For most other substances, the drinking-water intake range is very small (perhaps a factor of 2–4) compared with the much larger range in the toxicological uncertainty factors; hence, no such adjustment is necessary.

Volatile substances in water may be released to the atmosphere in showering and through a range of other household activities. Under such circumstances, inhalation may become a significant route of exposure. Some substances may also be absorbed through the skin during bathing, but this is not usually a major source of uptake. For those substances that are particularly volatile, such as chloroform, the correction factor would be approximately equivalent to a doubling of exposure, which is small in relation to the uncertainties inherent in the derivation of guideline values. However, in some parts of the world, houses have a very low rate of ventilation, and authorities may wish to take inhalation exposure into account in adapting the guideline values to local conditions, although other uncertainty factors used in the quantitative assessments may render this unnecessary. Where such exposure is shown to be important for a particular substance (i.e. high volatility, low ventilation rates and high rates of showering/bathing), it may be appropriate to adjust the guideline value accordingly.

8.3 Analytical achievability

As noted above, guideline values are not set at concentrations of substances that cannot reasonably be measured. In such circumstances, provisional guideline values are set at the reasonable analytical limits.

Guidance provided in this section and in Annex 4 is intended to assist readers to select appropriate analytical methods for specific circumstances. In carrying out hazard identification and risk assessment and for verification and auditing of the water safety plan for chemical contaminants, it is usually necessary to carry out some analysis. It is important that appropriate facilities are available to ensure that suitable methods are used in carrying out chemical analysis.

Various collections of "standard" or "recommended" methods for water analysis are published by a number of national and international agencies. It is often thought that adequate analytical accuracy can be achieved provided that all laboratories use the same standard method. Experience shows that this is not always the case, as a variety of factors may affect the accuracy of the results. Examples include reagent purity, apparatus type and performance, degree of modification of the method in a particular laboratory and the skill and care of the analyst. These factors are likely to vary both between laboratories and over time in an individual laboratory. Moreover, the precision and accuracy that can be achieved with a particular method frequently depend upon the adequacy of sampling and nature of the sample ("matrix"). While it is not essential to use standard methods, it is important that the methods used are properly validated and their precision and accuracy determined before significant decisions are made based on the results. In the case of "nonspecific" variables such as taste, odour, colour and turbidity, the result is method specific, and this needs to be considered when using the data to make comparisons.

A number of considerations are important in selecting methods:

- The overriding consideration is that the method chosen is demonstrated to have the required accuracy. Other factors, such as speed and convenience, should be considered only in selecting among methods that meet this primary criterion.
- Of primary importance is the expertise and diligence of the laboratories performing the analyses. They must utilize auditable quality control and quality assurance procedures for their results to be credible. External certification is highly desirable.
- There are a number of markedly different procedures for measuring and reporting the errors to which all methods are subject. This complicates and prejudices the effectiveness of method selection, and suggestions for standardizing such procedures have been made. It is therefore desirable that details of all analytical methods are published together with performance characteristics that can be interpreted unambiguously.
- If the analytical results from one laboratory are to be compared with those from others or with a numerical standard, it is obviously preferable for them not to have any associated systematic error. In practice, this is not possible, but each laboratory should select methods whose systematic errors have been thoroughly evaluated and shown to be acceptably small.

A qualitative ranking of analytical methods based on their degree of technical complexity is given in Table 8.4 for inorganic chemicals and in Table 8.5 for organic chemicals. These groups of chemicals are separated, as the analytical methods used differ greatly. The higher the ranking, the more complex the process in terms of equipment or operation. In general, higher rankings are also associated with higher total costs.

Analytical achievabilities, based on detection limits, of the inorganic and organic chemicals for which guideline values have been established are given in Annex 4, by source category.

Table 8.4 Ranking of complexity of analytical methods for inorganic chemicals

Ranking	Example of analytical methods
1	Volumetric method, colorimetric method
2	Electrode method
3	Ion chromatography
4	High-performance liquid chromatography
5	Flame atomic absorption spectrometry
6	Electrothermal atomic absorption spectrometry
7	Inductively coupled plasma atomic emission spectrometry
8	Inductively coupled plasma mass spectrometry

Table 8.5 Ranking of complexity of analytical methods for organic chemicals

Ranking	Example of analytical methods
1	High-performance liquid chromatography
2	Gas chromatography
3	Gas chromatography–mass spectrometry
4	Headspace gas chromatography–mass spectrometry
5	Purge-and-trap gas chromatography
	Purge-and-trap gas chromatography–mass spectrometry

Many kinds of field test kits are available to measure the concentrations of various chemicals in water. These are generally used for compliance examinations as well as for operational monitoring of drinking-water quality. Although the field test kits have the advantage of being simple to use in non-laboratory environments and are often available at relatively low prices, their analytical accuracy is generally less than that of the methods shown in Tables 8.4 and 8.5. However, when properly used, they provide valuable tools for rapidly assessing numerous contaminants in a non-formal laboratory setting at low cost compared with commercial laboratory tests. It is therefore necessary to check the validity of the field test kit before applying it.

A brief description of the analytical methods listed in Tables 8.4 and 8.5 is provided in Annex 4.

8.4 Treatment

As noted above, where a health-based guideline value cannot be achieved by reasonably practicable treatment, then the guideline value is designated as provisional and set at the concentration that can be reasonably achieved through treatment.

Collection, treatment, storage and distribution of drinking-water involve deliberate additions of numerous chemicals to improve the safety and quality of the finished drinking-water for consumers (direct additives). In addition, water is in constant contact with pipes, valves, taps and tank surfaces, all of which have the potential to impart additional chemicals to the water (indirect additives). The chemicals used in water treatment or from materials in contact with drinking-water are discussed in more detail in section 8.5.4.

Table 8.6 Ranking of technical complexity and cost of water treatment processes

Ranking	Examples of treatment processes
1	Simple chlorination
	Plain filtration (rapid sand, slow sand)
2	Prechlorination plus filtration
	Aeration
3	Chemical coagulation
	Process optimization for control of DBPs
4	Granular activated carbon treatment
	Ion exchange
5	Ozonation
6	Advanced oxidation processes
	Membrane treatment

8.4.1 Treatment performance

Treatment performance varies according to local conditions and circumstances. The ability to achieve a guideline value within a drinking-water supply depends on a number of factors, including:

- the concentration of the chemical in the raw water;
- control measures employed throughout the drinking-water system;
- nature of the raw water (groundwater or surface water, presence of natural organic matter and inorganic solutes and other components, such as turbidity);
- treatment processes already installed.

If a guideline value cannot be met with the existing system, then additional treatment may need to be considered, or water might need to be obtained from alternative sources.

The cost of achieving a guideline value will depend on the complexity of any additional treatment or other control measures required. It is not possible to provide general quantitative information on the cost of achieving individual guideline values. Treatment costs (capital and operating) will depend not only on the factors identified above, but also on issues such as plant throughput; local costs for labour, civil and mechanical works, chemicals and electricity; life expectancy of the plant; and so on. Guideline values may be progressively achieved in the long term through less capital-intensive non-treatment options, such as through agreements with land users to reduce application of chemicals (fertilizers, pesticides, etc.)

A qualitative ranking of treatment processes based on their degree of technical complexity is given in Table 8.6. The higher the ranking, the more complex the process in terms of plant or operation. In general, higher rankings are also associated with higher costs.

Annex 5 summarizes the treatment processes that are capable of removing chemical contaminants of health significance. The tables in Annex 5 include only those chemicals, by source category, for which some treatment data are available and for which guideline values have been established.

The tables in Annex 5 are provided to help inform decisions regarding the ability of existing treatment to meet guidelines and what additional treatment might need to be installed. They have been compiled on the basis of published literature, which includes mainly laboratory experiments, some pilot plant investigations and relatively few full-scale studies of water treatment processes. Consequently:

- Many of the treatments outlined are designed for larger treatment plants and may not necessarily be appropriate for smaller treatment plants or individual-type treatment. In these cases, the choice of technology must be made on a case-by-case basis.
- The information is probably "best case", as the data would have been obtained under laboratory conditions or with a carefully controlled plant for the purposes of experimentation.
- Actual process performance will depend on the concentration of the chemical in the raw water and on general raw water quality. For example, chlorination and removal of organic chemicals and pesticides using activated carbon or ozonation will be impaired if there is a high concentration of natural organic matter.
- For many contaminants, potentially several different processes could be appropriate, and the choice between processes should be made on the basis of technical complexity and cost, taking into account local circumstances. For example, membrane processes can remove a broad spectrum of chemicals, but simpler and cheaper alternatives are effective for the removal of most chemicals.
- It is normal practice to use a series of unit processes (e.g. coagulation, sedimentation, filtration, chlorination) to achieve desired water quality objectives. Each of these may contribute to the removal of chemicals. It may be technically and economically advantageous to use a combination of processes (e.g. ozonation plus granular activated carbon or membranes) to remove particular chemicals.
- The effectiveness of potential processes should be assessed using laboratory or pilot plant tests on the actual raw water concerned. These tests should be of sufficient duration to identify potential seasonal or other temporal variations in contaminant concentrations and process performance.
- These treatment technology characterizations are estimates and are not comprehensive, but are intended to provide some indications of the types of technologies that have shown greater or lesser capabilities for removing the indicated chemicals from drinking-water.

A brief description of the various treatment processes referred to in Table 8.6 is included in Annex 5.

8.4.2 Process control measures for disinfection by-products

All chemical disinfectants produce inorganic or organic DBPs that may be of concern.

The principal DBPs formed during chlorination are THMs, HAAs, haloketones and haloacetonitriles, as a result of chlorination of naturally occurring organic precursors such as humic substances. Monochloramine produces lower THM concentrations than chlorine but produces other DBPs, including cyanogen chloride.

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

Chlorine and ozone oxidize bromide to produce hypohalous acids, which react with precursors to form brominated THMs. A range of other DBPs, including aldehydes and carboxylic acids, may also be formed. Of particular concern is bromate, formed by the oxidation of bromide. Bromate may also be present in some sources of hypochlorite, but usually at concentrations that will give rise to levels in final water that are below the guideline value.

The main by-products from the use of chlorine dioxide are chlorite ion, which is an inevitable decomposition product, and chlorate ion. Chlorate is also produced in hypochlorate as it ages.

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

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

Changes to process conditions

The formation of THMs during chlorination can be reduced by removing precursors prior to contact with chlorine—for example, by installing or enhancing coagulation (this may involve using higher coagulant doses or lower coagulation pH values than are applied conventionally). DBP formation can also be reduced by lowering the applied chlorine dose; if this is done, it must be ensured that disinfection is still effective.

The pH value during chlorination affects the distribution of chlorinated by-products. Reducing the pH lowers the THM concentration, but at the expense of increased formation of HAAs. Conversely, increasing the pH reduces HAA production but leads to increased THM formation.

The formation of bromate during ozonation depends on several factors, including concentrations of bromide and ozone and the pH. It is not practicable to remove bromide from raw water, and it is difficult to remove bromate once formed, although granular activated carbon filtration has been reported to be effective under certain circumstances. Bromate formation can be minimized by using lower ozone dose, shorter contact time and a lower residual ozone concentration. Operating at lower pH (e.g. pH 6.5) followed by raising the pH after ozonation also reduces bromate formation, and addition of ammonia can also be effective. Addition of hydrogen peroxide can either increase or decrease bromate formation, depending on the point at which it is applied and local treatment conditions.

Changing disinfectants

It may be feasible to change disinfectant in order to achieve guideline values for DBPs. The extent to which this is possible will be dependent on the raw water quality and installed treatment (e.g. for precursor removal).

It may be effective to change from chlorine to monochloramine to provide a secondary disinfectant residual within distribution, in order to reduce THM formation and subsequent development within the distribution system. Although monochloramine provides a more stable residual within distribution, it is a less powerful disinfectant and should not be used as a primary disinfectant.

Chlorine dioxide can be considered as a potential alternative to both chlorine and ozone disinfection, although it does not provide a residual effect, as chlorine would. The main concerns with chlorine dioxide are with the residual concentrations of chlorine dioxide and the by-products chlorite and chlorate. These can be addressed by controlling the dose of chlorine dioxide at the treatment plant.

Non-chemical disinfection

Ultraviolet (UV) irradiation or membrane processes can be considered as alternatives to chemical disinfection. UV is particularly effective at inactivating *Cryptosporidium*, which is extremely resistant to chlorination. Neither of these provides any residual disinfection, and it may be considered appropriate to add a small dose of a persistent disinfectant such as chlorine or monochloramine to act as a preservative during distribution.

Removing DBPs prior to distribution

It is technically feasible to remove DBPs prior to distribution; however, this is the least attractive option for controlling DBP concentrations. Strategies for DBP control include source control, precursor removal, use of alternative disinfectants and removal of DBPs by technologies such as air stripping, activated carbon, UV light and advanced oxidation. These processes would need to be followed by a further disinfection step to guard against microbial contamination and to ensure a residual concentration of disinfectant within distribution.

8.4.3 Treatment for corrosion control

Corrosion is the partial dissolution of the materials constituting the treatment and supply systems, tanks, pipes, valves and pumps. In certain circumstances, all water can be corrosive. Corrosion may lead to structural failure, leaks, loss of capacity and deterioration of chemical and microbial water quality. The internal corrosion of pipes and fittings can have a direct impact on the concentration of water constituents, including lead and copper. Corrosion control is therefore an important aspect of the management of a drinking-water system for safety.

Corrosion control involves many parameters, including the concentrations of calcium, bicarbonate, carbonate and dissolved oxygen, as well as pH. The detailed requirements differ depending on water quality and the materials used in the distribution system. The pH controls the solubility and rate of reaction of most of the metal species involved in corrosion reactions. It is particularly important in relation to the

formation of a protective film at the metal surface. For some metals, alkalinity (carbonate and bicarbonate) and calcium (hardness) also affect corrosion rates.

Characterizing corrosivity

Most of the indices that have been developed to characterize the corrosion potential of waters are based on the assumption that water with a tendency to deposit a calcium carbonate scale on metal surfaces will be less corrosive. The Langelier index is the difference between the actual pH of a water and its "saturation pH", this being the pH at which a water of the same alkalinity and calcium hardness would be at equilibrium with solid calcium carbonate. Waters with a positive Langelier index are capable of depositing calcium carbonate scale from solution.

There is no corrosion index that applies to all materials, and corrosion indices, particularly those related to calcium carbonate saturation, have given mixed results. The parameters related to calcium carbonate saturation status are, strictly speaking, indicators of the tendency to deposit or dissolve calcium carbonate (calcite) scale, not indicators of the "corrosivity" of a water. For example, there are many waters with a negative Langelier index that are non-corrosive and many with a positive Langelier index that are corrosive. Nevertheless, there are many documented instances of the use of saturation indices for corrosion control based on the concept of laying down a protective "eggshell" scale of calcite in iron pipes. In general, waters with high pH, calcium and alkalinity are less corrosive, and this tends to be correlated with a positive Langelier index. However, these calcium carbonate precipitation indices are not necessarily considered to be good corrosion predictors for copper systems.

The ratio of the chloride and sulfate concentrations to the bicarbonate concentration (Larson ratio) has been shown to be helpful in assessing the corrosiveness of water to cast iron and steel. A similar approach has been used in studying zinc dissolution from brass fittings—the Turner diagram.

Water treatment for corrosion control

To control corrosion in water distribution networks, the methods most commonly applied are adjusting pH, increasing the alkalinity or hardness or adding corrosion inhibitors, such as polyphosphates, silicates and orthophosphates. The quality and maximum dose to be used should be in line with specifications for such water treatment chemicals. Although pH adjustment is an important approach, its possible impact on other aspects of water supply technology, including disinfection, must always be taken into account.

It is not always possible to achieve the desired values for all parameters. For example, the pH of hard waters cannot be increased too much, or softening will occur. The application of lime and carbon dioxide to soft waters can be used to increase both the calcium concentration and the alkalinity to at least 40 mg/l as calcium carbonate.

More detailed information on the corrosion of various metals commonly used in water treatment and distribution systems can be found in Annex 5.

8.4.4 Household treatment

The chemicals of greatest health concern in some natural waters are usually excess natural fluoride, nitrate/nitrite and arsenic.

Some commercial water treatment technologies are available for small applications for the removal of chemical contaminants. For example, anion exchange using activated alumina or iron-containing products will effectively reduce excess fluoride concentrations. Bone char has also been used to reduce fluoride concentrations. Arsenic is also removed by anion exchange processes similar to those employed for fluoride. Nitrates and nitrates, which are frequently present due to sewage contamination or agricultural runoff, are best managed by protecting the source water from contamination. They are difficult to remove, although disinfection will oxidize nitrite, the more toxic form, to nitrate. In addition, disinfection will sanitize the water and reduce the risk of gastrointestinal infection, which is a risk factor for methaemoglobinaemia caused by excess nitrate/nitrite exposure of infants up to approximately 3–6 months of age.

Cation exchange water softening is widely used in homes to remove excess hardness due to high calcium or magnesium, and it can also remove metals including iron and radium.

Synthetic and natural organic chemicals can be removed by granular activated carbon or carbon block technologies. The treatment systems must be well managed and replaced regularly, because their effectiveness is eventually lost, depending upon the types of contaminating chemicals and their concentrations in the water. Reverse osmosis technologies have general applicability for removal of most organic and inorganic chemicals; however, there is some selectivity, and also there is a significant amount of water wastage when low-pressure units are used in small-volume applications.

8.5 Guideline values for individual chemicals, by source category

8.5.1 Naturally occurring chemicals

There are a number of sources of naturally occurring chemicals in drinking-water. All natural water contains a range of inorganic and organic chemicals. The former derive from the rocks and soil through which water percolates or over which it flows. The latter derive from the breakdown of plant material or from algae and other microorganisms that grow in the water or on sediments. Most of the naturally occurring chemicals for which guideline values have been derived or that have been considered for guideline value derivation are inorganic. Only one, microcystin-LR, a toxin produced by cyanobacteria or blue-green algae, is organic. Cyanobacteria (see also section 11.5) occur widely in lakes, reservoirs, ponds and slow-flowing rivers. Many species are known to produce toxins, or "cyanotoxins", which are of concern for health. Cyanotoxins vary in structure and may be found within cells or released into water. There is wide variation in the toxicity of recognized cyanotoxins (including different structural variants within a group, such as microcystins), and it is likely that further toxins remain unrecognized, so control of blooms is the preferred control option.

The approach to dealing with naturally occurring chemicals will vary according to the nature of the chemical and the source. For inorganic contaminants that arise from rocks and sediments, it is important to screen possible water sources to determine whether the source is suitable for use or whether it will be necessary to treat the

Table 8.7 Naturally occurring chemicals for which guideline values have not been established

Chemical	Reason for not establishing a guideline value	Remarks
Bromide	Occurs in drinking-water at concentrations well below those of health concern	
Chloride	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Hardness	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Hydrogen sulfide	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Iron	Not of health concern at levels causing acceptability problems in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Manganese	Not of health concern at levels causing acceptability problems in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Molybdenum	Occurs in drinking-water at concentrations well below those of health concern	
pH	Not of health concern at levels found in drinking-water	An important operational water quality parameter
Potassium	Occurs in drinking-water at concentrations well below those of health concern	
Sodium	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Sulfate	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)
Total dissolved solids	Not of health concern at levels found in drinking-water	May affect acceptability of drinking-water (see chapter 10)

water to remove the contaminants of concern along with microbial contaminants. In some cases, where a number of sources may be available, dilution or blending of the water containing high levels of a contaminant with a water containing much lower levels may achieve the desired result.

A number of the most important chemical contaminants (i.e. those that have been shown to cause adverse health effects as a consequence of exposure through drinking-water) fall into the category of naturally occurring chemicals. Some naturally occurring chemicals have other primary sources and are therefore discussed in other sections of this chapter.

Guideline values have not been established for the naturally occurring chemicals listed in Table 8.7 for the reasons indicated in the table. Fact sheets are included in chapter 12.

Guideline values have been established for the naturally occurring chemicals listed in Table 8.8, which meet the criteria for inclusion. Fact sheets are included for each in chapter 12.

8.5.2 Chemicals from industrial sources and human dwellings

Chemicals from industrial sources can reach drinking-water directly from discharges or indirectly from diffuse sources arising from the use and disposal of materials and

Table 8.8 Guideline values for naturally occurring chemicals that are of health significance in drinking-water

Chemical	Guideline value µg/l	Guideline value mg/l	Remarks
Inorganic			
Arsenic	10 (A,T)	0.01 (A,T)	
Barium	700	0.7	
Boron	2400	2.4	
Chromium	50 (P)	0.05 (P)	For total chromium
Fluoride	1500	1.5	Volume of water consumed and intake from other sources should be considered when setting national standards
Selenium	40 (P)	0.04 (P)	
Uranium	30 (P)	0.03 (P)	Only chemical aspects of uranium addressed
Organic			
Microcystin-LR	1 (P)	0.001 (P)	For total microcystin-LR (free plus cell-bound)

A, provisional guideline value because calculated guideline value is below the achievable quantification level; P, provisional guideline value because of uncertainties in the health database; T, provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

products containing the chemicals. In some cases, inappropriate handling and disposal may lead to contamination (e.g. degreasing agents that are allowed to reach groundwater). Some of these chemicals, particularly inorganic substances, may also be encountered as a consequence of natural contamination, but this may also be a by-product of industrial activity, such as mining, that changes drainage patterns. Many of these chemicals are used in small industrial units within human settlements, and, particularly where such units are found in groups of similar enterprises, they may be a significant source of pollution. Petroleum oils are widely used in human settlements, and improper handling or disposal can lead to significant pollution of surface water and groundwater. Where plastic pipes are used, the smaller aromatic molecules in petroleum oils can sometimes penetrate the pipes where they are surrounded by earth soaked in the oil, with subsequent pollution of the local water supply.

A number of chemicals can reach water as a consequence of disposal of general household chemicals; in particular, a number of heavy metals may be found in domestic wastewater. Where wastewater is treated, these will usually partition out into the sludge. Some chemicals that are widely used both in industry and in materials used in a domestic setting are found widely in the environment (e.g. di(2-ethylhexyl)-phthalate), and these may be found in water sources, although usually at low concentrations.

Some chemicals that reach drinking-water from industrial sources or human settlements have other primary sources and are therefore discussed in other sections of this chapter. Where latrines and septic tanks are poorly sited, these can lead to contamination of drinking-water sources with nitrate (see section 8.5.3).

Identification of the potential for contamination by chemicals from industrial activities and human dwellings requires assessment of activities in the catchment and of

Table 8.9 Chemicals from industrial sources and human dwellings for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Beryllium	Rarely found in drinking-water at concentrations of health concern
Cyanide	Occurs in drinking-water at concentrations well below those of health concern, except in emergency situations following a spill to a water source
1,3-Dichlorobenzene	Available data inadequate to permit derivation of health-based guideline value
1,1-Dichloroethane	Available data inadequate to permit derivation of health-based guideline value
1,1-Dichloroethene	Occurs in drinking-water at concentrations well below those of health concern
Di(2-ethylhexyl)adipate	Occurs in drinking-water at concentrations well below those of health concern
Hexachlorobenzene	Occurs in drinking-water at concentrations well below those of health concern
Methyl *tertiary*-butyl ether	Any guideline that would be derived would be significantly higher than concentrations at which methyl *tertiary*-butyl ether would be detected by odour
Monochlorobenzene	Occurs in drinking-water at concentrations well below those of health concern, and health-based value would far exceed lowest reported taste and odour threshold
Nitrobenzene	Rarely found in drinking-water at concentrations of health concern
Petroleum products	Taste and odour will in most cases be detectable at concentrations below those of health concern, particularly with short-term exposure
Trichlorobenzenes (total)	Occur in drinking-water at concentrations well below those of health concern, and health-based value would exceed lowest reported odour threshold
1,1,1-Trichloroethane	Occurs in drinking-water at concentrations well below those of health concern

the risk that particular contaminants may reach water sources. The primary approach to addressing these contaminants is prevention of contamination by encouraging good practices. However, if contamination has occurred, then it may be necessary to consider the introduction of treatment.

Guideline values have not been established for the chemicals listed in Table 8.9 for the reasons indicated in the table. Fact sheets for each are included in chapter 12.

Guideline values have been established for the chemicals listed in Table 8.10, which meet all of the criteria for inclusion. Fact sheets for each are included in chapter 12.

8.5.3 Chemicals from agricultural activities

Chemicals are used in agriculture on crops and in animal husbandry. Nitrate may be present as a consequence of tillage when there is no growth to take up nitrate released from decomposing plants, from the application of excess inorganic or organic fertilizer and in slurry from animal production. Most chemicals that may arise from

Table 8.10 Guideline values for chemicals from industrial sources and human dwellings that are of health significance in drinking-water

Chemicals	Guideline value µg/l	Guideline value mg/l	Remarks
Inorganic			
Cadmium	3	0.003	
Mercury	6	0.006	For inorganic mercury
Organic			
Benzene	10[a]	0.01[a]	
Carbon tetrachloride	4	0.004	
1,2-Dichlorobenzene	1000 (C)	1 (C)	
1,4-Dichlorobenzene	300 (C)	0.3 (C)	
1,2-Dichloroethane	30[a]	0.03[a]	
1,2-Dichloroethene	50	0.05	
Dichloromethane	20	0.02	
Di(2-ethylhexyl)phthalate	8	0.008	
1,4-Dioxane	50[a]	0.05[a]	Derived using TDI approach as well as linear multistage modelling
Edetic acid	600	0.6	Applies to the free acid
Ethylbenzene	300 (C)	0.3 (C)	
Hexachlorobutadiene	0.6	0.0006	
Nitrilotriacetic acid	200	0.2	
Pentachlorophenol	9[a] (P)	0.009[a] (P)	
Styrene	20 (C)	0.02 (C)	
Tetrachloroethene	40	0.04	
Toluene	700 (C)	0.7 (C)	
Trichloroethene	20 (P)	0.02 (P)	
Xylenes	500 (C)	0.5 (C)	

C, concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints; P, provisional guideline value because of uncertainties in the health database

[a] For non-threshold substances, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional case of cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

agriculture are pesticides, although their presence will depend on many factors, and not all pesticides are used in all circumstances or climates. Contamination can result from application and subsequent movement following rainfall or from inappropriate disposal methods.

Some pesticides are also used in non-agricultural circumstances, such as the control of weeds on roads and railway lines. These pesticides are also included in this section.

Table 8.11 Chemicals from agricultural activities excluded from guideline value derivation

Chemical	Reason for exclusion
Amitraz	Degrades rapidly in the environment and is not expected to occur at measurable concentrations in drinking-water supplies
Chlorobenzilate	Unlikely to occur in drinking-water
Chlorothalonil	Unlikely to occur in drinking-water
Cypermethrin	Unlikely to occur in drinking-water
Deltamethrin	Unlikely to occur in drinking-water
Diazinon	Unlikely to occur in drinking-water
Dinoseb	Unlikely to occur in drinking-water
Ethylene thiourea	Unlikely to occur in drinking-water
Fenamiphos	Unlikely to occur in drinking-water
Formothion	Unlikely to occur in drinking-water
Hexachlorocyclohexanes (mixed isomers)	Unlikely to occur in drinking-water
MCPB[a]	Unlikely to occur in drinking-water
Methamidophos	Unlikely to occur in drinking-water
Methomyl	Unlikely to occur in drinking-water
Mirex	Unlikely to occur in drinking-water
Monocrotophos	Has been withdrawn from use in many countries and is unlikely to occur in drinking-water
Oxamyl	Unlikely to occur in drinking-water
Phorate	Unlikely to occur in drinking-water
Propoxur	Unlikely to occur in drinking-water
Pyridate	Not persistent and only rarely found in drinking-water
Pyriproxyfen	Unlikely to occur in drinking-water[b]
Quintozene	Unlikely to occur in drinking-water
Toxaphene	Unlikely to occur in drinking-water
Triazophos	Unlikely to occur in drinking-water
Tributyltin oxide	Unlikely to occur in drinking-water
Trichlorfon	Unlikely to occur in drinking-water

[a] 4-(4-chloro-*o*-tolyloxy)butyric acid.
[b] The use of pyriproxyfen as a larvicide for public health purposes is discussed further in section 8.6.

Guideline values have not been established for the chemicals listed in Table 8.11, as a review of the literature on occurrence or credibility of occurrence in drinking-water has shown evidence that the chemicals do not occur in drinking-water.

Guideline values have not been established for the chemicals listed in Table 8.12 for the reasons indicated in the table. Fact sheets for each are included in chapter 12.

Table 8.12 Chemicals from agricultural activities for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Ammonia	Occurs in drinking-water at concentrations well below those of health concern
Bentazone	Occurs in drinking-water at concentrations well below those of health concern
Carbaryl	Occurs in drinking-water at concentrations well below those of health concern
1,3-Dichloropropane	Available data inadequate to permit derivation of health-based guideline value
Diquat	May be used as an aquatic herbicide for the control of free-floating and submerged aquatic weeds in ponds, lakes and irrigation ditches, but rarely found in drinking-water
Endosulfan	Occurs in drinking-water at concentrations well below those of health concern
Fenitrothion	Occurs in drinking-water at concentrations well below those of health concern
Glyphosate and AMPA[a]	Occur in drinking-water at concentrations well below those of health concern
Heptachlor and heptachlor epoxide	Occur in drinking-water at concentrations well below those of health concern
Malathion	Occurs in drinking-water at concentrations well below those of health concern
Methyl parathion	Occurs in drinking-water at concentrations well below those of health concern
Parathion	Occurs in drinking-water at concentrations well below those of health concern
2-Phenylphenol and its sodium salt	Occurs in drinking-water at concentrations well below those of health concern
Propanil	Readily transformed into metabolites that are more toxic; a guideline value for the parent compound is considered inappropriate, and there are inadequate data to enable the derivation of guideline values for the metabolites

[a] Aminomethylphosphonic acid.

Guideline values have been established for the chemicals listed in Table 8.13, which meet the criteria for inclusion. Fact sheets for each are included in chapter 12.

8.5.4 Chemicals used in water treatment or from materials in contact with drinking-water

Chemicals used in water treatment and chemicals arising from materials in contact with water may give rise to contaminants in the final water.

Some substances are deliberately added to water in the course of treatment (direct additives), some of which may be inadvertently retained in the finished water

Table 8.13 Guideline values for chemicals from agricultural activities that are of health significance in drinking-water

Chemical	Guideline value µg/l	Guideline value mg/l	Remarks
Non-pesticides			
Nitrate (as NO_3^-)	50 000	50	Short-term exposure
Nitrite (as NO_2^-)	3 000	3	Short-term exposure; a provisional guideline value for chronic effects of nitrite that was in the third edition has been suspended and is under review owing to significant uncertainty surrounding the endogenous formation of nitrite and concentrations in human saliva.
Pesticides used in agriculture			
Alachlor	20[a]	0.02[a]	
Aldicarb	10	0.01	Applies to aldicarb sulfoxide and aldicarb sulfone
Aldrin and dieldrin	0.03	0.000 03	For combined aldrin plus dieldrin
Atrazine and its chloro-*s*-triazine metabolites	100	0.1	
Carbofuran	7	0.007	
Chlordane	0.2	0.000 2	
Chlorotoluron	30	0.03	
Chlorpyrifos	30	0.03	
Cyanazine	0.6	0.000 6	
2,4-D[b]	30	0.03	Applies to free acid
2,4-DB[c]	90	0.09	
1,2-Dibromo-3-chloropropane	1[a]	0.001[a]	
1,2-Dibromoethane	0.4[a] (P)	0.000 4[a] (P)	
1,2-Dichloropropane	40 (P)	0.04 (P)	
1,3-Dichloropropene	20[a]	0.02[a]	
Dichlorprop	100	0.1	
Dimethoate	6	0.006	
Endrin	0.6	0.000 6	
Fenoprop	9	0.009	
Hydroxyatrazine	200	0.2	Atrazine metabolite
Isoproturon	9	0.009	
Lindane	2	0.002	
MCPA[d]	2	0.002	
Mecoprop	10	0.01	
Methoxychlor	20	0.02	
Metolachlor	10	0.01	

Table 8.13 (continued)

Chemical	Guideline value µg/l	Guideline value mg/l	Remarks
Molinate	6	0.006	
Pendimethalin	20	0.02	
Simazine	2	0.002	
2,4,5-T[e]	9	0.009	
Terbuthylazine	7	0.007	
Trifluralin	20	0.02	

P, provisional guideline value because of uncertainties in the health database

[a] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

[b] 2,4-Dichlorophenoxyacetic acid.

[c] 2,4-Dichlorophenoxybutyric acid.

[d] 4-(2-Methyl-4-chlorophenoxy)acetic acid.

[e] 2,4,5-Trichlorophenoxyacetic acid.

(e.g. salts, coagulant polymer residues or monomers). Chloramine and chlorine disinfectant residuals, for example, are deliberate additives, and their presence confers a benefit. Others, such as DBPs, are generated during chemical interactions between disinfectant chemicals and substances normally in water (Table 8.14). Chlorination by-products and other DBPs may also occur in swimming pools, from which exposure by inhalation and skin absorption will be of greater importance (WHO, 2006).

Other chemicals, such as lead or copper from pipes or brass taps and chemicals leaching from coatings, may be taken up from contact with surfaces during treatment or distribution (indirect or unintentional additives).

Some chemicals used in water treatment (e.g. aluminium) or in materials in contact with drinking-water (e.g. styrene) have other principal sources and are therefore discussed in detail in other sections of this chapter.

Many of these additives, both direct and indirect or unintentional, are components of processes for producing safe drinking-water. The approach to monitoring and management is preferably through control of the material or chemical. It is important to optimize treatment processes and to ensure that such processes remain optimized in order to control residuals of chemicals used in treatment and to control the formation of DBPs. Inadvertent contamination caused by poor quality materials is best controlled by applying specifications governing the composition of the products themselves rather than by setting limits on the quality of finished water, whereas contamination due to the inappropriate use of additives can be addressed by guidance on use. Similarly, regulations on the quality of pipe can avoid possible contamination of water by leachable materials. Control of contamination from in situ applied coatings requires suitable codes of practice on their application in addition to controls on the composition of materials.

Numerous national and third-party evaluation and approval systems for additives and materials for contact with drinking-water exist throughout the world; however,

Table 8.14 Disinfection by-products present in disinfected waters (based on IPCS, 2000)

Disinfectant	Significant organohalogen products	Significant inorganic products	Significant non-halogenated products
Chlorine/ hypochlorous acid (hypochlorite)	THMs, HAAs, haloaceto-nitriles, chloral hydrate, chloropicrin, chlorophenols, *N*-chloramines, halo-furanones, bromohydrins	Chlorate (mostly from hypochlorite use)	Aldehydes, cyanoalkanoic acids, alkanoic acids, benzene, carboxylic acids, *N*-nitrosodimethylamine
Chlorine dioxide		Chlorite, chlorate	Unknown
Chloramine	Haloacetonitriles, cyanogen chloride, organic chloramines, chloramino acids, chloral hydrate, haloketones	Nitrate, nitrite, chlorate, hydrazine	Aldehydes, ketones, *N*-nitrosodimethylamine
Ozone	Bromoform, monobromoacetic acid, dibromoacetic acid, dibromoacetone, cyanogen bromide	Chlorate, iodate, bromate, hydrogen peroxide, hypo-bromous acid, epoxides, ozonates	Aldehydes, ketoacids, ketones, carboxylic acids
Sodium dichloroisocyanurate	As for chlorine/ hypochlorous acid (hypochlorite)		Cyanuric acid

many countries do not have or operate such systems. Governments and other organizations should consider establishing or adapting additive management systems and setting product quality standards and guidance on use that would apply to determining acceptable water contact products. Ideally, harmonized standards between countries or reciprocal recognition would reduce costs and increase access to such standards (see also section 1.2.9).

Guideline values have not been established for the chemicals listed in Table 8.15 for the reasons indicated in the table. Fact sheets for each are included in chapter 12.

Guideline values have been established for the chemicals listed in Table 8.16, which meet the criteria for inclusion. Fact sheets for each are included in chapter 12.

Indicator substances for monitoring chlorination by-products

Although guideline values have been established for a number of chlorination by-products, data from drinking-water supplies indicate that THMs and HAAs are adequate as indicators of the majority of chlorination by-products. The most appropriate means of controlling chlorination by-products is to remove the organic precursors, which are largely of natural origin. Measurement of THMs and, if appropriate, HAAs (e.g. where water is chlorinated at a low pH) can be used to optimize treatment efficiency and to establish the boundaries of other operational parameters that can be used to monitor treatment performance. In these circumstances, monitoring frequencies of other chlorination by-products can be reduced. Although total organohalogen does not correlate well with either THMs or HAAs, it is a measure of total chlorination by-products and may be another potential indicator for operational purposes.

Table 8.15 Chemicals used in water treatment or materials in contact with drinking-water for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Disinfectants	
Chlorine dioxide	Rapidly breaks down to chlorite, and the chlorite provisional guideline value is protective for potential toxicity from chlorine dioxide
Dichloramine	Available data inadequate to permit derivation of health-based guideline value
Iodine	Available data inadequate to permit derivation of health-based guideline value, and lifetime exposure to iodine through water disinfection is unlikely
Silver	Available data inadequate to permit derivation of health-based guideline value
Trichloramine	Available data inadequate to permit derivation of health-based guideline value
Disinfection by-products	
Bromochloroacetate	Available data inadequate to permit derivation of health-based guideline value
Bromochloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Chloral hydrate	Occurs in drinking-water at concentrations well below those of health concern
Chloroacetones	Available data inadequate to permit derivation of health-based guideline values for any of the chloroacetones
2-Chlorophenol	Available data inadequate to permit derivation of health-based guideline value
Chloropicrin	Available data inadequate to permit derivation of health-based guideline value
Cyanogen chloride	Occurs in drinking-water at concentrations well below those of health concern
Dibromoacetate	Available data inadequate to permit derivation of health-based guideline value
2,4-Dichlorophenol	Available data inadequate to permit derivation of health-based guideline value
Formaldehyde	Occurs in drinking-water at concentrations well below those of health concern
Monobromoacetate	Available data inadequate to permit derivation of health-based guideline value
MX[a]	Occurs in drinking-water at concentrations well below those of health concern
Trichloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Contaminants from treatment chemicals	
Aluminium	A health-based value of 0.9 mg/l could be derived, but this value exceeds practicable levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants: 0.1 mg/l or less in large water treatment facilities and 0.2 mg/l or less in small facilities

Table 8.15 (continued)

Chemical	Reason for not establishing a guideline value
Contaminants from pipes and fittings	
Asbestos	No consistent evidence that ingested asbestos is hazardous to health
Dialkyltins	Available data inadequate to permit derivation of health-based guideline values for any of the dialkyltins
Fluoranthene[b]	Occurs in drinking-water at concentrations well below those of health concern
Inorganic tin	Occurs in drinking-water at concentrations well below those of health concern
Zinc	Not of health concern at levels found in drinking-water[c]

[a] 3-Chloro-4-dichloromethyl-5-hydroxy-2(5H)-furanone.
[b] See fact sheet on polynuclear aromatic hydrocarbons.
[c] May affect acceptability of drinking-water (see chapter 10).

Table 8.16 Guideline values for chemicals used in water treatment or materials in contact with drinking-water that are of health significance in drinking-water

	Guideline value[a]		
Chemical	**µg/l**	**mg/l**	**Remarks**
Disinfectants			
Chlorine	5 000 (C)	5 (C)	For effective disinfection, there should be a residual concentration of free chlorine of ≥ 0.5 mg/l after at least 30 min contact time at pH < 8.0. A chlorine residual should be maintained throughout the distribution system. At the point of delivery, the minimum residual concentration of free chlorine should be 0.2 mg/l.
Monochloramine	3 000	3	
Sodium dichloroisocyanurate	50 000	50	As sodium dichloroisocyanurate
	40 000	40	As cyanuric acid
Disinfection by-products			
Bromate	10[a] (A,T)	0.01[a] (A,T)	
Bromodichloromethane	60[a]	0.06[a]	
Bromoform	100	0.1	
Chlorate	700 (D)	0.7 (D)	
Chlorite	700 (D)	0.7 (D)	
Chloroform	300	0.3	
Dibromoacetonitrile	70	0.07	
Dibromochloromethane	100	0.1	
Dichloroacetate	50[a] (D)	0.05[a] (D)	
Dichloroacetonitrile	20 (P)	0.02 (P)	

Table 8.16 (continued)

Chemical	Guideline value[a] µg/l	mg/l	Remarks
Monochloroacetate	20	0.02	
N-Nitrosodimethylamine	0.1	0.0001	
Trichloroacetate	200	0.2	
2,4,6-Trichlorophenol	200[a] (C)	0.2[a] (C)	
Trihalomethanes			The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1
Contaminants from treatment chemicals			
Acrylamide	0.5[a]	0.0005[a]	
Epichlorohydrin	0.4 (P)	0.0004 (P)	
Contaminants from pipes and fittings			
Antimony	20	0.02	
Benzo[*a*]pyrene	0.7[a]	0.0007[a]	
Copper	2000	2	Staining of laundry and sanitary ware may occur below guideline value
Lead	10 (A,T)	0.01 (A,T)	
Nickel	70	0.07	
Vinyl chloride	0.3[a]	0.0003[a]	

A, provisional guideline value because calculated guideline value is below the achievable quantification level; C, concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints; D, provisional guideline value because disinfection is likely to result in the guideline value being exceeded; P, provisional guideline value because of uncertainties in the health database; T, provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source control, etc.

[a] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional case of cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated upper-bound excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

In all circumstances, disinfection efficiency should not be compromised in trying to meet guidelines for DBPs, including chlorination by-products, or in trying to reduce concentrations of these substances.

Contaminants from storage and generation of hypochlorite solutions

Sodium hypochlorite solutions slowly decompose—more rapidly at warmer temperatures—to produce chlorate and chlorite ions. As the solution ages and the available chlorine concentration decreases, it is necessary to dose more product to achieve the desired residual chlorine concentration, with a consequent increase in the amounts of chlorate and chlorite added to the treated water. The decomposition of solid calcium hypochlorite is much slower, and consequently contamination is less likely to be significant. However, if calcium hypochlorite solutions are prepared and stored before use, then decomposition to form chlorate and chlorite would also occur.

Sodium hypochlorite is manufactured by electrolysing sodium chloride dissolved in water, which would naturally also contain small concentrations of sodium bromide. This results in the presence of bromate in the sodium hypochlorite solution and will contribute bromate to the treated water. The quality and acceptability of sodium hypochlorite will partly be a function of the concentration of the bromate residue. Industrial-grade product may not be acceptable for drinking-water applications. The sodium bromide naturally present in sodium chloride will also be oxidized to form bromate in systems using on-site electrochemical generation of hypochlorite.

Contaminants from use of ozone and chlorine dioxide

The use of ozone can lead to elevated bromate concentrations through oxidation of bromide present in the water. As a general rule, the higher the bromide concentration in the water, the more bromate that is produced.

Chlorine dioxide solutions can contain chlorate as a result of reactions that compete with the desired reaction for generation of chlorine dioxide. Chlorite ion is an inevitable decomposition product from the use of chlorine dioxide; typically, 60–70% of the applied dose is converted to chlorite in the treated water.

8.5.5 Chemicals of emerging concern

Pharmaceuticals

Pharmaceuticals can be introduced into water sources in sewage by excretion from individuals using these chemicals, from uncontrolled drug disposal (e.g. discarding drugs into toilets) and from agricultural runoff from livestock manure. They have become chemicals of emerging concern to the public because of their potential to reach drinking-water.

The specific types of pharmaceuticals and their metabolites in water sources can differ between countries or regions depending on social, cultural, technological and agricultural factors. Urban and rural areas may exhibit important differences in the occurrence and concentrations of these chemicals as a result of different usage patterns. The local physical and chemical characteristics of source waters can also affect the occurrence levels of pharmaceuticals by influencing their natural degradation.

Most occurrence data in drinking-water and source water have resulted from targeted investigations, rather than from systematic monitoring. Advancements in the sensitivity and accuracy of detection technologies and methodologies have led to increasing detection of trace amounts of pharmaceuticals, ranging from concentrations in the nanogram per litre to low microgram per litre range (although largely less than 0.1 µg/l) in drinking-water, surface water and groundwater. Higher concentrations of these contaminants are found in wastewater treatment effluents or wastewater discharges from poorly controlled manufacturing facilities.

The concentrations of pharmaceuticals found in drinking-water are typically orders of magnitude less than the lowest therapeutic doses. Therefore, exposure to individual compounds in drinking-water is unlikely to have appreciable adverse impacts on human health. Formal guideline values are therefore not proposed in these Guidelines.

Routine monitoring for pharmaceuticals in drinking-water and additional or specialized drinking-water treatment to reduce the concentrations of pharmaceuticals

in drinking-water are not considered necessary. However, where local circumstances indicate a potential for elevated concentrations of pharmaceuticals in drinking-water, investigative monitoring and surveys of impacted water sources can be undertaken to assess possible exposure. If undertaken, these surveys should be quality assured and should target pharmaceuticals that are of local significance—i.e. those that are commonly prescribed and used or manufactured locally. Based on the risk assessment, screening values can be developed to assess the potential risks from exposure through drinking-water, and possible control measures could be considered within the context of water safety plans. Practical difficulties with implementing monitoring programmes include lack of standardized sampling and analysis protocols, high costs and limited availability of technologies needed to detect the diverse range of pharmaceuticals that may be present.

Effective treatment of pharmaceuticals depends on the physicochemical properties of the specific compounds. Typically, 50% of these compounds can be removed by conventional treatment processes (coagulation, filtration and chloramination), and advanced treatment such as ozone, advanced oxidation, activated carbon, nanofiltration and reverse osmosis can achieve higher removal rates.

Preventive measures, such as rational drug use and education of prescribers and the public to reduce disposal and discharges to the environment, will likely reduce human exposure.

8.6 Pesticides used in water for public health purposes

The control of insect vectors of disease (e.g. dengue fever) is vital in many countries, and there are occasions when vectors, particularly mosquitoes, breed in containers used for the storage and collection of drinking-water. Although actions should be taken to prevent access of vectors to or breeding of vectors in these containers, this is not always possible or may not always be fully effective, and use of mosquito larvicides may be indicated in certain settings.

WHOPES carries out evaluations of pesticides for public health uses. There are currently seven larvicidal compounds (diflubenzuron, methoprene, novaluron, pirimiphos-methyl, pyriproxyfen, spinosad and temephos) and a bacterial larvicide (*Bacillus thuringiensis israelensis*) that have been evaluated and listed by WHOPES for the control of container-breeding mosquitoes.

While it is not appropriate to set guideline values for pesticides used for vector control, it is valuable to provide information regarding their safety in use. Formulations of pesticides used for vector control in drinking-water should strictly follow the label recommendations and should only be those approved for such use by national authorities, taking into consideration the ingredients and formulants used in making the final product. In evaluating vector control pesticides for the Guidelines, an assessment is made of the potential exposure compared with the ADI. However, exceeding the ADI does not necessarily mean that this will result in adverse health effects. The diseases spread by vectors are significant causes of morbidity and mortality. It is therefore important to achieve an appropriate balance between the intake of the pesticide from drinking-water and the control of disease-carrying insects. It is stressed that every effort should be made to keep overall exposure and the concentration of

Table 8.17 Pesticides used for public health purposes for which guideline values have not been derived

Pesticide	Reason for not establishing a guideline value
Bacillus thuringiensis israelensis (Bti)	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Diflubenzuron	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Methoprene	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Novaluron	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Permethrin	Not recommended for direct addition to drinking-water as part of WHO's policy to exclude the use of any pyrethroids for larviciding of mosquito vectors of human disease
Pirimiphos-methyl	Not recommended for use for vector control in drinking-water
Pyriproxyfen	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Spinosad	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Temephos	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water

any larvicide no greater than that recommended by WHOPES and as low as possible commensurate with efficacy.

Member States should consider the use of larvicides within the context of their broad vector control strategy. The use of larvicides should be only part of a comprehensive management plan for household water storage and domestic waste management that does not rely exclusively on larviciding by insecticides, but also includes other environmental management measures and social behaviour change. Nevertheless, it would be valuable to obtain actual data on exposure to these substances under field conditions in order to carry out a more refined assessment of margins of exposure.

In addition to the use of larvicides approved for drinking-water application to control disease vector insects, other control measures should also be considered. For example, the stocking of fish of appropriate varieties (e.g. larvae-eating mosquitofish and predatory copepods) in water bodies may adequately control infestations and breeding of mosquitoes in those bodies. Other mosquito breeding areas where water collects should be managed by draining, especially after rainfall.

Those pesticides used for public health purposes for which guideline values have not been derived are listed in Table 8.17. Dichlorodiphenyltrichloroethane (DDT) has been used for public health purposes in the past. It is being reintroduced (but not for water applications) in some areas to control malaria-carrying mosquitoes. Its guideline value is shown in Table 8.18. A summary of the product formulations and dosage rates, with corresponding exposures, is provided in Table 8.19.

Fact sheets for all larvicides considered in the Guidelines are included in chapter 12.

Table 8.18 Guideline values for pesticides that were previously used for public health purposes and are of health significance in drinking-water

Pesticides previously used for public health purposes	Guideline value	
	µg/l	mg/l
DDT and metabolites	1	0.001

8.7 Identifying local actions in response to chemical water quality problems and emergencies

It is difficult to give comprehensive guidance concerning emergencies in which chemicals cause massive contamination of the drinking-water supply, caused either by accident or by deliberate action. Most of the guideline values recommended in these Guidelines (see section 8.5 and Annex 3) relate to a level of exposure that is regarded as tolerable throughout life. Acute toxic effects are considered for a limited number of chemicals. The length of time for which exposure to a chemical far in excess of the guideline value would have adverse effects on health will depend upon factors that vary from contaminant to contaminant. In an emergency situation, the public health authorities should be consulted about appropriate action.

The exceedance of a guideline value may not result in a significant or increased risk to health. Therefore, deviations above the guideline values in either the short or long term may not necessarily mean that the water is unsuitable for consumption. The amount by which, and the period for which, any guideline value can be exceeded without affecting public health depends upon the specific substance involved, and acceptability judgements need to be made by qualified health officials. However, exceedance should be a signal:

- as a minimum, to investigate the cause with a view to taking remedial action as necessary;
- to consult the authority responsible for public health for advice on suitable action, taking into account the intake of the substance from sources other than drinking-water, the toxicity of the substance, the likelihood and nature of any adverse effects and the practicality of remedial measures.

If a guideline value is to be exceeded by a significant amount or for more than a few days, it may be necessary to act rapidly so as to ensure that health protective action is taken and to inform consumers of the situation so that they can act appropriately.

The primary aim with regard to chemical contaminants when a guideline value is exceeded or in an emergency is to prevent exposure of the population to toxic concentrations of pollutants. However, in applying the Guidelines under such circumstances, an important consideration is that, unless there are appropriate alternative supplies of drinking-water available, maintenance of adequate quantities of water is a high priority. In the case of an incident in which chemical contaminants are spilt into a source water and enter a drinking-water supply or enter a supply through treatment or during distribution, the primary aim is to minimize the risk of adverse effects without unnecessarily disrupting the use of the water supply.

Table 8.19 WHO-recommended compounds and formulations for control of mosquito larvae in container habitats[a]

Insecticide	Formulation	Dosage (mg/l)[b]	ADI (mg/kg bw)	Exposure (mg/kg bw)[c]	Use in drinking-water
Bacillus thuringiensis israelensis (Bti)[d]	WG	1–5	—	Adult: 0.17 Child: 0.5 Infant: 0.75	Can be used at recommended doses
Diflubenzuron	DT, GR, WP	0.02–0.25	0–0.02	Adult: 0.008 Child: 0.025[e] Infant: 0.0375[e]	Can be used at recommended doses
Methoprene	EC	1	0–0.09	Adult: 0.033 Child: 0.1[e] Infant: 0.15[e]	Can be used at recommended doses
Novaluron	EC	0.01–0.05	0–0.01	Adult: 0.0017 Child: 0.005 Infant: 0.0075	Can be used at recommended doses
Pirimiphos-methyl	EC	1	0–0.03	Adult: 0.033 Child: 0.1[e] Infant: 0.15[e]	Not recommended for direct application to drinking-water
Pyriproxyfen	GR	0.01	0–0.1	Adult: 0.000 33 Child: 0.001 Infant: 0.0015	Can be used at recommended doses
Spinosad	DT, GR, SC	0.1–0.5[f]	0–0.02	Adult: 0.0017 Child: 0.0052 Infant: 0.0078	Can be used at recommended doses
Temephos	EC, GR	1	0.023[g]	Adult: 0.033 Child: 0.1[e] Infant: 0.15[e]	Can be used at recommended doses

bw, body weight; DT, tablet for direct application; EC, emulsifiable concentrate; GR, granule; SC, suspension concentration; WG, water dispersible granule; WP, wettable powder

[a] WHO recommendations on the use of pesticides in public health are valid only if linked to WHO specifications for their quality control. WHO specifications for public health pesticides are available at http://who.int/whopes/quality/en. Label instructions must always be followed when using insecticides.

[b] Active ingredient for control of container-breeding mosquitoes.

[c] Exposure at the maximum dosage in drinking-water for (a) a 60 kg adult drinking 2 litres of water per day, (b) a 10 kg child drinking 1 litre of water per day and (c) a 5 kg bottle-fed infant drinking 0.75 litre of water per day.

[d] Bti itself is not considered to pose a hazard to humans through drinking-water.

[e] Consideration should be given to using alternative sources of water for small children and bottle-fed infants for a period after application, where this is practical. However, exceeding the ADI will not necessarily result in adverse effects.

[f] The maximum concentration actually achieved with the slow-release formulation of spinosad was approximately 52 µg/l.

[g] This is a TDI rather than an ADI, as JMPR considered that the database was insufficiently robust to serve as the basis for establishing an ADI for temephos. For the purposes of these Guidelines, a TDI has been calculated from the lowest oral NOAEL in the critical study identified by JMPR.

Source: Adapted from WHO/TDR (2009)

This section of the Guidelines can be used to assist evaluation of the risks associated with a particular situation and—especially if a guideline value exists or an authoritative risk assessment is available from an alternative source—support appropriate decision-making on short- and medium-term actions. The approaches proposed provide a basis for discussion between various authorities and for judging the urgency of taking further action.

Normally, a specific review of the situation will be required and should call on suitable expertise. It is important to take local circumstances into account, including the availability of alternative water supplies and exposure to the contaminant from other sources, such as food. It is also important to consider what water treatment is applied or available and whether this will reduce the concentration of the substance.

Where the nature of contamination is unknown, expert opinion should be sought as quickly as possible to identify the contaminants, to determine what actions can be taken to prevent the contaminants from entering the supply and to minimize the exposure of the population and so minimize any potential for adverse effects.

A water safety plan should include planning for response to both predictable events and undefined "emergencies". Such planning facilitates rapid and appropriate response to events when they occur (see section 4.4).

Consideration of emergency planning and planning for response to incidents in which a guideline value is exceeded, covering both microbial and chemical contaminants, is discussed in section 4.4. Broader discussion of actions in emergency situations can be found in section 6.7 and, for microbial contamination, section 7.6.

8.7.1 Trigger for action

Triggers for action may include:

- detection of a spill by, or reporting of a spill to, the drinking-water supplier;
- an alarm raised by the observation of items, such as chemical drums, adjacent to a vulnerable part of the drinking-water supply;
- the detection of a substance in the water;
- a sudden change to water treatment;
- consumer complaints (e.g. an unusual odour, taste or discoloration).

8.7.2 Investigating the situation

Each incident is unique, and it is therefore important to determine associated facts, including what the contaminant is; what the likely concentration is, and by how much the guideline value has been exceeded, if at all; and the potential duration of the incident. These are important in determining the actions to be taken.

8.7.3 Talking to the right people

In any emergency, it is important that there be good communication between the various authorities, particularly the water supplier and health authorities. It will usually be the health authorities that make the final decisions, but knowledge of the water supply and the nature of the supply is vital in making the most appropriate decisions.

In addition, timely and clear communication with consumers is a vital part of successfully handling drinking-water problems and emergencies.

Liaison with key authorities is discussed in section 4.4. It is particularly important to inform the public health authority of any exceedance or likely exceedance of a guideline value or other conditions likely to affect human health and to ensure that the public health authority is involved in decision-making. In the event of actions that require all consumers to be informed or where the provision of temporary supplies of drinking-water is appropriate, civil authorities should also be involved. Planning for these actions is an important part of the development of water safety plans. Involving the public health authorities at an early stage enables them to obtain specialist information and to make the appropriate staff available.

8.7.4 Informing the public

Consumers may be aware of a potential problem with the safety of their drinking-water because of media coverage, their own senses or informal networks. Lack of confidence in the drinking-water or the authorities may drive consumers to alternative, potentially less safe sources. Not only do consumers have a right to information on the safety of their drinking-water, but they have an important role to play in assisting the authorities in an incident by their own actions and by carrying out the necessary measures at the household level. Trust and goodwill from consumers are extremely important in both the short and long term.

The health authorities should be involved whenever a decision to inform the public of health-based concerns or advice to adopt health protection measures such as boiling of water may be required. Such guidance needs to be both timely and clear.

8.7.5 Evaluating the significance to public health and individuals

In assessing the significance of an exceedance of a guideline value, account should be taken of:

- information underpinning the guideline value derivation;
- local exposure to the substance of concern through other routes (e.g. food);
- any sensitive subpopulations;
- locally relevant protective measures to prevent the chemical from entering the source water or supply in the case of a spill.

Information underpinning guideline value derivation

The derivation of guideline values for chemical contaminants is described in section 8.2.

Most guideline values are derived by calculating a TDI or using an existing TDI or ADI. A proportion of the TDI or ADI is then allocated to drinking-water to make allowance for exposure from other sources, particularly food. This allocation is often 20%, but it may be as low as 1% or as high as 80%. In many circumstances, a review of likely local sources of exposure may identify that sources other than drinking-water are less significant than assumed and that a larger proportion of total exposure can be safely allocated to drinking-water. The fact sheets in chapter 12 and background documents on all chemicals addressed in these Guidelines (http://www.who.int/water_sanitation_health/dwq/chemicals/en/#V) provide further information on likely

sources of the chemicals concerned, including their allocation factors. When rapid decision-making is required for such chemicals, it is possible to allow 100% of the TDI to come from drinking-water for a short period (e.g. a few days) while undertaking a more substantive review. In the event that there is significant exposure from other sources or exposure is likely to be for more than a few days, then it is possible to allocate more than the allocation used in the guideline value derivation, but no more than 100%.

In some cases, the guideline value is derived from epidemiological or clinical studies in humans. In most cases (e.g. benzene, barium), these relate to long-term exposure, and short-term exposure to concentrations higher than the guideline value is unlikely to be of significant concern; however, it is important to seek expert advice. In other cases of guideline values derived from epidemiological studies, the associated health effects are acute in nature. For example:

- The guideline value for nitrate (50 mg/l) is based on the occurrence of methaemoglobinaemia, or blue-baby syndrome, in bottle-fed infants. This outcome is complicated by the concurrent presence of microbial contamination, which can significantly increase the risk to this group. Methaemoglobinaemia has rarely been associated with nitrate in the absence of faecal contamination of the drinking-water. As a short-term measure, water should not be used for bottle-fed infants when nitrate levels are above 100 mg/l; however, it may be used if medical authorities are increasingly vigilant when the nitrate concentration is between 50 and 100 mg/l, provided that the water is known and is confirmed to be microbially safe. The guideline value for nitrate relates to a specific and vulnerable subgroup (i.e. bottle-fed infants), and therefore the guideline value will be more than adequately protective for older children and adults.
- The guideline value for copper is also based on short-term exposure but is intended to protect against direct gastric irritation, which is a concentration-dependent phenomenon. The guideline value may be exceeded, but there will be an increasing risk of consumers suffering from gastrointestinal irritation as the concentration increases above the guideline value. The occurrence of such irritation can be assessed in exposed populations.

In some cases, the guideline value is derived from a cancer risk estimate obtained from studies in laboratory animals. In these cases, short-term (a few months to a year) exposure to concentrations up to 10 times the guideline value would result in only a small increase in estimated risk of cancer. Because the estimate of risk varies over a wide range, there may be no, or a very small, increase in risk. In such a circumstance, accepting a 10-fold increase in the guideline value for a short period would have no discernible impact on the risk over a lifetime. However, care would be needed to determine whether other toxicological end-points more relevant for short-term exposure, such as neurotoxicity, would become significant.

Health-based values for short-term exposures are now being developed for a small number of substances that are used in significant quantities and are frequently implicated in an emergency as a consequence of spills, usually to surface water sources. The methodology used in the derivation of these health-based values is described below.

Health-based values for use in emergencies

Health-based values for short-term exposures can be derived for any chemicals that are used in significant quantities and are frequently involved in an emergency as a consequence of spills, usually to surface water sources. JMPR has provided guidance on the setting of acute reference doses (ARfDs) for pesticides (Solecki et al., 2005). These ARfDs can be used as a basis for deriving short-term health-based values for pesticides in drinking-water, and the general guidance can also be applied to derive ARfDs for other chemicals.

The ARfD can be defined as the amount of a chemical, normally expressed on a body weight basis, that can be ingested in a period of 24 hours or less without appreciable health risk to the consumer. Most of the scientific concepts applicable to the setting of ADIs or TDIs for chronic exposure apply equally to the setting of ARfDs. The toxicological end-points most relevant for a single or 1-day exposure should be selected. For ARfDs for pesticides, possible relevant end-points include haematotoxicity (including methaemoglobin formation), immunotoxicity, acute neurotoxicity, liver and kidney toxicity (observed in single-dose studies or early in repeated-dose studies), endocrine effects and developmental effects. The most relevant or adequate study in which these end-points have been determined (in the most sensitive species or most vulnerable subgroup) is selected, and NOAELs are established. The most relevant end-point providing the lowest NOAEL is then used in the derivation of the ARfD. Uncertainty factors are used to extrapolate from experimental animal data to the average human and to allow for variation in sensitivity within the human population. An ARfD derived in such a manner can then be used to establish a health-based value by allocating 100% of the ARfD to drinking-water.

Available data sets do not allow the accurate evaluation of the acute toxicity for a number of compounds of interest. If appropriate single-dose or short-term data are lacking, an end-point from a repeated-dose toxicity study can be used. This is likely to be a more conservative approach, and this should be clearly stated in the health-based value derivation.

When a substance has been spilt into a drinking-water source, contamination may be present for a period longer than 24 hours, but not usually longer than a few days. Under these circumstances, the use of data from repeated-dose toxicity studies is appropriate. As the period of exposure used in these studies will often be much longer than a few days, this, too, is likely to be a conservative approach.

Where there is a need for a rapid response and suitable data are not available to establish an ARfD (for ARfDs established by JMPR, see http://www.who.int/ipcs/food/jmpr/en/index.html; for short-term drinking-water health advisories for contaminants in drinking-water produced by the United States Environmental Protection Agency, see http://www.epa.gov/waterscience/criteria/drinking/), but a guideline value is available for the chemical of concern, a simple pragmatic approach would be to allocate a higher proportion of the ADI or TDI to drinking-water. As the ADI or TDI is intended to be protective of lifetime exposure, small exceedances of the ADI or TDI for short periods will not be of significant concern for health. It would therefore be possible to allow 100% of the ADI or TDI to come from drinking-water for a short period.

Health-based values for acute and short-term exposures provide a basis for deciding when water can continue to be supplied without serious risk to consumers in such an emergency situation. However, it is important to minimize exposure wherever practical. It is recognized that losing a water supply carries risks to public health and is a major challenge to maintaining proper hygiene as well as ensuring the availability of microbially safe drinking-water. The acute and short-term health-based values assist in determining the balance of risks between supplying water containing a contaminant and not supplying water in such emergencies.

Assessing locally relevant sources of the substance of concern through other routes of exposure

The most useful sources of information regarding local exposure to substances through food and, to a lesser extent, air and other environmental routes are usually government departments dealing with food and environmental pollution. Other sources of information may include universities. In the absence of specific data, the Guidelines background documents consider the sources of exposure and give a generic assessment that can be used to make a local evaluation as to the potential use of a chemical and whether this would be likely to enter the food-chain. Further information is available in the supporting document *Chemical safety of drinking-water* (Annex 1).

Sensitive subpopulations

In some cases, there may be a specific subpopulation that is at greater risk from a substance than the rest of the population. These usually relate to high exposure relative to body weight (e.g. bottle-fed infants) or a particular sensitivity (e.g. fetal haemoglobin and nitrate/nitrite). However, some genetic subpopulations may show greater sensitivity to particular toxicity (e.g. glucose-6-phosphate dehydrogenase–deficient groups and oxidative stress on red blood cells). If the potential exposure from drinking-water in an incident is greater than the ADI or TDI or exposure is likely to be extended beyond a few days, then this would require consideration in conjunction with health authorities. In such circumstances, it may be possible to target action to avoid exposure of the specific group concerned, such as supplying bottled water for bottle-fed infants.

Specific mitigation measures affecting risk assessment

Such measures relate to actions taken locally or on a household basis that can have an impact on the presence of a particular contaminant. For example, the presence of a substance that is volatile or heat labile will be affected by heating the water for cooking or the preparation of beverages. Where such measures are routinely undertaken by the exposed population, the risk assessment may be modified accordingly. Alternatively, such steps can be used on a household basis to reduce exposure and allow the continued use of the supply without interruption.

8.7.6 Determining appropriate action

Determining appropriate action means that various risks will need to be balanced. The interruption of water supply to consumers is a serious step and can lead to

risks associated with contamination of drinking-water stored in the household with pathogens and limiting use for purposes of hygiene and health protection. Issuing a "do not drink" notice may allow the use of the supply for hygiene purposes such as showering or bathing, but creates pressure on consumers and authorities to provide a safe alternative for drinking and cooking. In some cases, this option will be expensive and could divert resources from other, more important issues. Appropriate action will always be decided on a case-by-case basis in conjunction with other authorities, including the health protection and civil authorities, who may be required to participate in informing consumers, delivering alternative supplies or supervising the collection of water from bowsers and tankers. Responding to a potential risk to health from a chemical contaminant should not lead to an increase in overall health risk from disruption of supply, microbial contaminants or other chemical contaminants.

8.7.7 Consumer acceptability

Even though, in an emergency, supplying water that contains a substance present at higher concentrations than would normally be desirable may not result in an undue risk to health, the water may not be acceptable to consumers. A number of substances that can contaminate drinking-water supplies as a consequence of spills can give rise to severe problems with taste or odour. Under these circumstances, drinking-water may become so unpalatable as to render the water undrinkable or to cause consumers to turn to alternative drinking-water sources that may present a greater risk to health. In addition, water that is clearly contaminated may cause some consumers to feel unwell due to a perception of poor water quality. Consumer acceptability may be the most important factor in determining the advice given to consumers about whether or not the water should be used for drinking or cooking.

8.7.8 Ensuring remedial action, preventing recurrence and updating the water safety plan

The recording of an incident, the decisions taken and the reasons for them are essential parts of handling an incident. The water safety plan, as discussed in chapter 4, should be updated in the light of experience. This would include making sure that problem areas identified during an incident are corrected. Where possible, it would also mean that the cause of the incident is dealt with to prevent its recurrence. For example, if the incident has arisen as a consequence of a spill from industry, the source of the spill can be advised as to how to prevent another spill and the information passed on to other similar industrial establishments.

8.7.9 Mixtures

A spill may contain more than one contaminant of potential health concern (see section 8.2.8). Under these circumstances, it will be important to determine whether the substances present interact. Where the substances have a similar mechanism or mode of action, it is appropriate to consider them as additive. This may be particularly true of some pesticides, such as atrazine and simazine. In these circumstances,

appropriate action must take local circumstances into consideration. Specialist advice should generally be sought.

8.7.10 Water avoidance advisories

Water avoidance advisories share many features with boil water advisories (see section 7.6.1), but are less common. Like boil water advisories, they are a serious measure that should be instituted only when there is evidence that an advisory is necessary to reduce a substantial public health risk. In cases where alternative sources of water are recommended, particular consideration should be given to the potential for microbial hazards in those alternative sources. Water avoidance advisories are applied when the parameter of concern is not susceptible to boiling or when risks from dermal contact or inhalation of the contaminant are also significant. Water avoidance advisories may also be issued when an unknown agent or chemical substance is detected in the distribution system. It is important that the water avoidance advisories include the information that boiling is ineffective or insufficient to reduce the risk.

As with the case of boil water advisories, water suppliers in conjunction with public health authorities should develop protocols for water avoidance advisories. Protocols should be prepared before any incident occurs and incorporated within water safety plans. Decisions to issue advisories are often made within a short period of time, and developing responses during an event can complicate decision-making, compromise communication and undermine public confidence.

In addition to the information discussed in section 4.4.3, the protocols should provide information to the general public and specific groups on the following:

- criteria for issuing and rescinding an advisory;
- activities impacted by the advisory;
- alternative sources of safe water for drinking and other domestic uses.

Protocols should identify mechanisms for the communication of water avoidance advisories. The mechanisms may vary, depending on the nature of the supply and the size of the community affected, and could include:

- media releases through television, radio and newspapers;
- telephone, e-mail and fax contact of specific facilities, community groups and local authorities;
- posting of notices in conspicuous locations;
- personal delivery;
- mail delivery.

The methods chosen should provide a reasonable assurance that all of those affected by the advisory, including residents, workers and travellers, are notified as soon as possible.

The issuing of a water avoidance advisory may be necessary, for example, following contamination—for example, chemical or radiological—as a result of accidental, natural or malicious origin that leads to:

- a significant exceedance of a guideline value, which may pose a threat to health from short-term exposure;

- concentrations of a chemical with no guideline value that may pose a threat to health from short-term exposure;
- significant odour or taste that has no identified source or that will give rise to significant public anxiety.

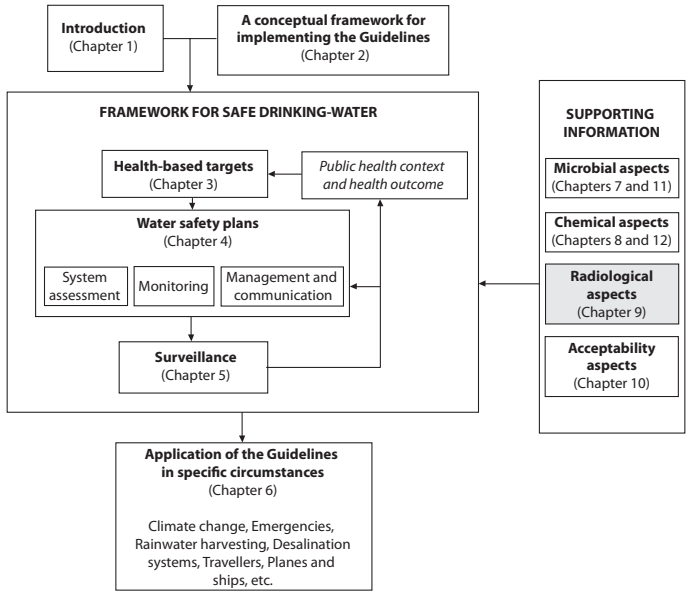
When issued, water avoidance advisories should provide information on the same issues included in boil water advisories (see section 7.6.1), although recommendations relating to affected uses and users will vary, depending on the nature of the problem. For example, for elevated concentrations of contaminants that are of concern only from a drinking or cooking perspective, the public could be advised to avoid using the water for drinking, food preparation, preparing cold drinks, making ice and hygienic uses, such as tooth brushing. Where the advisory applies to elevated levels of chemicals that can cause skin or eye irritation or gastrointestinal upsets, the public could be advised not to use the water for drinking, cooking, tooth brushing or bathing/showering. Alternatively, specific water avoidance advice might be issued where the contamination might affect subgroups of the population—for example, pregnant women or bottle-fed infants.

As for boil water advisories, specific advice may need to be issued for dentists, doctors, hospitals and other health-care facilities, child-care facilities, schools, food suppliers and manufacturers, hotels, restaurants and operators of public swimming pools.

Water avoidance advisories do not equate to cessation of supply; water will generally be suitable for flushing toilets and other uses, such as clothes washing. However, suitable alternative supplies of drinking-water, such as bottled water and carted or tankered water, will be required for drinking and other domestic uses.

Criteria for rescinding water avoidance advisories will generally be based on evidence that the source of elevated concentrations of hazardous contaminants has been removed, that distribution systems have been appropriately flushed and that the water is safe for drinking and other uses. In buildings, the flushing would extend to storages and internal plumbing systems.

9
Radiological aspects



Drinking-water may contain radioactive substances ("radionuclides") that could present a risk to human health. These risks are normally small compared with the risks from microorganisms and chemicals that may be present in drinking-water. Except in extreme circumstances, the radiation dose resulting from the ingestion of radionuclides in drinking-water is much lower than that received from other sources of radiation. The objective of this chapter is to provide criteria with which to assess the safety of drinking-water with respect to its radionuclide content and to provide guidance on reducing health risks by taking measures to decrease radionuclide concentrations, and therefore radiation doses, in situations where this is considered necessary.

In terms of health risk assessment, the Guidelines do not differentiate between radionuclides that occur naturally and those that arise from human activities. However, in terms of risk management, a differentiation is made because, in principle, human-made radionuclides are often controllable at the point at which they enter the water supply. Naturally occurring radionuclides, in contrast, can potentially enter the water supply at any point, or at several points, prior to consumption. For this reason, naturally occurring radionuclides in drinking-water are often less amenable to control.

Naturally occurring radionuclides in drinking-water usually give radiation doses higher than those provided by artificially produced radionuclides and are therefore of greater concern. Radiological risks are best controlled through a preventive risk management approach following the framework for safe drinking-water (see chapter 2) and the water safety plan approach (see chapter 4). When considering what action to take in assessing and managing radiological risks, care should be taken to ensure that scarce resources are not diverted away from other, more important public health concerns.

The screening levels and guidance levels for radioactivity presented in these Guidelines are based on the latest recommendations of the International Commission on Radiological Protection (ICRP, 2008).

Some drinking-water supplies, in particular those sourced from groundwater, may contain radon, a radioactive gas. Although radon can enter indoor air in buildings through its release from water from taps or during showering, the most significant source of radon in indoor air arises through natural accumulation from the environment. An evaluation of international research data (UNSCEAR, 2000) has concluded that, on average, 90% of the dose attributable to radon in drinking-water comes from inhalation rather than ingestion. Consequently, the setting of screening levels and guidance levels to limit the dose from ingestion of radon contained in drinking-water is not usually necessary. The screening measurements for gross alpha and gross beta activities will include the contribution from radon progeny, which is the principal source of dose from ingestion of radon present in drinking-water supplies. This is further discussed in section 9.7.

9.1 Sources[1] and health effects of radiation exposure

Radioactivity from several naturally occurring and human-made sources is present throughout the environment. Some chemical elements present in the environment are naturally radioactive. These are found in varying amounts in soils, water, indoor and outdoor air and even within our bodies, and so exposure to them is inevitable. In addition, Earth is constantly bombarded by high-energy particles originating both from the sun and from outside the solar system. Collectively, these particles are referred to as cosmic radiation. Everybody receives a dose from cosmic radiation, which is influenced by latitude, longitude and height above sea level.

The use of radiation in medicine for diagnosis and treatment is the largest human-made source of radiation exposure today. The testing of nuclear weapons, routine discharges from industrial and medical facilities and accidents such as Chernobyl have added human-made radionuclides to our environment.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2008) has estimated that the global average annual dose per person from all sources of radiation in the environment is approximately 3.0 mSv/year (see Box 9.1). Of this, 80% (2.4 mSv) is due to naturally occurring sources of radiation, 19.6% (almost 0.6 mSv) is due to the use of radiation for medical diagnosis and the remaining 0.4%

[1] When the term "source" appears in this chapter without any other reference, it is used in the context of "radiation source". For any other purpose, additional information is provided (e.g. "water source").

Box 9.1 Key terms, quantities and units

Becquerel (Bq)—The becquerel is the unit of radioactivity in the International System of Units (abbreviated SI from the French *Système international d'unités*), corresponding to one radioactive disintegration per second. In the case of drinking-water, it is usual to talk about the activity concentration, expressed in units of Bq/l.

Effective dose—When radiation interacts with body tissues and organs, the radiation dose received is a function of factors such as the type of radiation, the part of the body affected and the exposure pathway. This means that 1 Bq of radioactivity will not always deliver the same radiation dose. A unit called "effective dose" has been developed to take account of the differences between different types of radiation so that their biological impacts can be compared directly. The effective dose is expressed in SI units called sieverts (Sv). The sievert is a very large unit, and it is often more practical to talk in terms of millisieverts (mSv). There are 1000 mSv in 1 Sv.

Effective half-life—Radioisotopes have a "physical" half-life, which is the period of time it takes for one half of the atoms to disintegrate. Physical half-lives for various radioisotopes can range from a few microseconds to billions of years. When a radioisotope is present in a living organism, it may be excreted. The rate of this elimination is influenced by biological factors and is referred to as the "biological" half-life. The effective half-life is the actual rate of halving the radioactivity in a living organism as determined by both the physical and biological half-lives. Whereas for certain radionuclides, the biological processes are dominant, for others, physical decay is the dominant influence.

(around 0.01 mSv) is due to other sources of human-made radiation (see Figure 9.1). There can be large variability in the dose received by individual members of the population, depending on where they live, their dietary preferences and other lifestyle choices. Individual radiation doses can also differ depending on medical treatments and occupational exposures. Annual average doses and typical ranges of individual doses from naturally occurring sources are presented in Table 9.1 (UNSCEAR, 2008).

9.1.1 Radiation exposure through ingestion of drinking-water

Water sources can contain radionuclides of natural and artificial origin (i.e. human-made):

- Natural radionuclides, including potassium-40, and those of the thorium and uranium decay series, in particular radium-226, radium-228, uranium-234, uranium-238 and lead-210, can be found in water as a result of either natural processes (e.g. absorption from the soil) or technological processes involving naturally occurring radioactive materials (e.g. the mining and processing of mineral sands or phosphate fertilizer production).
- Human-made radionuclides may be present in water from several sources, such as
  - — radionuclides discharged from nuclear fuel cycle facilities;
  - — manufactured radionuclides (produced and used in unsealed form in medicine or industry) entered into drinking-water supplies as a result of regular or incidental discharges;
  - — radionuclides released in the past into the environment, including drinking-water sources.

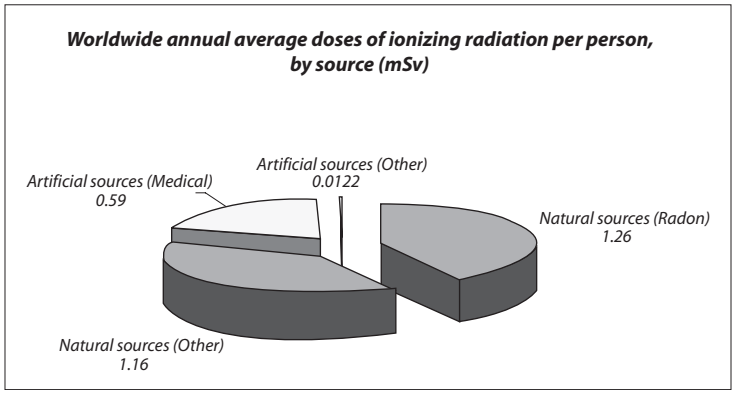


Figure 9.1 Distribution of average radiation exposure for the world population

Table 9.1 Average radiation dose from naturally occurring sources

Source	Worldwide average annual effective dose (mSv)	Typical annual effective dose range (mSv)
External exposure		
Cosmic rays	0.39	0.3–1[a]
Terrestrial radiation (outdoors and indoors)	0.48	0.3–1[b]
Internal exposure		
Inhalation (mainly radon)	1.26	0.2–10[c]
Ingestion (food and drinking-water)	0.29	0.2–1[d]
Total	**2.4**	**1–13**

[a] Range from sea level to high ground elevation.
[b] Depending on radionuclide composition of soil and building material.
[c] Depending on indoor accumulation of radon gas.
[d] Depending on radionuclide composition of foods and drinking-water.
Source: Adapted from UNSCEAR (2008)

9.1.2 Radiation-induced health effects through drinking-water

Radiation protection is based on the assumption that any exposure to radiation involves some level of risk. For prolonged exposures, as is the case for ingestion of drinking-water containing radionuclides over extended periods of time, evidence of an increased cancer risk in humans is available at doses above 100 mSv (Brenner et al., 2003). Below this dose, an increased risk has not been identified through epidemiological studies. It is assumed that there is a linear relationship between exposure and risk, with no threshold value below which there is no risk. The individual dose criterion (IDC) of 0.1 mSv/year represents a very low level of risk that is not expected to give rise to any detectable adverse health effect.

Box 9.2 Radiation exposure situations

The ICRP (2008) distinguishes between three types of radiation exposure situations—planned, existing and emergency exposure situations:

- A ***planned exposure*** situation is a situation that arises from the planned operation of a radiation source or from a planned activity that results in an exposure to a radiation source (e.g. exposure to a radiation source during a medical procedure for diagnosis or treatment).
- An ***existing exposure*** situation is a situation that already exists when a decision on the need for control has to be taken (e.g. exposure to indoor radon in dwellings).
- An ***emergency exposure*** situation is a situation that arises as a result of an accident, a malicious act or any other unexpected event. The present Guidelines do not apply during emergency exposure situations (see chapter 6).

Box 9.3 Individual dose criterion (IDC) and health risks

The additional risk to health from exposure to an annual dose of 0.1 mSv associated with the intake of radionuclides from drinking-water is considered to be low for the following reasons:

- Individual doses from natural radioactivity in the environment vary widely. The average is about 2.4 mSv/year, but in some parts of the world, average doses can be up to 10 times higher (i.e. 24 mSv/year) without any observed increase in health risks, as noted in long-term population studies (Tao, 2000; Nair et al., 2009). An IDC of 0.1 mSv/year therefore represents a small addition to natural levels.
- The nominal risk coefficient for radiation-induced cancer incidence is 5.5×10^{-2}/Sv (ICRP, 2008). Multiplying this by an IDC of 0.1 mSv/year from drinking-water gives an estimated annual cancer risk of approximately 5.5×10^{-6}.

9.2 Rationale for screening levels and guidance levels

The current Guidelines are based on the approach proposed by the ICRP in situations of prolonged radiation exposure of the public. According to the ICRP, in planned exposure situations (see Box 9.2), it is prudent to restrict the prolonged component of the individual dose to 0.1 mSv in any given year (ICRP, 2000). It is recognized that exposure to radionuclides in drinking-water may be a consequence of a planned exposure situation, but is more likely to be from an existing exposure situation. Rather than adopt a different approach depending on whether or not the radionuclides are naturally occurring or human-made, a pragmatic and conservative approach was adopted, with an IDC of 0.1 mSv from 1 year's consumption of drinking-water, regardless of the origin of the radionuclides (see Box 9.3).

Screening levels and guidance levels are conservative and should not be interpreted as mandatory limits. Exceeding a guidance level should be taken as a trigger for further investigation, but not necessarily as an indication that the drinking-water is unsafe.

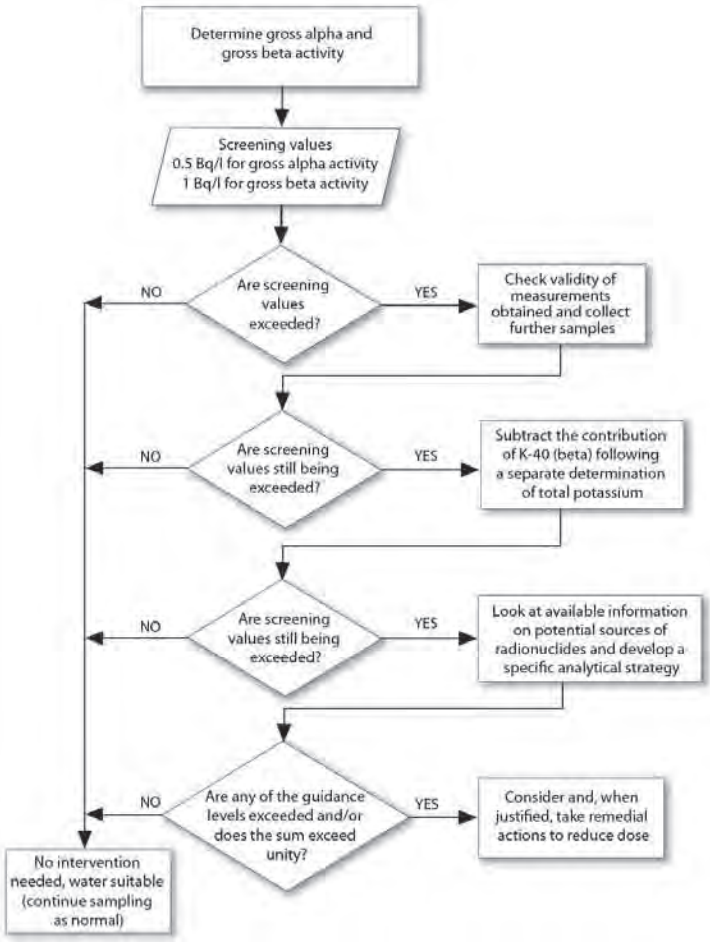


Figure 9.2 Application of screening and guidance levels for radionuclides in drinking-water

In the second edition of the Guidelines, the IDC of 0.1 mSv/year was based on screening levels for gross alpha activity and gross beta activity of 0.1 Bq/l and 1 Bq/l, respectively. This IDC represents less than 5% of the average annual dose attributable to radiation of natural origin (see section 9.1). Subsequent experience indicated that, in practice, the 0.1 mSv annual dose would usually not be exceeded if the gross alpha activity was equal to or below 0.5 Bq/l. For this reason, in the third edition of the Guidelines, the IDC was based on screening levels of 0.5 Bq/l for gross alpha activity and 1 Bq/l for gross beta activity. This change was carried forward to the current edition of the Guidelines.

9.3 Monitoring and assessment for dissolved radionuclides

The recommended assessment methodology for controlling radionuclide health risks from drinking-water is illustrated in Figure 9.2 and summarized in Box 9.4.

Box 9.4 Recommended assessment methodology

The recommended assessment methodology for controlling radionuclide health risks from drinking-water involves four steps:

1. An IDC[1] of 0.1 mSv from 1 year's consumption of drinking-water is adopted.
2. Initial screening is undertaken for both gross alpha activity and gross beta activity. If the measured activity concentrations are below the screening levels of 0.5 Bq/l for gross alpha activity and 1 Bq/l for gross beta activity, no further action is required.
3. If either of the screening levels is exceeded, the concentrations of individual radionuclides should be determined and compared with the guidance levels (see Table 9.2).
4. The outcome of this further evaluation may indicate that no action is required or that further evaluation is necessary before a decision can be made on the need for measures to reduce the dose.

9.3.1 Screening of drinking-water supplies

The process of identifying individual radionuclides in drinking-water and determining their concentration is time-consuming and expensive. Because, in most circumstances, the concentrations are low, such detailed analysis is normally not justified for routine monitoring. A more practical approach is to use a screening procedure, where the total radioactivity present in the form of alpha and beta radiation is first determined, without regard to the identity of specific radionuclides.

These measurements are suitable as a preliminary screening procedure to determine whether further radioisotope-specific analysis is necessary. They can also be used for detecting changes in the radiological characteristics of the drinking-water source as well as for identifying spatial and/or temporal trends in the radionuclide content of drinking-water.

Screening levels for drinking-water, below which no further action is required, are 0.5 Bq/l for gross alpha activity and 1 Bq/l for gross beta activity. If neither of these values is exceeded, the IDC of 0.1 mSv/year will also not be exceeded. The use of these screening levels is recommended, as this maximizes both the reliability and the cost-effectiveness of assessing the radionuclide content of drinking-water.

Radionuclides emitting low-energy beta activity, such as tritium, and some gaseous or volatile radionuclides, such as iodine, will not be detected by standard gross activity measurements. Routine analysis for these radionuclides is not necessary, but, if there are any reasons for believing that they may be present, radionuclide-specific sampling and measurement techniques should be used.[2]

Gross beta measurements include a contribution from potassium-40, a beta emitter that occurs naturally in a fixed ratio to stable potassium. Potassium is an essential element for humans and is absorbed mainly from ingested food. If the screening level of 1 Bq/l for gross beta is exceeded, the contribution of potassium-40 to beta activity should be subtracted following a separate determination of total potassium. The

[1] In the European Commission Drinking Water Directive (European Commission, 2001), this parameter is called the total indicative dose (TID), and the same value of 0.1 mSv/year is adopted.

[2] References for analytical methods and treatment technologies specific to radionuclides are provided in Annex 6.

beta activity of potassium-40 is 27.9 Bq/g of stable potassium, which is the factor that should be used to calculate the beta activity due to potassium-40.

9.3.2 Strategy for assessing drinking-water if screening levels are exceeded

If either of the screening levels is exceeded, then the specific radionuclides should be identified and their individual activity concentrations measured. This will allow the contribution from each radionuclide to the IDC to be calculated. If the following additive formula is satisfied, then no further action is required:

$$\sum_i \frac{C_i}{GL_i} \leq 1$$

where:

C_i = the measured activity concentration of radionuclide *i*, and
GL = the guidance level (see Tables 9.2 and A6.1 in Annex 6) of radionuclide *i* that, at an intake of 2 litres/day[1] for 1 year, will result in an effective dose of 0.1 mSv/year.

If any of the guidance levels is exceeded, then the sum will exceed unity. The sum may also exceed unity even if none of the individual guidance levels is exceeded. Where the sum exceeds unity for a single sample, the IDC of 0.1 mSv/year would be exceeded only if the exposure to the same measured concentrations were to continue for a full year. *Hence, such a result does not in itself imply that the water is unsuitable for consumption.*

9.3.3 Strategy for assessing drinking-water if guidance levels are exceeded

An annual dose of 0.1 mSv is a small percentage of the average radiation dose received by any individual. Both the screening levels and guidance levels are highly conservative values that allow national authorities to determine, without further consideration, that the drinking-water is fit for consumption from a radiological viewpoint. National experiences have shown that the vast majority of water supplies comply with these criteria.

Occasionally, the situation may arise where the guidance levels are consistently exceeded for one or a combination of specific radionuclides. National authorities will then need to make a decision regarding the need to implement remedial measures or to place some restriction on the continued use of the water supply for drinking purposes.

From a radiological point of view, one of the key considerations is the extent to which the guidance levels are exceeded. The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources address drinking-water in the chapter on existing exposure situations and contain a requirement that the highest annual individual doses received from the consumption of

[1] Where national or regional consumption rates are known, the guidance level should be adjusted to take this into account.

Table 9.2 Guidance levels for common[a] natural and artificial radionuclides for members of the public

Category	Radionuclide	Dose coefficient (Sv/Bq)	Guidance level[b] (Bq/l)
Naturally occurring radioactive isotope that starts the uranium decay series[c]	Uranium-238	4.5×10^{-8}	10
Naturally occurring radioactive isotopes belonging to the uranium decay series	Uranium-234	4.9×10^{-8}	1
	Thorium-230	2.1×10^{-7}	1
	Radium-226	2.8×10^{-7}	1
	Lead-210	6.9×10^{-7}	0.1
	Polonium-210	1.2×10^{-6}	0.1
Naturally occurring radioactive isotope that starts the thorium decay series	Thorium-232	2.3×10^{-7}	1
Naturally occurring radioactive isotopes belonging to the thorium decay series	Radium-228	6.9×10^{-7}	0.1
	Thorium-228	7.2×10^{-8}	1
Artificial radionuclides that can be released to the environment as part of the fission products found in reactor emissions or nuclear weapons tests	Caesium-134[d]	1.9×10^{-8}	10
	Caesium-137[d]	1.3×10^{-8}	10
	Strontium-90[d]	2.8×10^{-8}	10
Artificial radionuclide that can be released to the environment as a fission product (see above). It is also used in nuclear medicine procedures and thus can be released into water bodies through sewage effluent.	Iodine-131[d,e]	2.2×10^{-8}	10
Radioactive isotope of the hydrogen produced artificially as a fission product from nuclear power reactors and nuclear weapons tests. It may be naturally present in the environment in a very small amount. Its presence in a water source suggests potential industrial contamination.	Tritium[e]	1.8×10^{-11}	10 000
Naturally occurring radioactive isotope widely distributed in nature and present in organic compounds and in the human body	Carbon-14	5.8×10^{-10}	100
Artificial isotope formed in nuclear reactors that also exists in trace quantities in *natural* uranium ores	Plutonium-239[d]	2.5×10^{-7}	1
Artificial isotope by-product formed in nuclear reactors	Americium-241[d]	2.0×10^{-7}	1

[a] This list is not exhaustive. In certain circumstances, other radionuclides should be investigated (see Annex 6).

[b] Guidance levels are rounded to the nearest order of magnitude.

[c] Separate guidance levels are provided for individual uranium radioisotopes in terms of radioactivity (i.e. expressed as Bq/l). The provisional guideline value for total content of uranium in drinking-water is 30 µg/l based on its chemical toxicity, which is predominant compared with its radiological toxicity (see chapter 12).

[d] These radionuclides either may not occur in drinking-water in normal situations or may be found at doses that are too low to be of significance to public health. Therefore, they are of lower priority for investigation following an exceedance of a screening level.

[e] Although iodine and tritium will not be detected by standard gross activity measurements and routine analysis for these radionuclides is not necessary, if there are any reasons for believing that they may be present, radionuclide-specific sampling and measurement techniques should be used. This is the reason for including them in this table.

drinking-water do not exceed a value of approximately 1 mSv.[1] This should not be regarded either as an "acceptable" dose or as a dose limit, and all reasonable efforts should be made to minimize the doses received. Each situation will be different, and non-radiological factors, such as the costs of remediation and the availability of other drinking-water supplies, will need to be taken into account in reaching a final decision. National authorities also need to be aware that radionuclides such as uranium are chemically toxic, and the allowable concentrations in drinking-water may be determined by a radioisotope's toxicological rather than its radioactive properties (see chapter 12).

9.3.4 Sampling frequency

Criteria for monitoring radiological contamination of drinking-water should be developed, taking into account available resources and the potential for radiological risks. It should not detract from the adequate assessment and management of microbial and chemical risks. New water supplies should be sampled to determine their suitability for drinking-water, whereas existing supplies would need monitoring occasionally. If the water supply is adequately characterized and measured concentrations are consistently below screening levels, then sampling frequency should be reduced. However, if sources of potential radionuclide contamination exist nearby or are expected to be changing rapidly with time, then the sampling should be more frequent. Sampling frequency should be maintained, or even increased, if concentrations are approaching the screening levels or if the sum of ratios of the observed concentrations of individual radionuclides to their guidance levels approaches unity (see below). A graded approach to sampling frequency should be developed commensurate with the degree of contamination, the source of supply (i.e. surface water or groundwater), the size of the population served, the expected variability of radionuclide concentrations and the availability and results of historical monitoring records. International standards are available relating to the assessment of radiological water quality, including sampling procedures (e.g. preservation and handling of samples) and programmes (Standards Australia & Standards New Zealand, 1998; ISO, 2003, 2006a,b, 2009a).

9.4 Guidance levels for radionuclides commonly found in drinking-water

Guidance levels established for naturally occurring and human-made radionuclides most commonly detected in drinking-water supplies as well as for human-made radionuclides potentially relevant for prolonged exposure situations resulting from past nuclear emergency situations are presented in Table 9.2. The respective dose coefficients for adults are also presented (IAEA, 1996; ICRP, 1996).

The guidance level for each radionuclide in Table 9.2 represents the concentration that, if present in the drinking-water consumed throughout the year, would result in an individual dose of 0.1 mSv.

The guidance levels were calculated using dose coefficients for adults. Insufficient evidence was found to introduce separate guidance levels for different age groups. Although infants and children consume a lower mean volume of drinking-water, the

[1] IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (revised edition, in preparation).

age-dependent dose coefficients for children are higher than those for adults, accounting for higher uptake or metabolic rates. In the case of prolonged contamination of the water source, an assessment of doses to infants and children may be considered.

The guidance levels apply to routine ("normal") operational conditions of existing or new drinking-water supplies. They do not apply during an emergency exposure situation involving the release of radionuclides into the environment. However, the guidance levels apply again once the relevant authorities have declared an end to the emergency exposure situation. Additional guidance is provided in section 6.7 and in several publications (IAEA, 2002; IAEA & WHO, 2005, 2010; ICRP, 2009a).

The guidance levels for radionuclides in drinking-water were calculated using the following equation:

$$GL = \frac{IDC}{h_{ing} \times q}$$

where:

GL = guidance level of radionuclide in drinking-water (Bq/l)
IDC = individual dose criterion, equal to 0.1 mSv/year for this calculation
h_{ing} = dose coefficient for ingestion by adults (mSv/Bq)
q = annual ingested volume of drinking-water, assumed to be 730 litres/year (equivalent to the standard World Health Organization drinking-water consumption rate of 2 litres/day)

9.5 Analytical methods

9.5.1 Measuring gross alpha and gross beta activity concentrations

To analyse drinking-water for gross alpha and gross beta activities (excluding radon), the most common approach is to evaporate a known volume of the sample to dryness and measure the activity of the residue. As alpha radiation is easily absorbed within a thin layer of solid material, the reliability and sensitivity of the method for alpha determination may be reduced in samples with high total dissolved solids (TDS) content. Where possible, standardized methods should be used to determine concentrations of gross alpha and gross beta activities. Procedures for this analysis are listed in Table 9.3.

The determination of gross beta activity using the evaporation method includes the contribution from potassium-40. An additional analysis of total potassium is therefore required if the gross beta screening value is exceeded.

The co-precipitation technique (APHA et al., 2005) excludes the contribution due to potassium-40; therefore, determination of total potassium is not necessary. This method is not applicable to assessment of water samples containing certain fission products, such as caesium-137. However, under normal circumstances, concentrations of fission products in drinking-water supplies are extremely low.

9.5.2 Measuring specific radionuclides

If either of the gross alpha and gross beta screening levels is exceeded, then the specific radionuclides should be identified and their individual activity concentrations measured.

Table 9.3 Methods for the analysis of gross alpha and gross beta activities in drinking-water

Method (reference)	Technique	Detection limit	Application
International Organization for Standardization: ISO 9696 for gross alpha (ISO, 2007) ISO 9697 for gross beta (ISO, 2008) ISO 10704 for gross alpha and gross beta (ISO, 2009b)	Evaporation	0.02–0.1 Bq/l	Groundwater with TDS less than 0.1 g/l
American Public Health Association (APHA et al., 2005)	Co-precipitation	0.02 Bq/l	Surface water and groundwater (TDS is not a factor)

References for analytical methods for specific radionuclides are provided in Annex 6. Information on measuring radon concentrations in water is provided in section 9.7.4.

9.6 Remedial measures

If the IDC of 0.1 mSv/year is being exceeded, then the options available to the regulatory authority to reduce the dose should be examined. Where remedial measures are contemplated, any strategy considered should first be justified (in the sense that it achieves a net benefit). Any decision that alters the radiation exposure situation should do more good than harm. This means that by reducing existing exposure, it will achieve sufficient individual or societal benefit to offset the detriment it causes (ICRP, 2008).

Once the remedial action is justified, then protection should be optimized in accordance with the recommendations of ICRP (2008). The principle of optimization of protection implies that the likelihood of incurring exposures, the number of people exposed and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking economic and societal factors into account.

When source water contains unacceptably high concentrations of radionuclides, control options include use of an alternative supply, controlled blending with another source or additional water treatment. Treatment plants with a combination of coagulation, sedimentation and sand filtration processes may remove up to 100% of the suspended radioactivity present in raw waters. Lime–soda ash softening plants can also remove practically all of the suspended radioactivity, depending on the radionuclide and on the proportion of radioactivity that might be associated with particulates.

A comprehensive review of the removal of dissolved radionuclides by water treatment processes has been undertaken (Brown, Hammond & Wilkins, 2008). The results summarized in that report are reproduced in Table 9.4. References for treatment technologies specific to radionuclides are provided in Annex 6.

9.7 Radon

9.7.1 Radon in air and water

Uranium, radium and radon are all soluble in water. Radon present in surface waters, such as lakes and rivers, is readily released into outdoor air by agitation as it passes

Table 9.4 Treatment performance for some common radionuclides[a]

Element	Coagulation	Sand filtration	Activated carbon	Precipitation softening	Ion exchange	Reverse osmosis
Strontium	xx	xx	x	xxxx	xxx	xxxx
Iodine	xx	xx	xxx	x	xxx	xxxx
Caesium	xx	xx	x	xx	xxx	xxxx
Radium	xx	xxx	xx	xxxx	xxxx	xxxx
Uranium	xxxx	x	xx	xxxx	xxxx	xxxx
Plutonium	xxxx	xx	xxx	x	xxxx	xxxx
Americium	xxxx	xx	xxx	x	xxxx	xxxx
Tritium	Not possible to remove (some removal by aeration of water, not quantified)					

[a] x = 0–10% removal; xx = 10–40% removal; xxx = 40–70% removal; xxxx = > 70% removal.

Box 9.5 Radon in drinking-water

- Some groundwater supplies may contain elevated concentrations of radon. High radon concentrations are seldom found in surface drinking-water supplies.
- Radon dissolved in drinking-water can be released into indoor air. Normally, a higher radon dose is received from inhaling the radon and radon progeny compared with their ingestion.
- Radon released from drinking-water is not the only source of radon in indoor air. Where high indoor radon concentrations exist, the underlying soil and building materials, rather than the drinking-water, are normally the predominant sources.
- Straightforward and effective techniques exist to reduce the concentration of radon in drinking-water supplies.
- In deciding whether or not to take steps to reduce the concentration of radon in drinking-water supplies, it is important to take account of the contribution of other sources of radon to the total radiation dose. Any action should be both justified and optimized and take account of local conditions.

over rocks and soils. Groundwater from wells and boreholes usually contains higher radon concentrations than surface waters. In some extreme circumstances, very high radon concentrations can be found in drinking-water supplies from these sources (see Box 9.5).

Radon is soluble in water, its solubility decreasing rapidly with an increase in temperature. When a tap or shower is turned on, some of the dissolved radon is released into indoor air. This adds to the radon present from other sources and will give rise to a radiation dose when inhaled.

An evaluation of international research data (UNSCEAR, 2000) has concluded that, on average, 90% of the dose attributable to radon in drinking-water comes from inhalation rather than ingestion. Therefore, controlling the inhalation pathway rather than the ingestion pathway is the most effective way to control doses from radon in drinking-water.

The percentage of radon present in drinking-water that is released into indoor air will depend on local conditions, such as the total consumption of water in the house, the volume of the house and its ventilation rate, and is likely to be highly variable. It has been estimated that a radon concentration of 1000 Bq/l in drinking-water discharged from a tap or shower will, on average, increase the radon concentration by 100 Bq/m^3 in indoor air (NAS, 1999; European Commission, 2001; Health Canada, 2009). This contribution is not constant, as it occurs only while the water is being discharged through the tap or shower. Radon in air also comes from other sources, in particular radon entering the home from the underlying soil.

9.7.2 Health risks from radon

Epidemiological studies have clearly shown that long-term exposure to high radon concentrations in indoor air increases the risk of lung cancer (WHO, 2009). Radon ingested in drinking-water will give a radiation dose to the lining of the stomach. Scientific studies have not shown a definitive link between consumption of drinking-water containing radon and an increased risk of stomach cancer (Ye et al., 1998; Auvinen et al., 2005; WHO, 2009).

9.7.3 Guidance on radon in drinking-water supplies

As the dose from radon present in drinking-water is normally received from inhalation rather than ingestion, it is more appropriate to measure the radon concentration in air than in drinking-water.

The World Health Organization reference level for radon concentration in indoor air is 100 Bq/m^3 in dwellings. If this level cannot be reached under prevailing country-specific conditions, the level should not exceed 300 Bq/m^3, corresponding to an annual dose of approximately 10 mSv (WHO, 2009). This recommendation is consistent with the International Basic Safety Standards[1] and with the most recent recommendations of the ICRP (2009b).

Screening levels for radon in water should be set on the basis of the national reference level for radon in air and the distribution of radon in the national housing stock. Where high radon concentrations are identified in indoor air, this is nearly always due to ingress of radon from the soil rather than degassing from the drinking-water supply. Nevertheless, in circumstances where high radon concentrations might be expected in drinking-water, it is prudent to measure for radon and, if high concentrations are identified, consider whether measures to reduce the concentrations present are justified.

The concentration of radon in groundwater supplies can vary considerably. Consequently, in situations where high radon concentrations have been identified or are suspected, the frequency of gross alpha and gross beta measurements may need to be increased so that the presence of radon progeny (in particular polonium-210), which can be major contributors to dose, can be assessed and monitored on an ongoing basis.

[1] International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (revised edition, in preparation).

9.7.4 Measuring radon in drinking-water

There are difficulties in deriving activity concentrations of radon in drinking-water because of the ease with which radon is released from water during handling. Stirring and transferring water from one container to another will release dissolved radon. Water that has been left to stand will have reduced radon activity, and boiling will also completely release radon from the water into the air. A variety of methods can be used to measure radon in water, including liquid scintillation counting, which is a sensitive and widely used method (WHO, 2009).

9.7.5 Decreasing radon concentrations in drinking-water

Reasonably simple measures are available to decrease radon concentrations in drinking-water by aeration. High-performance aeration is an effective means for the removal of radon in groundwater supplies and can achieve up to 99.9% removal. However, these methods may create a large source of airborne radon. Adsorption via granular activated carbon, with or without ion exchange, can also achieve high radon removal efficiencies, but is less efficient and requires large amounts of granular activated carbon.

9.8 Risk communication

9.8.1 Reporting results

The analytical results for each sample should contain the following information:

- sample identification code;
- sample collection date and time;
- standard analytical methods used or brief description of any non-standard analytical methods used;
- identification of the radionuclides or type of radioactivity and total radioactivity determined;
- measurement-based concentration or activity value calculated using the appropriate blank for each radionuclide;
- estimates of the counting uncertainty;
- a minimum detectable concentration for each radionuclide or parameter analysed;
- estimate of total projected uncertainty of the reported result, including the contributions from all the parameters within the analytical method (i.e. counting and other random and systematic uncertainties or errors).

9.8.2 Communicating risks

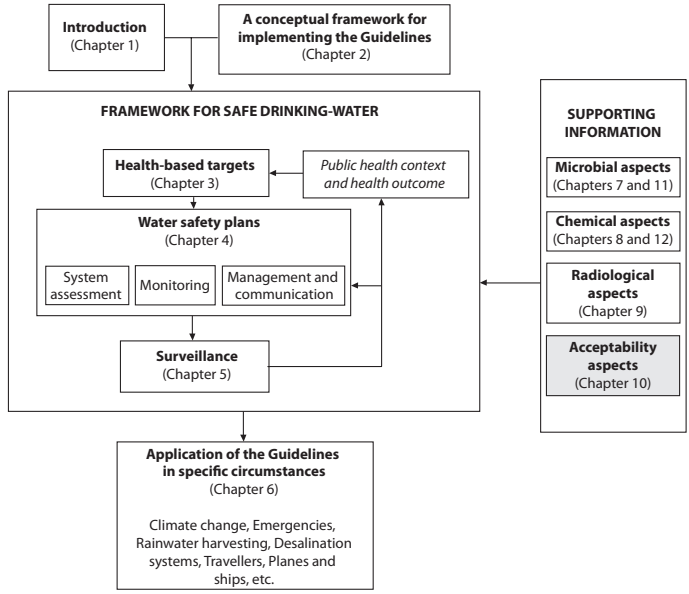
Communicating radiation risks clearly and effectively includes identifying target audiences (e.g. public, policy-makers and decision-makers) and tailoring the messages to them (WHO, 2002). Risk has different meaning for different people, but, in general, risk communication requires a description of the likelihood of harm and its severity.

Risk communication with the public should utilize plain language. The technical lexicon of radiation protection is not readily understood by non-specialists (Picano, 2008). In some situations, comparisons are helpful to explain radiation risks

(e.g. placing possible health risks from ingestion of drinking-water in the context of risk associated with exposure to natural radiation in different parts of the world). It should be clearly explained that guidance levels should not be interpreted as mandatory limits and that exceeding a guidance level may be taken as a trigger for further investigation, but it is not necessarily an indication that the drinking-water is unsafe.

The persons in charge of communicating risk should be skilled in interpersonal communication, able to convey empathy, effective listeners and respectful of people's concerns. They should be knowledgeable about the topic area with which they are dealing and be able to answer basic questions about the current as well as possible future risks. Guidance on radiation risk communication is provided elsewhere (USEPA, 2007; WHO, 2009).

10
Acceptability aspects: Taste, odour and appearance



The provision of drinking-water that is not only safe but also acceptable in appearance, taste and odour is of high priority. Water that is aesthetically unacceptable will undermine the confidence of consumers, will lead to complaints and, more importantly, could lead to the use of water from sources that are less safe.

To a large extent, consumers have no means of judging the safety of their drinking-water themselves, but their attitude towards their drinking-water supply and their drinking-water suppliers will be affected to a considerable extent by the aspects of water quality that they are able to perceive with their own senses. It is natural for consumers to regard with suspicion water that appears dirty or discoloured or that has an unpleasant taste or smell, even though these characteristics may not in themselves be of direct consequence to health.

> The appearance, taste and odour of drinking-water should be acceptable to the consumer. Water that is aesthetically unacceptable can lead to the use of water from sources that are aesthetically more acceptable, but potentially less safe.

Some substances of health concern have effects on the taste, odour or appearance of drinking-water that would normally lead to rejection of the water at concentrations significantly lower than those of concern for health. The concentration at which constituents are objectionable to consumers is variable and dependent on individual and local factors, including the quality of the water to which the community is accustomed and a variety of social, environmental and cultural considerations. Guideline values have not been established for constituents influencing water quality that have no direct link to adverse health impacts. However, guideline values have been established for some substances that may cause taste or odour in drinking-water at much lower concentrations than the guideline value because there is such a wide range in the ability of consumers to detect them by taste or odour. In the summaries in this chapter and the fact sheets in chapter 12, reference is made to levels likely to give rise to complaints from consumers. These are not precise numbers, and tastes or odours may be detectable by consumers at lower or higher levels, depending on individual and local circumstances.

Guideline values have not been established for constituents influencing water quality that have no direct link to adverse health impacts.

It is important to consider whether existing or proposed water treatment and distribution practices can affect the acceptability of drinking-water and to manage change and operations to minimize the risk of problems for acceptability as well as health. For example, chloramination that is not properly managed can lead to the formation of trichloramines, which can cause unacceptable taste and odour. Other problems may be indirect, such as the disturbance of internal pipe deposits and biofilms when the flow is disturbed or changed in distribution systems.

It is not normally appropriate to directly regulate or monitor substances of health concern whose effects on the acceptability of water would normally lead to rejection of the water at concentrations significantly lower than those of concern for health; rather, these substances may be addressed through a general requirement that water be acceptable to the majority of consumers. For such substances, a formal guideline value is not usually derived, but a health-based value is derived in order to assist in judging the response that is needed when problems are encountered and in some cases to provide reassurance to health authorities and consumers with regard to possible health risks. In the fact sheets in chapter 12, this is explained, and information on acceptability is described. In the tables of guideline values (see chapter 8 and Annex 3), for those chemicals for which health-based guideline values were derived, the guideline value is designated with a "C", with a footnote explaining that while the substance is of health significance, water would normally be rejected by consumers at concentrations well below the health-based guideline value. Monitoring of such substances should be undertaken in response to consumer complaints.

Taste and odour can originate from natural inorganic and organic chemical contaminants and biological sources or processes (e.g. aquatic microorganisms), from contamination by synthetic chemicals, from corrosion or as a result of problems with water treatment (e.g. chlorination). Taste and odour may also develop during storage and distribution as a result of microbial activity.

Taste and odour in drinking-water may be indicative of some form of pollution or of a malfunction during water treatment or distribution. It may therefore be an indication of the presence of potentially harmful substances. The cause should be investigated and the appropriate health authorities should be consulted, particularly if there is a sudden or substantial change.

Colour, cloudiness, particulate matter and visible organisms may also be noticed by consumers and may create concerns about the quality and acceptability of a drinking-water supply.

10.1 Biologically derived contaminants

There are a number of diverse organisms that often have no public health significance but which are undesirable because they produce taste and odour. As well as affecting the acceptability of the water, they indicate that water treatment and/or the state of maintenance and repair of the distribution system are insufficient.

Actinomycetes and fungi

Actinomycetes and fungi can be abundant in surface water sources, including reservoirs, and they can also grow on unsuitable materials in the water supply distribution systems, such as rubber. They can produce geosmin, 2-methyl isoborneol and other substances, resulting in objectionable tastes and odours in the drinking-water.

Cyanobacteria and algae

Blooms of cyanobacteria and other algae in reservoirs and in river waters may impede coagulation and filtration, causing coloration and turbidity of water after filtration. They can also produce geosmin, 2-methyl isoborneol and other chemicals, which have taste thresholds in drinking-water of a few nanograms per litre. Some other cyanobacterial products—cyanotoxins—are also of direct health significance (see section 8.5.1), but the production by cyanobacteria of chemicals with effects on taste does not seem to be linked to the production of cyanotoxins.

Invertebrate animal life[1]

Invertebrate animals are naturally present in many water resources used as sources for the supply of drinking-water and often infest shallow, open wells. Small numbers of invertebrates may also pass through water treatment works where the barriers to particulate matter are not completely effective and colonize filters or the distribution system. Their motility may enable them and their larvae to penetrate filters at the treatment works and vents on storage reservoirs.

The types of invertebrates concerned can be considered, for control purposes, as belonging to two groups. First, there are free-swimming organisms in the water itself or on water surfaces, such as the crustaceans *Gammarus pulex* (freshwater shrimp), *Crangonyx pseudogracilis*, *Cyclops* spp. and *Chydorus sphaericus.* Second, there are other invertebrates that either move along surfaces or are anchored to them (e.g. water

[1] The section was drawn largely from chapter 6 of the supporting document *Safe piped water* (Annex 1).

louse [*Asellus aquaticus*], snails, zebra mussel [*Dreissena polymorpha*], other bivalve molluscs and the bryozoan *Plumatella* sp.) or inhabit slimes (e.g. *Nais* spp., nematodes and the larvae of chironomids). In warm weather, slow sand filters can sometimes discharge the larvae of gnats (*Chironomus* and *Culex* spp.) into the water. In certain circumstances, these can reproduce parthenogenetically (i.e. asexual reproduction), which can exacerbate the problem in service reservoirs and distribution.

Many of these invertebrates can survive, deriving food from bacteria, algae and protozoa in the water or present on slimes on pipe and tank surfaces. Few water distribution systems are completely free of animals at all times. However, the density and composition of invertebrate populations vary widely, from heavy infestations, including readily visible species that are objectionable to consumers, to sparse occurrences of microscopic species.

The presence of invertebrates has largely been regarded by piped drinking-water suppliers in temperate regions as an acceptability problem, either directly or through their association with discoloured water. Large invertebrate populations also indicate high levels of organic material that may give rise to other water quality issues, such as microbial growth. In tropical and subtropical countries, in contrast, there are species of aquatic invertebrates that act as secondary hosts for parasites. For example, the small crustacean *Cyclops* is the intermediate host of the guinea worm (*Dracunculus medinensis*) (see sections 7.1.1 and 11.4). However, there is no evidence that guinea worm transmission occurs from piped drinking-water supplies. The presence of invertebrates in drinking-water, especially if visible, raises consumer concern about the quality of the drinking-water supply and should be controlled.

Penetration of waterworks and mains is more likely to be a problem when high-rate filtration processes are used, but problems can arise even at well-run treatment works. Regular cleaning of water mains by flushing and/or swabbing will usually control infestation.

Treatment of invertebrate infestations in piped distribution systems is discussed in detail in chapter 6 of the supporting document *Safe piped water* (Annex 1).

Iron bacteria

In waters containing ferrous and manganous salts, oxidation by iron bacteria (or by exposure to air) may cause rust-coloured deposits on the walls of tanks, pipes and channels and carry-over of deposits into the water.

10.2 Chemically derived contaminants

Aluminium

Naturally occurring aluminium as well as aluminium salts used as coagulants in drinking-water treatment are the primary sources of aluminium in drinking-water. The presence of aluminium at concentrations in excess of 0.1–0.2 mg/l often leads to consumer complaints as a result of deposition of aluminium hydroxide floc and the exacerbation of discoloration of water by iron. It is therefore important to optimize treatment processes in order to minimize any residual aluminium entering the distribution system. Under good operating conditions, aluminium concentrations of less

than 0.1 mg/l are achievable in many circumstances. Available evidence does not support the derivation of a health-based guideline value for aluminium in drinking-water (see sections 8.5.4 and 12.1).

Ammonia

The threshold odour concentration of ammonia at alkaline pH is approximately 1.5 mg/l, and a taste threshold of 35 mg/l has been proposed for the ammonium cation. Ammonia is not of direct relevance to health at these levels, and no health-based guideline value has been proposed (see sections 8.5.3 and 12.1). However, ammonia does react with chlorine to reduce free chlorine and to form chloramines.

Chloramines

Chloramines, such as monochloramine, dichloramine and trichloramine (nitrogen trichloride), are generated from the reaction of chlorine with ammonia. Among chloramines, monochloramine is the only useful chlorine disinfectant, and chloramination systems are operated to minimize the formation of dichloramine and trichloramine. Higher chloramines, particularly trichloramine, are likely to give rise to taste and odour complaints, except at very low concentrations.

For monochloramine, no odour or taste was detected at concentrations between 0.5 and 1.5 mg/l. However, slight organoleptic effects within this range and odour and taste thresholds of 0.65 and 0.48 mg/l have been reported. For dichloramine, the organoleptic effects between 0.1 and 0.5 mg/l were found to be "slight" and "acceptable". Odour and taste thresholds of 0.15 and 0.13 mg/l were reported, respectively. An odour threshold of 0.02 mg/l has been reported for trichloramine, and it has been described as "geranium".

A guideline value for monochloramine has been established (see sections 8.5.4 and 12.1).

Chloride

High concentrations of chloride give a salty taste to water and beverages. Taste thresholds for the chloride anion depend on the associated cation and are in the range of 200–300 mg/l for sodium, potassium and calcium chloride. Concentrations in excess of 250 mg/l are increasingly likely to be detected by taste, but some consumers may become accustomed to low levels of chloride-induced taste. No health-based guideline value is proposed for chloride in drinking-water (see sections 8.5.1 and 12.1).

Chlorine

Most individuals are able to taste or smell chlorine in drinking-water at concentrations well below 5 mg/l, and some at levels as low as 0.3 mg/l. The taste threshold for chlorine is below the health-based guideline value of 5 mg/l (see sections 8.5.4 and 12.1).

Chlorobenzenes

Taste and odour thresholds of 10–20 µg/l and odour thresholds ranging from 40 to 120 µg/l have been reported for monochlorobenzene. A health-based guideline value

has not been derived for monochlorobenzene (see sections 8.5.2 and 12.1), although the health-based value that could be derived far exceeds the lowest reported taste and odour threshold in water.

Odour thresholds of 2–10 and 0.3–30 µg/l have been reported for 1,2- and 1,4-dichlorobenzene, respectively. Taste thresholds of 1 and 6 µg/l have been reported for 1,2- and 1,4-dichlorobenzene, respectively. The health-based guideline values of 1 mg/l derived for 1,2-dichlorobenzene and of 0.3 mg/l for 1,4-dichlorobenzene (see sections 8.5.2 and 12.1) far exceed the lowest reported taste and odour thresholds for these compounds.

Odour thresholds of 10, 5–30 and 50 µg/l have been reported for 1,2,3-, 1,2,4- and 1,3,5-trichlorobenzene, respectively. A taste and odour threshold concentration of 30 µg/l has been reported for 1,2,4-trichlorobenzene. A health-based guideline value was not derived for trichlorobenzenes, although the health-based value that could be derived (see sections 8.5.2 and 12.1) exceeds the lowest reported odour threshold in water of 5 µg/l.

Chlorophenols

Chlorophenols generally have very low taste and odour thresholds. The taste thresholds in water for 2-chlorophenol, 2,4-dichlorophenol and 2,4,6-trichlorophenol are 0.1, 0.3 and 2 µg/l, respectively. Odour thresholds are 10, 40 and 300 µg/l, respectively. If water containing 2,4,6-trichlorophenol is free from taste, it is unlikely to present a significant risk to health (see sections 8.5.4 and 12.1). Microorganisms in distribution systems may sometimes methylate chlorophenols to produce chlorinated anisoles, for which the odour threshold is considerably lower.

Colour

Drinking-water should ideally have no visible colour. Colour in drinking-water is usually due to the presence of coloured organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products. It may also result from the contamination of the water source with industrial effluents and may be the first indication of a hazardous situation. The source of colour in a drinking-water supply should be investigated, particularly if a substantial change has taken place.

Most people can detect colour above 15 true colour units (TCU) in a glass of water. Levels of colour below 15 TCU are often acceptable to consumers. High colour from natural organic carbon (e.g. humics) could also indicate a high propensity to produce by-products from disinfection processes. No health-based guideline value is proposed for colour in drinking-water.

Copper

Copper in a drinking-water supply usually arises from the corrosive action of water leaching copper from copper pipes in buildings. High levels of dissolved oxygen have been shown to accelerate copper corrosion in some cases. Concentrations can vary significantly with the period of time the water has been standing in contact with the pipes; for example, first-draw water would be expected to have a higher copper con-

centration than a fully flushed sample. High concentrations can interfere with the intended domestic uses of the water. Staining of sanitary ware and laundry may occur at copper concentrations above 1 mg/l. At levels above 5 mg/l, copper also imparts a colour and an undesirable bitter taste to water. Although copper can give rise to taste, it should be acceptable at the health-based guideline value of 2 mg/l (see sections 8.5.4, 12.1 and A5.3 in Annex 5).

Dissolved oxygen

The dissolved oxygen content of water is influenced by the source, raw water temperature, treatment and chemical or biological processes taking place in the distribution system. Depletion of dissolved oxygen in water supplies can encourage the microbial reduction of nitrate to nitrite and sulfate to sulfide. It can also cause an increase in the concentration of ferrous iron in solution, with subsequent discoloration at the tap when the water is aerated. No health-based guideline value is recommended. However, very high levels of dissolved oxygen may exacerbate corrosion of metal pipes.

Ethylbenzene

Ethylbenzene has an aromatic odour; the reported odour threshold in water ranges from 2 to 130 µg/l. The lowest reported odour threshold is 100-fold lower than the health-based guideline value of 0.3 mg/l (see sections 8.5.2 and 12.1). The taste threshold ranges from 72 to 200 µg/l.

Hardness

Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. Consumers are likely to notice changes in hardness. Public acceptability of the degree of hardness of water may vary considerably from one community to another. The taste threshold for the calcium ion is in the range of 100–300 mg/l, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium. In some instances, consumers tolerate water hardness in excess of 500 mg/l.

Depending on the interaction of other factors, such as pH and alkalinity, water with a hardness above approximately 200 mg/l may cause scale deposition in the treatment works, distribution system and pipework and tanks within buildings. It will also result in high soap consumption and subsequent "scum" formation. On heating, hard waters form deposits of calcium carbonate scale. Soft water, but not necessarily cation exchange softened water, with a hardness of less than 100 mg/l may, in contrast, have a low buffering capacity and so be more corrosive for water pipes.

No health-based guideline value is proposed for hardness in drinking-water (see the supporting document *Calcium and magnesium in drinking-water*; Annex 1).

Hydrogen sulfide

The taste and odour thresholds of hydrogen sulfide in water are estimated to be between 0.05 and 0.1 mg/l. The "rotten eggs" odour of hydrogen sulfide is particularly

noticeable in some groundwaters and in stagnant drinking-water in the distribution system, as a result of oxygen depletion and the subsequent reduction of sulfate by bacterial activity.

Sulfide is oxidized rapidly to sulfate in well-aerated or chlorinated water, and hydrogen sulfide levels in oxygenated water supplies are normally very low. The presence of hydrogen sulfide in drinking-water can be easily detected by the consumer and requires immediate corrective action. It is unlikely that a person could consume a harmful dose of hydrogen sulfide from drinking-water; hence, a health-based guideline value has not been derived for this compound (see sections 8.5.1 and 12.1).

Iron

Anaerobic groundwater may contain ferrous iron at concentrations up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well. On exposure to the atmosphere, however, the ferrous iron oxidizes to ferric iron, giving an objectionable reddish-brown colour to the water.

Iron also promotes the growth of "iron bacteria", which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping. At levels above 0.3 mg/l, iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.3 mg/l, although turbidity and colour may develop. No health-based guideline value is proposed for iron (see sections 8.5.4 and 12.1).

Manganese

At levels exceeding 0.1 mg/l, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry. The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. Concentrations below 0.1 mg/l are usually acceptable to consumers. Even at a concentration of 0.2 mg/l, manganese will often form a coating on pipes, which may slough off as a black precipitate. The health-based value of 0.4 mg/l for manganese is higher than this acceptability threshold of 0.1 mg/l (see sections 8.5.1 and 12.1).

Petroleum oils

Petroleum oils can give rise to the presence of a number of low molecular weight hydrocarbons that have low odour thresholds in drinking-water. Benzene, toluene, ethylbenzene and xylenes (BTEX) are considered individually in this section, as health-based guideline values have been derived for these chemicals. However, a number of other hydrocarbons, particularly alkylbenzenes such as trimethylbenzene, may give rise to a very unpleasant "diesel-like" odour at concentrations of a few micrograms per litre. There is experience indicating that the taste threshold of a mixture of low molecular weight aromatic hydrocarbons is lower than the threshold of individual substances. Diesel is a particularly rich source of such substances.

pH and corrosion

Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. Careful attention to pH control is ne-

cessary at all stages of water treatment to ensure satisfactory water clarification and disinfection (see the supporting document *Safe piped water*; Annex 1). For effective disinfection with chlorine, the pH should preferably be less than 8; however, lower-pH water (approximately pH 7 or less) is more likely to be corrosive. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems. Alkalinity and calcium management also contribute to the stability of water and control its aggressiveness to pipes and appliances. Failure to minimize corrosion can result in the contamination of drinking-water and in adverse effects on its taste and appearance. The optimum pH required will vary in different supplies according to the composition of the water and the nature of the construction materials used in the distribution system, but it is usually in the range 6.5–8.5 (see section 8.4.3). Extreme values of pH can result from accidental spills, treatment breakdowns and insufficiently cured cement mortar pipe linings or cement mortar linings applied when the alkalinity of the water is low. No health-based guideline value has been proposed for pH (see section 12.1).

Sodium

The taste threshold concentration of sodium in water depends on the associated anion and the temperature of the solution. At room temperature, the average taste threshold for sodium is about 200 mg/l. No health-based guideline value has been derived (see sections 8.5.1 and 12.1), as the contribution from drinking-water to daily intake is small.

Styrene

Styrene has a sweet/sickly odour, and reported odour thresholds for styrene in water range from 0.004 to 2.6 mg/l, depending on temperature. Styrene may therefore be detected in water at concentrations below its health-based guideline value of 0.02 mg/l (see sections 8.5.2 and 12.1).

Sulfate

The presence of sulfate in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers. Taste impairment varies with the nature of the associated cation; taste thresholds have been found to range from 250 mg/l for sodium sulfate to 1000 mg/l for calcium sulfate. It is generally considered that taste impairment is minimal at levels below 250 mg/l. No health-based guideline value has been derived for sulfate (see sections 8.5.1 and 12.1).

Synthetic detergents

In many countries, persistent types of anionic detergent have been replaced by others that are more easily biodegraded, and hence the levels found in water sources have decreased substantially. The concentration of detergents in drinking-water should not be allowed to reach levels giving rise to either foaming or taste problems. The presence of any detergent may indicate contamination of source water with sewage or ingress of detergent solution into the distribution system, as a result of back-flow, for example.

Toluene

Toluene has a sweet, pungent, benzene-like odour. The reported taste threshold ranges from 0.04 to 0.12 mg/l. The reported odour threshold for toluene in water ranges from 0.024 to 0.17 mg/l. Toluene may therefore affect the acceptability of water at concentrations below its health-based guideline value of 0.7 mg/l (see sections 8.5.2 and 12.1).

Total dissolved solids

The palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. No health-based guideline value for TDS has been proposed (see sections 8.5.1 and 12.1).

Turbidity

Turbidity in water is caused by suspended particles or colloidal matter that obstructs light transmission through the water. It may be caused by inorganic or organic matter or a combination of the two. Microorganisms (bacteria, viruses and protozoa) are typically attached to particulates, and removal of turbidity by filtration will significantly reduce microbial contamination in treated water. Turbidity in some groundwater sources is a consequence of inert clay or chalk particles or the precipitation of non-soluble reduced iron and other oxides when water is pumped from anaerobic waters, whereas turbidity in surface waters may be the result of particulate matter of many types and is more likely to include attached microorganisms that are a threat to health. Turbidity in distribution systems can occur as a result of the disturbance of sediments and biofilms but is also from the ingress of dirty water from outside the system.

In addition, turbidity can seriously interfere with the efficiency of disinfection by providing protection for organisms, and much of water treatment is directed at removal of particulate matter before disinfection. This not only will increase the efficacy of disinfection by chemical disinfectants such as chlorine and ozone, but is an essential step in ensuring the effectiveness of physical disinfection processes such as ultraviolet irradiation, because light transmission through water is impaired by particulates.

Removal of particulate matter by coagulation and sedimentation and by filtration is an important barrier in achieving safe drinking-water. Achieving low turbidity by filtration (before disinfection) of water from surface sources and groundwaters where raised turbidity occurs—for instance, where these are under the influence of surface waters—is strongly recommended to ensure microbially safe water.

Turbidity can also have a negative impact on consumer acceptability of water as a result of visible cloudiness. Although turbidity per se (e.g. from groundwater minerals or from post-precipitation of calcium carbonate from lime treatment) is not necessarily a threat to health, it is an important indicator of the possible presence of contaminants that would be of concern for health, especially from inadequately treated or unfiltered surface water. Data are emerging that show an increasing risk of gastro-

intestinal infections that correlates with high turbidity and turbidity events in distribution. This may be because turbidity is acting as an indicator of possible sources of microbial contamination. Therefore, turbidity events should be investigated and the causes corrected, whereas turbidity should be minimized as far as is possible within the constraints of the type of system and the resources available as one part of the management of distribution to achieve water safety. Turbidity is also an important consideration when investment decisions are made regarding sources and treatment for water supplies and should be identified in the water safety plan as a hazard that needs to be controlled.

Turbidity is measured by nephelometric turbidity units (NTU) and can be initially noticed by the naked eye above approximately 4.0 NTU. However, to ensure effectiveness of disinfection, turbidity should be no more than 1 NTU and preferably much lower. Large, well-run municipal supplies should be able to achieve less than 0.5 NTU before disinfection at all times and should be able to average 0.2 NTU or less. Surface water (and groundwater under the influence of surface water) treatment systems that achieve less than 0.3 NTU prior to disinfection will have demonstrated that they have significant barriers against pathogens that adsorb to particulate matter. Of particular importance is the fact that this will be a good indicator that they are removing chlorine-resistant pathogens such as *Cryptosporidium*.

Small water supplies where resources are very limited and where there is limited or no treatment may not be able to achieve such low levels of turbidity. In these cases, the aim should be to produce water that has turbidity of at least less than 5 NTU and, if at all possible, below 1 NTU. For many of these small and usually rural supplies, measuring turbidity below 5 NTU may present a significant cost challenge, and thus providing low-cost measuring systems that can measure lower turbidities is an important requirement.

Occasionally, turbidity can be caused by minute air bubbles released when water has a high dissolved air content. Such turbidity clears rapidly upwards through the surface but can cause concern for consumers, and efforts should be made to manage distribution systems to ensure that this does not happen.

Xylenes

Xylene concentrations in the range of 0.3 mg/l produce a detectable taste and odour. The odour threshold for xylene isomers in water has been reported to range from 0.02 to 1.8 mg/l. The lowest odour threshold is well below the health-based guideline value of 0.5 mg/l for xylene (see sections 8.5.2 and 12.1).

Zinc

Zinc imparts an undesirable astringent taste to water at a taste threshold concentration of about 4 mg/l (as zinc sulfate). Water containing zinc at concentrations in excess of 3–5 mg/l may appear opalescent and develop a greasy film on boiling. Although drinking-water seldom contains zinc at concentrations above 0.1 mg/l, levels in tap water can be considerably higher because of the zinc used in older galvanized plumbing materials; this may also be an indicator of elevated cadmium from such older

material. No health-based guideline value has been proposed for zinc in drinking-water (see sections 8.5.4 and 12.1).

10.3 Treatment of taste, odour and appearance problems

In many cases, aesthetic problems will be prevented by optimizing conventional treatment processes such as coagulation, sedimentation and chlorination. However, if specific treatment is deemed necessary, aeration, granular or powdered activated carbon and ozonation are generally effective techniques in removing organic chemicals and some inorganic chemicals, such as hydrogen sulfide, that cause tastes and odours (see Annex 5).

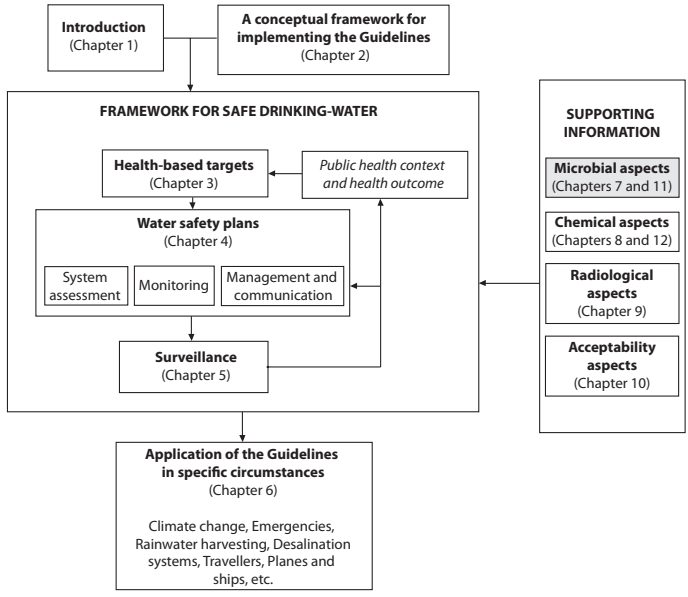
Tastes and odours caused by disinfectants are best controlled through careful operation of the disinfection process and pretreatment to remove precursors.

Manganese can be removed by chlorination followed by filtration. Techniques for removing hydrogen sulfide include aeration, granular activated carbon, filtration and oxidation. Ammonia can be removed by biological nitrification. Precipitation softening or cation exchange can reduce hardness. Other taste- and odour-causing inorganic chemicals (e.g. chloride and sulfate) are generally not amenable to treatment (see the supporting document *Chemical safety of drinking-water*; Annex 1).

10.4 Temperature

Cool water is generally more palatable than warm water, and temperature will have an impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. High water temperature enhances the growth of microorganisms and may increase problems related to taste, odour, colour and corrosion.

11
Microbial fact sheets



Fact sheets are provided on potential waterborne pathogens as well as on indicator microorganisms.

The waterborne microorganisms potentially causing illness include:

- bacteria, viruses, protozoa and helminths identified in Table 7.1 and Figure 7.1, with the exception of *Schistosoma*, which is primarily spread by contact with contaminated surface water during bathing and washing;
- potentially emerging pathogens, including *Helicobacter pylori*, *Tsukamurella*, *Isospora belli* and microsporidia, for which waterborne transmission is plausible but unconfirmed;
- *Bacillus*, which includes the foodborne pathogenic species *Bacillus cereus* but for which there is no evidence at this time of waterborne transmission;
- hazardous cyanobacteria.

The human health effects caused by waterborne transmission vary in severity from mild gastroenteritis to severe and sometimes fatal diarrhoea, dysentery, hepatitis and typhoid fever. Contaminated water can be the source of large outbreaks of disease, including cholera, dysentery and cryptosporidiosis; for the majority of waterborne

pathogens, however, there are other important sources of infection, such as person-to-person contact and food.

Most waterborne pathogens are introduced into drinking-water supplies in human or animal faeces, do not grow in water and initiate infection in the gastrointestinal tract following ingestion. However, *Legionella*, atypical mycobacteria, *Burkholderia pseudomallei*, *Acanthamoeba* spp. and *Naegleria fowleri* are environmental organisms that can grow in water and soil. Besides ingestion, other routes of transmission can include inhalation, leading to infections of the respiratory tract (e.g. *Legionella*, atypical mycobacteria), and contact, leading to infections at sites as diverse as the skin and brain (e.g. *Naegleria fowleri*, *Burkholderia pseudomallei*).

Of all the waterborne pathogens, the helminth *Dracunculus medinensis* is unique in that it is the only pathogen that is solely transmitted through drinking-water.

The fact sheets on potential pathogens include information on human health effects, sources and occurrence, routes of transmission and the significance of drinking-water as a source of infection. The fact sheets on microorganisms that can be used as indicators of the effectiveness of control measures or of the potential presence of pathogenic microorganisms provide information on indicator value, source and occurrence, application and significance of detection.

11.1 Bacterial pathogens

Most bacterial pathogens potentially transmitted by water infect the gastrointestinal tract and are excreted in the faeces of infected humans and animals. However, there are also some waterborne bacterial pathogens, such as *Legionella*, *Burkholderia pseudomallei* and atypical mycobacteria, that can grow in water and soil. The routes of transmission of these bacteria include inhalation and contact (bathing), with infections occurring in the respiratory tract, in skin lesions or in the brain.

Acinetobacter

General description

Acinetobacter spp. are Gram-negative, oxidase-negative, non-motile coccobacilli (short plump rods). Owing to difficulties in naming individual species and biovars, the term *Acinetobacter calcoaceticus baumannii* complex is used in some classification schemes to cover all subgroups of this species, such as *A. baumannii*, *A. iwoffii* and *A. junii*.

Human health effects

Acinetobacter spp. are usually commensal organisms, but they occasionally cause infections, predominantly in susceptible patients in hospitals. They are opportunistic pathogens that may cause urinary tract infections, pneumonia, bacteraemia, secondary meningitis and wound infections. These diseases are predisposed by factors such as malignancy, burns, major surgery and weakened immune systems, such as in neonates and elderly individuals. The emergence and rapid spread of multidrug-resistant *A. calcoaceticus baumannii* complex, causing nosocomial infections, are of concern in health-care facilities.

Source and occurrence

Acinetobacter spp. are ubiquitous inhabitants of soil, water and sewage environments. *Acinetobacter* has been isolated from 97% of natural surface water samples in numbers of up to 100/ml. The organisms have been found to represent 1.0–5.5% of the heterotrophic plate count (HPC) flora in drinking-water samples and have been isolated from 5–92% of distribution water samples. In a survey of untreated groundwater supplies in the United States of America (USA), *Acinetobacter* spp. were detected in 38% of the groundwater supplies at an arithmetic mean density of 8/100 ml. The study also revealed that slime production, a virulence factor for *A. calcoaceticus*, was not significantly different between well water isolates and clinical strains, suggesting some degree of pathogenic potential for strains isolated from groundwater. *Acinetobacter* spp. are part of the natural microbial flora of the skin and occasionally the respiratory tract of healthy individuals.

Routes of exposure

Environmental sources within hospitals and person-to-person transmission are the likely sources for most outbreaks of hospital infections. Infection is most commonly associated with contact with wounds and burns or inhalation by susceptible individuals. In patients with *Acinetobacter* bacteraemia, intravenous catheters have also been identified as a source of infection. Outbreaks of infection have been associated with water baths and room humidifiers. Ingestion is not a usual source of infection.

Significance in drinking-water

Although *Acinetobacter* spp. are often detected in treated drinking-water supplies, an association between the presence of *Acinetobacter* spp. in drinking-water and clinical disease has not been confirmed. There is no evidence of gastrointestinal infection through ingestion of *Acinetobacter* spp. in drinking-water among the general population. However, transmission of non-gastrointestinal infections by drinking-water may be possible in susceptible individuals, particularly in settings such as health-care facilities and hospitals. As discussed in chapter 6, specific water safety plans should be developed for buildings, including hospitals and other health-care facilities. These plans need to take account of particular sensitivities of occupants. *Acinetobacter* spp. are sensitive to disinfectants such as chlorine, and numbers will be low in the presence of a disinfectant residual. Control measures that can limit growth of the bacteria in distribution systems include treatment to optimize organic carbon removal, restriction of the residence time of water in distribution systems and maintenance of disinfectant residuals. *Acinetobacter* spp. are detected by HPC, which can be used together with parameters such as disinfectant residuals to indicate conditions that could support growth of these organisms. However, *Escherichia coli* (or, alternatively, thermotolerant coliforms) cannot be used as an indicator for the presence/absence of *Acinetobacter* spp.

Selected bibliography

Bartram J et al., eds (2003) *Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health*. London, IWA Publishing (WHO Emerging Issues in Water and Infectious Disease Series).

Bergogne-Berezin E, Towner KJ (1996) *Acinetobacter* as nosocomial pathogens: Microbiological, clinical and epidemiological features. *Clinical Microbiology Reviews*, 9:148–165.

Bifulco JM, Shirey JJ, Bissonnette GK (1989) Detection of *Acinetobacter* spp. in rural drinking water supplies. *Applied and Environmental Microbiology*, 55:2214–2219.

Jellison TK, McKinnon PS, Rybak MJ (2001) Epidemiology, resistance and outcomes of *Acinetobacter baumannii* bacteremia treated with imipenem-cilastatin or ampicillin-sulbactam. *Pharmacotherapy*, 21:142–148.

Rusin PA et al. (1997) Risk assessment of opportunistic bacterial pathogens in drinking-water. *Reviews of Environmental Contamination and Toxicology*, 152:57–83.

Aeromonas

General description

Aeromonas spp. are Gram-negative, non-spore-forming, facultative anaerobic bacilli belonging to the family Vibrionaceae. They bear many similarities to the Enterobacteriaceae. The genus is divided into two groups. The group of psychrophilic non-motile aeromonads consists of only one species, *A. salmonicida*, an obligate fish pathogen that is not considered further here. The group of mesophilic motile (single polar flagellum) aeromonads is considered of potential human health significance and consists of the species *A. hydrophila*, *A. caviae*, *A. veronii* subsp. *sobria*, *A. jandaei*, *A. veronii* subsp. *veronii* and *A. schubertii*. The bacteria are normal inhabitants of fresh water and occur in water, soil and many foods, particularly meat and milk.

Human health effects

Aeromonas spp. can cause infections in humans, including septicaemia, particularly in immunocompromised patients, wound infections and respiratory tract infections. There have been some claims that *Aeromonas* spp. can cause gastrointestinal illness, but epidemiological evidence is not consistent. Despite marked toxin production by *Aeromonas* spp. in vitro, diarrhoea has not yet been introduced in test animals or human volunteers.

Source and occurrence

Aeromonas spp. occur in water, soil and food, particularly meat, fish and milk. *Aeromonas* spp. are generally readily found in most fresh waters, and they have been detected in many treated drinking-water supplies, mainly as a result of regrowth in distribution systems. The factors that affect the occurrence of *Aeromonas* spp. in water distribution systems are not fully understood, but organic content, temperature, the residence time of water in the distribution network and the presence of residual chlorine have been shown to influence population sizes.

Routes of exposure

Wound infections have been associated with contaminated soil and water-related activities, such as swimming, diving, boating and fishing. Septicaemia can follow from such wound infections. In immunocompromised individuals, septicaemia may arise from aeromonads present in their own gastrointestinal tract.

Significance in drinking-water

Despite frequent isolation of *Aeromonas* spp. from drinking-water, the body of evidence does not provide significant support for waterborne transmission. Aeromonads typically found in drinking-water do not belong to the same deoxyribonucleic acid (DNA) homology groups as those associated with cases of gastroenteritis. The presence of *Aeromonas* spp. in drinking-water supplies is generally considered a nuisance. Entry of aeromonads into distribution systems can be minimized by adequate disinfection. Control measures that can limit growth of the bacteria in distribution systems include treatment to optimize organic carbon removal, restriction of the residence time of water in distribution systems and maintenance of disinfectant residuals. *Aeromonas* spp. are detected by HPC, which can be used together with parameters such as disinfectant residuals to indicate conditions that could support growth of these organisms. However, *E. coli* (or, alternatively, thermotolerant coliforms) cannot be used as an indicator for the presence/absence of *Aeromonas* spp.

Selected bibliography

Bartram J et al., eds (2003) *Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health*. London, IWA Publishing (WHO Emerging Issues in Water and Infectious Disease Series).

Borchardt MA, Stemper ME, Standridge JH (2003) *Aeromonas* isolates from human diarrheic stool and groundwater compared by pulsed-field gel electrophoresis. *Emerging Infectious Diseases*, 9:224–228.

WHO (2002) *Aeromonas*. In: *Guidelines for drinking-water quality*, 2nd ed. *Addendum: Microbiological agents in drinking water.* Geneva, World Health Organization.

Bacillus

General description

Bacillus spp. are large (4–10 μm), Gram-positive, strictly aerobic or facultatively anaerobic encapsulated bacilli. They have the important feature of producing spores that are exceptionally resistant to unfavourable conditions. *Bacillus* spp. are classified into the subgroups *B. polymyxa*, *B. subtilis* (which includes *B. cereus* and *B. licheniformis*), *B. brevis* and *B. anthracis*.

Human health effects

Although most *Bacillus* spp. are harmless, a few are pathogenic to humans and animals. *Bacillus cereus* causes food poisoning similar to staphylococcal food poisoning. Some strains produce heat-stable toxin in food that is associated with spore germination and gives rise to a syndrome of vomiting within 1–5 hours of ingestion. Other strains produce a heat-labile enterotoxin after ingestion that causes diarrhoea within 10–15 hours. *Bacillus cereus* is known to cause bacteraemia in immunocompromised patients as well as symptoms such as vomiting and diarrhoea. *Bacillus anthracis* causes anthrax in humans and animals.

Source and occurrence

Bacillus spp. commonly occur in a wide range of natural environments, such as soil and water. They form part of the HPC bacteria, which are readily detected in most drinking-water supplies.

Routes of exposure

Infection with *Bacillus* spp. is associated with the consumption of a variety of foods, especially rice, pastas and vegetables, as well as raw milk and meat products. Disease may result from the ingestion of the organisms or toxins produced by the organisms. Drinking-water has not been identified as a source of infection of pathogenic *Bacillus* spp., including *Bacillus cereus.* Waterborne transmission of *Bacillus* gastroenteritis has not been confirmed.

Significance in drinking-water

Bacillus spp. are often detected in drinking-water supplies, even supplies treated and disinfected by acceptable procedures. This is largely due to the resistance of spores to disinfection processes. Owing to a lack of evidence that waterborne *Bacillus* spp. are clinically significant, specific management strategies are not required.

Selected bibliography

Bartram J et al., eds (2003) *Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health*. London, IWA Publishing (WHO Emerging Issues in Water and Infectious Disease Series).

Burkholderia pseudomallei

General description

Burkholderia pseudomallei is a Gram-negative bacillus commonly found in soil and muddy water, predominantly in tropical regions such as northern Australia and south-east Asia. The organism is acid tolerant and survives in water for prolonged periods in the absence of nutrients.

Human health effects

Burkholderia pseudomallei can cause the disease melioidosis, which is endemic in northern Australia and other tropical regions. The most common clinical manifestation is pneumonia, which may be fatal. In some of these areas, melioidosis is the most common cause of community-acquired pneumonia. Cases appear throughout the year but peak during the rainy season. Many patients present with milder forms of pneumonia, which respond well to appropriate antibiotics, but some may present with a severe septicaemic pneumonia. Other symptoms include skin abscesses or ulcers, abscesses in internal organs and unusual neurological illnesses, such as brainstem encephalitis and acute paraplegia. Although melioidosis can occur in healthy children and adults, it occurs mainly in people whose defence mechanisms against infection are impaired by underlying conditions or poor general health associated with poor nutrition or living conditions.

Source and occurrence

The organism occurs predominantly in tropical regions, typically in soil or surface-accumulated muddy water, from where it may reach raw water sources and also drinking-water supplies. The number of organisms in drinking-water that would constitute a significant risk of infection is not known.

Routes of exposure

Most infections appear to be through contact of skin cuts or abrasions with contaminated water. In south-east Asia, rice paddies represent a significant source of infection. Infection may also occur via other routes, particularly through inhalation or ingestion. The relative importance of these routes of infection is not known.

Significance in drinking-water

In two Australian outbreaks of melioidosis, indistinguishable isolates of *B. pseudomallei* were cultured from cases and the drinking-water supply. The detection of the organisms in one drinking-water supply followed replacement of water pipes and chlorination failure, whereas the second supply was unchlorinated. Within a water safety plan, control measures that should provide effective protection against this organism include application of established treatment and disinfection processes for drinking-water coupled with protection of the distribution system from contamination, including during repairs and maintenance. HPC and disinfectant residual as measures of water treatment effectiveness and application of appropriate mains repair procedures could be used to indicate protection against *B. pseudomallei.* Because of the environmental occurrence of *B. pseudomallei*, *E. coli* (or, alternatively, thermotolerant coliforms) is not a suitable indicator for the presence/absence of this organism.

Selected bibliography

Ainsworth R, ed. (2004) *Safe piped water: Managing microbial water quality in piped distribution systems*. IWA Publishing, London, for the World Health Organization, Geneva.

Currie BJ (2000) The epidemiology of melioidosis in Australia and Papua New Guinea. *Acta Tropica*, 74:121–127.

Currie BJ et al. (2001) A cluster of melioidosis cases from an endemic region is clonal and is linked to the water supply using molecular typing of *Burkholderia pseudomallei* isolates. *American Journal of Tropical Medicine and Hygiene*, 65:177–179.

Inglis TJJ et al. (2000) Outbreak strain of *Burkholderia pseudomallei* traced to water treatment plant. *Emerging Infectious Diseases*, 6:56–59.

Campylobacter

General description

Campylobacter spp. are microaerophilic (require decreased oxygen) and capnophilic (require increased carbon dioxide), Gram-negative, curved spiral rods with a single unsheathed polar flagellum. *Campylobacter* spp. are one of the most important causes of acute gastroenteritis worldwide. *Campylobacter jejuni* is the most frequently isolated species from patients with acute diarrhoeal disease, whereas *C. coli*, *C. laridis* and *C. fetus* have also been isolated in a small proportion of cases. Two closely related genera, *Helicobacter* and *Archobacter*, include species previously classified as *Campylobacter* spp.

Human health effects

An important feature of *C. jejuni* is relatively high infectivity compared with other bacterial pathogens. As few as 1000 organisms can cause infection. Most symptomatic

infections occur in infancy and early childhood. The incubation period is usually 2–4 days. Clinical symptoms of *C. jejuni* infection are characterized by abdominal pain, diarrhoea (with or without blood or faecal leukocytes), vomiting, chills and fever. The infection is self-limited and resolves in 3–7 days. Relapses may occur in 5–10% of untreated patients. Other clinical manifestations of *C. jejuni* infections in humans include reactive arthritis and meningitis. Several reports have associated *C. jejuni* infection with Guillain-Barré syndrome, an acute demyelinating disease of the peripheral nerves.

Source and occurrence

Campylobacter spp. occur in a variety of environments. Wild and domestic animals, especially poultry, wild birds and cattle, are important reservoirs. Pets and other animals may also be reservoirs. Food, including meat and unpasteurized milk, are important sources of *Campylobacter* infections. Water is also a significant source. The occurrence of the organisms in surface waters has proved to be strongly dependent on rainfall, water temperature and the presence of waterfowl.

Routes of exposure

Most *Campylobacter* infections are reported as sporadic in nature, with food considered a common source of infection. Transmission to humans typically occurs by the consumption of animal products. Meat, particularly poultry products, and unpasteurized milk are important sources of infection. Contaminated drinking-water supplies have been identified as a source of outbreaks. The number of cases in these outbreaks ranged from a few to several thousand, with sources including unchlorinated or inadequately chlorinated surface water supplies and faecal contamination of water storage reservoirs by wild birds.

Significance in drinking-water

Contaminated drinking-water supplies have been identified as a significant source of outbreaks of campylobacteriosis. The detection of waterborne outbreaks and cases appears to be increasing. Waterborne transmission has been confirmed by the isolation of the same strains from patients and drinking-water they had consumed. Within a water safety plan, control measures that can be applied to manage potential risk from *Campylobacter* spp. include protection of raw water supplies from waste from humans and animals, adequate treatment and protection of water during distribution. Storages of treated and disinfected water should be protected from bird faeces. *Campylobacter* spp. are faecally borne pathogens and are not particularly resistant to disinfection. Hence, *E. coli* (or thermotolerant coliforms) is an appropriate indicator for the presence/absence of *Campylobacter* spp. in drinking-water supplies.

Selected bibliography

Frost JA (2001) Current epidemiological issues in human campylobacteriosis. *Journal of Applied Microbiology*, 90:85S–95S.

Koenraad PMFJ, Rombouts FM, Notermans SHW (1997) Epidemiological aspects of thermophilic *Campylobacter* in water-related environments: A review. *Water Environment Research*, 69:52–63.

Kuroki S et al. (1991) Guillain-Barré syndrome associated with *Campylobacter* infection. *Pediatric Infectious Diseases Journal*, 10:149–151.

Enterobacter sakazakii

General description

Enterobacter sakazakii is a motile, Gram-negative, non-spore-forming, rod-shaped bacterium that has been found in infant formulas as a contaminant. *Enterobacter* species are biochemically similar to *Klebsiella*; unlike *Klebsiella*, however, *Enterobacter* is ornithine positive. *Enterobacter sakazakii* has been found to be more resistant to osmotic and dry stress than other members of the Enterobacteriaceae family.

Human health effects

Enterobacter sakazakii has been associated with sporadic cases or small outbreaks of sepsis, meningitis, cerebritis and necrotizing enterocolitis. Most of the infections are seen in low-birth-weight infants (i.e. less than 2 kg) or infants born prematurely (i.e. less than 37 weeks of gestation). Mortality has been reported to be as high as 50% but has decreased to less than 20% in recent years.

Source and occurrence

The reservoir for *E. sakazakii* is unknown. Various environmental samples (surface water, soil, mud, bird faeces) have tested negative. *Enterobacter sakazakii* has been identified in the guts of certain flies. The organism has been frequently identified in factories that produce milk powder and other food substances and in households. Commercially produced non-sterile powdered infant formula has often been implicated as the source of the bacteria during outbreaks. In a study of 141 powdered infant formulas, 20 were found to be culture-positive for *E. sakazakii*, even though the formulas complied with Codex microbial requirements for coliforms (< 3 colony-forming units per gram). The bacteria have been found in samples from newly opened sealed cans. Although sources of the bacteria other than infant formula have not been identified, environmental sources probably exist.

Routes of exposure

Disease caused by *E. sakazakii* in infants has been associated with the consumption of commercially prepared non-sterile infant formula. Contamination has been linked back to either the infant formula itself or formula preparation equipment (e.g. blenders). Many of the outbreaks have occurred without identified hygienic lapses during formula preparation. The organism has not been found in drinking-water sources used to prepare the formula. There is no evidence for person-to-person or more general environmental transmission.

Significance in drinking-water

There is no evidence that these bacteria are transmitted through drinking-water, although it is plausible that the organism could be present in water of poor quality. *Enterobacter sakazakii* is sensitive to disinfectants, and its presence can be prevented by adequate treatment.

Selected bibliography

Block C et al. (2002) Cluster of neonatal infections in Jerusalem due to unusual biochemical variant of *Enterobacter sakazakii*. *European Journal of Microbiology and Infectious Disease*, 21:613–616.

Breeuwer P et al. (2003) Desiccation and heat tolerance of *Enterobacter sakazakii*. *Journal of Applied Microbiology*, 95:967–973.

Hamilton JV, Lehane MJ, Braig HR (2003) Isolation of *Enterobacter sakazakii* from midgut of *Stomoxys calcitrans* [letter to the editor]. *Emerging Infectious Diseases*, 9(10):1355–1356.

Kandhai CM et al. (2004) Occurrence of *Enterobacter sakazakii* in food production environments and households [research letters]. *Lancet*, 363:39–40.

WHO/FAO (2004) *Enterobacter sakazakii and other microorganisms in powdered infant formula, meeting report*. Geneva, World Health Organization and Food and Agriculture Organization of the United Nations (Microbiological Risk Assessment Series 6).

Escherichia coli pathogenic strains

General description

Escherichia coli is present in large numbers in the normal intestinal flora of humans and animals, where it generally causes no harm. However, in other parts of the body, *E. coli* can cause serious disease, such as urinary tract infections, bacteraemia and meningitis. A limited number of enteropathogenic strains can cause acute diarrhoea. Several classes of enteropathogenic *E. coli* have been identified on the basis of different virulence factors, including enterohaemorrhagic *E. coli* (EHEC), enterotoxigenic *E. coli* (ETEC), enteropathogenic *E. coli* (EPEC), enteroinvasive *E. coli* (EIEC), enteroaggregative *E. coli* (EAEC) and diffusely adherent *E. coli* (DAEC). More is known about the first four classes named; the pathogenicity and prevalence of EAEC and DAEC strains are less well established.

Human health effects

EHEC serotypes, such as *E. coli* O157:H7 and *E. coli* O111, cause diarrhoea that ranges from mild and non-bloody to highly bloody, which is indistinguishable from haemorrhagic colitis. Between 2% and 7% of cases can develop the potentially fatal haemolytic uraemic syndrome, which is characterized by acute renal failure and haemolytic anaemia. Children under 5 years of age are at most risk of developing haemolytic uraemic syndrome. The infectivity of EHEC strains is substantially higher than that of the other strains. As few as 100 EHEC organisms can cause infection. ETEC produces heat-labile or heat-stable *E. coli* enterotoxin, or both toxins simultaneously, and is an important cause of diarrhoea in developing countries, especially in young children. Symptoms of ETEC infection include mild watery diarrhoea, abdominal cramps, nausea and headache. Infection with EPEC has been associated with severe, chronic, non-bloody diarrhoea, vomiting and fever in infants. EPEC infections are rare in developed countries, but occur commonly in developing countries, with infants presenting with malnutrition, weight loss and growth retardation. EIEC causes watery and occasionally bloody diarrhoea where strains invade colon cells by a pathogenic mechanism similar to that of *Shigella*.

Source and occurrence

Enteropathogenic *E. coli* are enteric organisms, and humans are the major reservoir, particularly of EPEC, ETEC and EIEC strains. Livestock, such as cattle and sheep and, to a lesser extent, goats, pigs and chickens, are a major source of EHEC strains. The latter have also been associated with raw vegetables, such as bean sprouts. The pathogens have been detected in a variety of water environments.

Routes of exposure

Infection is associated with person-to-person transmission, contact with animals, food and consumption of contaminated water. Person-to-person transmissions are particularly prevalent in communities where there is close contact between individuals, such as nursing homes and day-care centres.

Significance in drinking-water

Waterborne transmission of pathogenic *E. coli* has been well documented for recreational waters and contaminated drinking-water. A well-publicized waterborne outbreak of illness caused by *E. coli* O157:H7 (and *Campylobacter jejuni*) occurred in the farming community of Walkerton in Ontario, Canada. The outbreak took place in May 2000 and led to 7 deaths and more than 2300 illnesses. The drinking-water supply was contaminated by rainwater runoff containing cattle excreta. Within a water safety plan, control measures that can be applied to manage potential risk from enteropathogenic *E. coli* include protection of raw water supplies from human and animal waste, adequate treatment and protection of water during distribution. There is no indication that the response of enteropathogenic strains of *E. coli* to water treatment and disinfection procedures differs from that of other *E. coli*. Hence, conventional testing for *E. coli* (or, alternatively, thermotolerant coliform bacteria) provides an appropriate indicator for the enteropathogenic serotypes in drinking-water. This applies even though standard tests will generally not detect EHEC strains.

Selected bibliography

Nataro JP, Kaper JB (1998) Diarrheagenic *Escherichia coli*. *Clinical Microbiology Reviews*, 11:142–201.

O'Connor DR (2002) *Report of the Walkerton Inquiry: The events of May 2000 and related issues. Part 1: A summary*. Toronto, Ontario, Ontario Ministry of the Attorney General, Queen's Printer for Ontario.

Helicobacter pylori

General description

Helicobacter pylori, originally classified as *Campylobacter pylori*, is a Gram-negative, microaerophilic, spiral-shaped, motile bacterium. There are at least 14 species of *Helicobacter*, but only *H. pylori* has been identified as a human pathogen.

Human health effects

Helicobacter pylori is found in the stomach; although most infections are asymptomatic, the organism is associated with chronic gastritis, which may lead to complications such as peptic and duodenal ulcer disease and gastric cancer. Whether the organism

is truly the cause of these conditions remains unclear. The majority of *H. pylori* infections are initiated in childhood and without treatment are chronic. The infections are more prevalent in developing countries and are associated with overcrowded living conditions. Interfamilial clustering is common.

Source and occurrence

Humans appear to be the primary host of *H. pylori*. Other hosts may include domestic cats. There is evidence that *H. pylori* is sensitive to bile salts, which would reduce the likelihood of faecal excretion, although it has been isolated from faeces of young children. *Helicobacter pylori* has been detected in water. Although *H. pylori* is unlikely to grow in the environment, it has been found to survive for 3 weeks in biofilms and up to 20–30 days in surface waters. In a study conducted in the USA, *H. pylori* was found in the majority of surface water and shallow groundwater samples. The presence of *H. pylori* was not correlated with the presence of *E. coli*. Possible contamination of the environment can be through children with diarrhoea or through vomiting by children as well as adults.

Routes of exposure

Person-to-person contact within families has been identified as the most likely source of infection through oral–oral transmission. *Helicobacter pylori* can survive well in mucus or vomit. However, it is difficult to detect in mouth or faecal samples. Faecal–oral transmission is also considered possible.

Significance in drinking-water

Consumption of contaminated drinking-water has been suggested as a potential source of infection, but further investigation is required to establish any link with waterborne transmission. Humans are the principal source of *H. pylori*, and the organism is sensitive to oxidizing disinfectants. Hence, control measures that can be applied to protect drinking-water supplies from *H. pylori* include preventing contamination by human waste and adequate disinfection. *Escherichia coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator for the presence/absence of this organism.

Selected bibliography

Dunn BE, Cohen H, Blaser MJ (1997) *Helicobacter pylori*. *Clinical Microbiology Reviews*, 10: 720–741.

Hegarty JP, Dowd MT, Baker KH (1999) Occurrence of *Helicobacter pylori* in surface water in the United States. *Journal of Applied Microbiology*, 87:697–701.

Hulten K et al. (1996) *Helicobacter pylori* in drinking-water in Peru. *Gastroenterology*, 110: 1031–1035.

Mazari-Hiriart M, López-Vidal Y, Calva JJ (2001) *Helicobacter pylori* in water systems for human use in Mexico City. *Water Science and Technology*, 43:93–98.

Klebsiella

General description

Klebsiella spp. are Gram-negative, non-motile bacilli that belong to the family Enterobacteriaceae. The genus *Klebsiella* consists of a number of species, including *K. pneumoniae*, *K. oxytoca*, *K. planticola* and *K. terrigena*. The outermost layer of *Klebsiella*

spp. consists of a large polysaccharide capsule that distinguishes the organisms from other members of the family. Approximately 60–80% of all *Klebsiella* spp. isolated from faeces and clinical specimens are *K. pneumoniae* and are positive in the thermotolerant coliform test. *Klebsiella oxytoca* has also been identified as a pathogen.

Human health effects

Klebsiella spp. have been identified as colonizing hospital patients, where spread is associated with the frequent handling of patients (e.g. in intensive-care units). Patients at highest risk are those with impaired immune systems, such as the elderly or very young, patients with burns or excessive wounds, those undergoing immunosuppressive therapy or those with human immunodeficiency virus (HIV)/acquired immunodeficiency syndrome (AIDS) infection. Colonization may lead to invasive infections. On rare occasions, *Klebsiella* spp., notably *K. pneumoniae* and *K. oxytoca*, may cause serious infections, such as destructive pneumonia.

Source and occurrence

Klebsiella spp. are natural inhabitants of many water environments, and they may multiply to high numbers in waters rich in nutrients, such as pulp mill wastes, textile finishing plants and sugar-cane processing operations. In drinking-water distribution systems, they are known to colonize washers in taps. The organisms can grow in water distribution systems. *Klebsiella* spp. are also excreted in the faeces of many healthy humans and animals, and they are readily detected in sewage-polluted water.

Routes of exposure

Klebsiella can cause nosocomial infections, and contaminated water and aerosols may be a potential source of the organisms in hospital environments and other health-care facilities.

Significance in drinking-water

Klebsiella spp. are not considered to represent a source of gastrointestinal illness in the general population through ingestion of drinking-water. *Klebsiella* spp. detected in drinking-water are generally biofilm organisms and are unlikely to represent a health risk. The organisms are reasonably sensitive to disinfectants, and entry into distribution systems can be prevented by adequate treatment. Growth within distribution systems can be minimized by strategies that are designed to minimize biofilm growth, including treatment to optimize organic carbon removal, restriction of the residence time of water in distribution systems and maintenance of disinfectant residuals. *Klebsiella* is a coliform and can be detected by traditional tests for total coliforms.

Selected bibliography

Ainsworth R, ed. (2004) *Safe piped water: Managing microbial water quality in piped distribution systems*. IWA Publishing, London, for the World Health Organization, Geneva.

Bartram J et al., eds (2003) *Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health*. London, IWA Publishing (WHO Emerging Issues in Water and Infectious Disease Series).

Legionella

General description

The genus *Legionella*, a member of the family Legionellaceae, has at least 50 species comprising 70 distinct serogroups. Legionellae are Gram-negative, rod-shaped, non-spore-forming bacteria that require L-cysteine for growth and primary isolation. *Legionella* spp. are heterotrophic bacteria found in a wide range of water environments and can proliferate at temperatures above 25 °C.

Human health effects

Although all *Legionella* spp. are considered potentially pathogenic for humans, *L. pneumophila* is the major waterborne pathogen responsible for legionellosis, of which two clinical forms are known: Legionnaires' disease and Pontiac fever. The former is a pneumonic illness with an incubation period of 3–6 days. Host factors influence the likelihood of illness: males are more frequently affected than females, and most cases occur in the 40- to 70-year age group. Risk factors include smoking, alcohol abuse, cancer, diabetes, chronic respiratory or kidney disease and immunosuppression, as in transplant recipients. Pontiac fever is a milder, self-limiting disease with a high attack rate and an onset (5 hours to 3 days) and symptoms similar to those of influenza: fever, headache, nausea, vomiting, aching muscles and coughing. Studies of seroprevalence of antibodies indicate that many infections are asymptomatic.

Source and occurrence

Legionella spp. are members of the natural flora of many freshwater environments, such as rivers, streams and impoundments, where they occur in relatively low numbers. However, they thrive in certain human-made water environments, such as water cooling devices (cooling towers and evaporative condensers) associated with air-conditioning systems, hot water distribution systems and spas, which provide suitable temperatures (25–50 °C) and conditions for their multiplication. Devices that support multiplication of *Legionella* have been associated with outbreaks of Legionnaires' disease. *Legionella* survive and grow in biofilms and sediments and are more easily detected from swab samples than from flowing water. Legionellae can be ingested by trophozoites of certain amoebae such as *Acanthamoeba*, *Hartmanella* and *Naegleria*, which play an important role in their persistence in water environments.

Routes of exposure

The most common route of infection is the inhalation of aerosols containing the bacteria. Such aerosols can be generated by contaminated cooling towers, warm water showers, humidifiers and spas. Aspiration has also been identified as a route of infection in some cases associated with contaminated water, food and ice. There is no evidence of person-to-person transmission.

Significance in drinking-water

Legionella spp. are common waterborne organisms, and devices such as cooling towers, hot water systems and spas that utilize mains water have been associated with outbreaks of infection. Owing to the prevalence of *Legionella*, the potential for ingress

into drinking-water systems should be considered as a possibility, and control measures should be employed to reduce the likelihood of survival and multiplication. Disinfection strategies designed to minimize biofilm growth and temperature control can minimize the potential risk from *Legionella* spp. The organisms are sensitive to disinfection. Monochloramine has been shown to be particularly effective, probably due to its stability and greater effectiveness against biofilms. Water temperature is an important element of control strategies. Wherever possible, water temperatures should be kept outside the range of 25–50 °C and preferably 20–50 °C to prevent the growth of the organism. In hot water systems, temperatures leaving heaters should be above 60 °C, and temperatures above 50°C should be maintained throughout associated pipework. However, maintaining temperatures of hot water above 50 °C may represent a scalding risk in young children, the elderly and other vulnerable groups. Where temperatures in hot or cold water distribution systems cannot be maintained outside the range of 25–50 °C, greater attention to disinfection and strategies aimed at limiting development of biofilms are required. Accumulation of sludge, scale, rust, algae or slime deposits in water distribution systems supports the growth of *Legionella* spp., as does stagnant water. Systems that are kept clean and flowing are less likely to support excess growth of *Legionella* spp. Care should also be taken to select plumbing materials that do not support microbial growth and the development of biofilms.

Legionella spp. represent a particular concern in devices such as cooling towers and hot water systems in large buildings. As discussed in chapter 6, specific water safety plans incorporating control measures for *Legionella* spp. should be developed for these buildings. *Legionella* are not detected by HPC techniques, and *E. coli* (or, alternatively, thermotolerant coliforms) is not a suitable indicator for the presence/absence of this organism.

Selected bibliography

Bartram J et al., eds (2007) *Legionella and the prevention of legionellosis*. Geneva, World Health Organization.

Codony F et al. (2002) Factors promoting colonization by legionellae in residential water distribution systems: An environmental case–control survey. *European Journal of Clinical Microbiology and Infectious Diseases*, 21:717–721.

Emmerson AM (2001) Emerging waterborne infections in health-care settings. *Emerging Infectious Diseases*, 7:272–276.

Rusin PA et al. (1997) Risk assessment of opportunistic bacterial pathogens in drinking-water. *Reviews of Environmental Contamination and Toxicology*, 152:57–83.

Leptospira

General description

Leptospires are aerobic spirochetes that are typically 0.1 μm in diameter and 5–25 μm in length. There are two genera: *Leptospira*, which includes the pathogenic *L. interrogans*, and *Leptonoma*. *Leptospira interrogans* causes the important zoonotic and widespread disease leptospirosis. Pathogenic leptospires are maintained in host animals but, depending on conditions, can survive for days to weeks in water. More than 200 pathogenic serovars have been identified, and these have been divided into 25 serogroups based on serologic relatedness.

Human health effects

Leptospirosis occurs globally, affecting people living in temperate and tropical climates in both rural and urban areas. The severity of illness and the types of symptoms vary widely. Infections are often subclinical or so mild that medical attention is not sought. Symptoms include fever, headache, muscle pain, chills, redness in the eyes, abdominal pain, jaundice, haemorrhages in skin and mucous membranes (including pulmonary bleeding), vomiting, diarrhoea and rash. Pulmonary bleeding has been recognized as a dangerous and often fatal result of leptospirosis, but the way it develops after infection remains unclear. Long-lasting sequelae have been identified, including depression, headaches, fatigue and joint pains. Weil disease, characterized by jaundice, renal failure, haemorrhage and myocarditis, has been used as an alternative term for leptospirosis, but it represents a subset of the manifestations. Estimates of case fatalities vary from less than 5% to 30%, but the figures are not considered reliable owing to uncertainties over case prevalence. Fatality rates are influenced by timeliness of treatment interventions. The number of cases is not well documented as a result of lack of awareness and adequate methods of diagnosis. It has been estimated that there are about 0.1–1 cases per 100 000 persons per year in temperate climates and up to 10–100 cases per 100 000 persons per year in tropical climates.

Source and occurrence

Pathogenic *Leptospira interrogans* are maintained in the renal tubules of many animal hosts. This can take the form of chronic asymptomatic infections, with excretion persisting for very long periods and even for life. Rats, especially the brown rat (*Rattus norvegicus*), serve as a reservoir for *Leptospira interrogans* serovars Icterohaemorrhagiae and Copenhageni. Cattle are the most important reservoir for serovar Hardjo, and field mice (*Microtus arvalis*) and muskrats (*Ondatra zibethicus*) are the most important reservoirs for serovar Grippotyphosa. Recent research has shown that the house mouse (*Crocidura russula*) may be a reservoir for serovar Mozdok (type 3). Water contaminated with urine and tissues of infected animals is an established source of pathogenic leptospires. Leptospires have a relatively low resistance to adverse environmental conditions (e.g. low pH, desiccation, direct sunlight); in the right circumstances (neutral pH, moderate temperatures), however, they can survive for months in water.

Routes of exposure

Leptospira interrogans can enter the body through cuts and abrasions or via the mucous membranes of the mouth, nose and eyes. It is not transmitted by the faecal–oral route. Leptospirosis is associated with a broad range of occupational activities predominantly associated with direct contact with dead or living animals, but also indirectly via urine-contaminated environments, especially surface water, plants and mud. Ingestion of contaminated food and water or inhalation of aerosols may occasionally cause infection. Direct person-to-person transmission is rarely observed. Sexual contact, transplacental transmission and mothers' milk are potential routes of exposure. Transmission via urine of infected patients could represent a risk to those who provide medical attention. There is an increasing trend of outbreaks associated

with recreational exposure to water contaminated with urine from infected animals. Outbreaks have also been associated with natural disasters involving flooding.

Significance in drinking-water

Waterborne leptospirosis is normally caused by contact with contaminated surface water. Leptospires are sensitive to disinfectants; within a water safety plan, control measures that should provide effective protection against this organism include application of standard disinfection processes for drinking-water together with protection of distribution systems from contamination associated with flooding events. Because leptospires are excreted in urine and persist in favourable environments, *E. coli* (or, alternatively, thermotolerant coliforms) is not a suitable indicator for the presence/absence of this organism.

Selected bibliography

Bharti AR et al. (2003) Leptospirosis: A zoonotic disease of global importance. *Lancet Infectious Diseases*, 3:757–771.

Pond K (2005) *Water recreation and disease. Plausibility of associated infections: Acute effects, sequelae and mortality.* IWA Publishing, London, for the World Health Organization.

WHO (2003) *Human leptospirosis: Guidance for diagnosis, surveillance and control.* Geneva, World Health Organization.

Mycobacterium

General description

The tuberculous or "typical" species of *Mycobacterium*, such as *M. tuberculosis*, *M. bovis*, *M. africanum* and *M. leprae*, have only human or animal reservoirs and are not transmitted by water. In contrast, the non-tuberculous or "atypical" species of *Mycobacterium* are natural inhabitants of a variety of water environments. These aerobic, rod-shaped and acid-fast bacteria grow slowly in suitable water environments and on culture media. Typical examples include the species *M. gordonae*, *M. kansasii*, *M. marinum*, *M. scrofulaceum*, *M. xenopi*, *M. intracellulare* and *M. avium* and the more rapid growers *M. chelonae* and *M. fortuitum*. The term *M. avium* complex has been used to describe a group of pathogenic species including *M. avium* and *M. intracellulare*. However, other atypical mycobacteria are also pathogenic. A distinct feature of all *Mycobacterium* spp. is a cell wall with high lipid content, which is used in identification of the organisms using acid-fast staining.

Human health effects

Atypical *Mycobacterium* spp. can cause a range of diseases involving the skeleton, lymph nodes, skin and soft tissues, as well as the respiratory, gastrointestinal and genitourinary tracts. Manifestations include pulmonary disease, Buruli ulcer, osteomyelitis and septic arthritis in people with no known predisposing factors. These bacteria are a major cause of disseminated infections in immunocompromised patients and are a common cause of death in HIV-positive persons.

Source and occurrence

Atypical *Mycobacterium* spp. multiply in a variety of suitable water environments, notably biofilms. One of the most commonly occurring species is *M. gordonae*. Other

species have also been isolated from water, including *M. avium*, *M. intracellulare*, *M. kansasii*, *M. fortuitum* and *M. chelonae*. High numbers of atypical *Mycobacterium* spp. may occur in distribution systems after events that dislodge biofilms, such as flushing or flow reversals. They are relatively resistant to treatment and disinfection and have been detected in well-operated and well-maintained drinking-water supplies with HPC less than 500/ml and total chlorine residuals of up to 2.8 mg/l. The growth of these organisms in biofilms reduces the effectiveness of disinfection. In one survey, the organisms were detected in 54% of ice and 35% of public drinking-water samples.

Routes of exposure

Principal routes of infection appear to be inhalation, contact and ingestion of contaminated water. Infections by various species have been associated with their presence in drinking-water supplies. In 1968, an endemic of *M. kansasii* infections was associated with the presence of the organisms in the drinking-water supply, and the spread of the organisms was associated with aerosols from showerheads. In Rotterdam, the Netherlands, an investigation into the frequent isolation of *M. kansasii* from clinical specimens revealed the presence of the same strains, confirmed by phage type and weak nitrase activity, in tap water. An increase in numbers of infections by the *M. avium* complex in Massachusetts, USA, has also been attributed to their incidence in drinking-water. In all these cases, there is only circumstantial evidence of a causal relationship between the occurrence of the bacteria in drinking-water and human disease. Infections have been linked to contaminated water in spas.

Significance in drinking-water

Detections of atypical mycobacteria in drinking-water and the identified routes of transmission suggest that drinking-water supplies are a plausible source of infection. There are limited data on the effectiveness of control measures that could be applied to reduce the potential risk from these organisms. One study showed that a water treatment plant could achieve a 99% reduction in numbers of mycobacteria from raw water. Atypical mycobacteria are relatively resistant to disinfection. Persistent residual disinfectant should reduce numbers of mycobacteria in the water column but is unlikely to be effective against organisms present in biofilms. Control measures that are designed to minimize biofilm growth, including treatment to optimize organic carbon removal, restriction of the residence time of water in distribution systems and maintenance of disinfectant residuals, could result in less growth of these organisms. Mycobacteria are not detected by HPC techniques, and *E. coli* (or, alternatively, thermotolerant coliforms) is not a suitable indicator for the presence/absence of this organism.

Selected bibliography

Bartram J et al., eds (2003) *Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health*. London, IWA Publishing (WHO Emerging Issues in Water and Infectious Disease Series).

Bartram J et al., eds (2004) *Pathogenic mycobacteria in water: A guide to public health consequences, monitoring and management*. Geneva, World Health Organization.

Covert TC et al. (1999) Occurrence of nontuberculous mycobacteria in environmental samples. *Applied and Environmental Microbiology*, 65:2492–2496.

Falkinham JO, Norton CD, LeChevallier MW (2001) Factors influencing numbers of *Mycobacterium avium*, *Mycobacterium intracellulare* and other mycobacteria in drinking water distribution systems. *Applied and Environmental Microbiology*, 66:1225–1231.

Grabow WOK (1996) Waterborne diseases: Update on water quality assessment and control. *Water SA*, 22:193–202.

Rusin PA et al. (1997) Risk assessment of opportunistic bacterial pathogens in drinking-water. *Reviews of Environmental Contamination and Toxicology*, 152:57–83.

Singh N, Yu VL (1994) Potable water and *Mycobacterium avium* complex in HIV patients: Is prevention possible? *Lancet*, 343:1110–1111.

Von Reyn CF et al. (1994) Persistent colonization of potable water as a source of *Mycobacterium avium* infection in AIDS. *Lancet*, 343:1137–1141.

Pseudomonas aeruginosa

General description

Pseudomonas aeruginosa is a member of the family Pseudomonadaceae and is a polarly flagellated, aerobic, Gram-negative rod. When grown in suitable media, it produces the non-fluorescent bluish pigment pyocyanin. Many strains also produce the fluorescent green pigment pyoverdin. *Pseudomonas aeruginosa*, like other fluorescent pseudomonads, produces catalase, oxidase and ammonia from arginine and can grow on citrate as the sole source of carbon.

Human health effects

Pseudomonas aeruginosa can cause a range of infections but rarely causes serious illness in healthy individuals without some predisposing factor. It predominantly colonizes damaged sites such as burn and surgical wounds, the respiratory tract of people with underlying disease and physically damaged eyes. From these sites, it may invade the body, causing destructive lesions or septicaemia and meningitis. Cystic fibrosis and immunocompromised patients are prone to colonization with *P. aeruginosa,* which may lead to serious progressive pulmonary infections. Water-related folliculitis and ear infections are associated with warm, moist environments such as swimming pools and spas. Many strains are resistant to a range of antimicrobial agents, which can increase the significance of the organism in hospital settings.

Source and occurrence

Pseudomonas aeruginosa is a common environmental organism and can be found in faeces, soil, water and sewage. It can multiply in water environments and also on the surface of suitable organic materials in contact with water. *Pseudomonas aeruginosa* is a recognized cause of hospital-acquired infections with potentially serious complications. It has been isolated from a range of moist environments such as sinks, water baths, hot water systems, showers and spa pools.

Routes of exposure

The main route of infection is by exposure of susceptible tissue, notably wounds and mucous membranes, to contaminated water or contamination of surgical instruments.

Cleaning of contact lenses with contaminated water can cause a form of keratitis. Ingestion of drinking-water is not an important source of infection.

Significance in drinking-water

Although *P. aeruginosa* can be significant in certain settings such as health-care facilities, there is no evidence that normal uses of drinking-water supplies are a source of infection in the general population. However, the presence of high numbers of *P. aeruginosa* in potable water, notably in packaged water, can be associated with complaints about taste, odour and turbidity. *Pseudomonas aeruginosa* is sensitive to disinfection, and entry into distribution systems can be minimized by adequate disinfection. Control measures that are designed to minimize biofilm growth, including treatment to optimize organic carbon removal, restriction of the residence time of water in distribution systems and maintenance of disinfectant residuals, should reduce the growth of these organisms. *Pseudomonas aeruginosa* is detected by HPC, which can be used together with parameters such as disinfectant residuals to indicate conditions that could support growth of these organisms. However, as *P. aeruginosa* is a common environmental organism, *E. coli* (or, alternatively, thermotolerant coliforms) cannot be used for this purpose.

Selected bibliography

Bartram J et al., eds (2003) *Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health*. London, IWA Publishing (WHO Emerging Issues in Water and Infectious Disease Series).

De Victorica J, Galván M (2001) *Pseudomonas aeruginosa* as an indicator of health risk in water for human consumption. *Water Science and Technology*, 43:49–52.

Hardalo C, Edberg SC (1997) *Pseudomonas aeruginosa*: Assessment of risk from drinking-water. *Critical Reviews in Microbiology*, 23:47–75.

Salmonella

General description

Salmonella spp. belong to the family Enterobacteriaceae. They are motile, Gram-negative bacilli that do not ferment lactose, but most produce hydrogen sulfide or gas from carbohydrate fermentation. Originally, they were grouped into more than 2000 species (serotypes) according to their somatic (O) and flagellar (H) antigens (Kauffmann-White classification). There has been much debate about the nomenclature and taxonomy of *Salmonella*, but it is now considered that there are actually two species (*Salmonella enterica* and *Salmonella bongori*). Other previously named species, including *S.* Typhi and *S.* Paratyphi, are considered to be serovars.

Human health effects

Salmonella infections typically cause four clinical manifestations: gastroenteritis (ranging from mild to fulminant diarrhoea, nausea and vomiting), bacteraemia or septicaemia (high spiking fever with positive blood cultures), typhoid fever/enteric fever (sustained fever with or without diarrhoea) and a carrier state in persons with previous infections. With regard to enteric illness, *Salmonella* spp. can be divided into two fairly distinct groups: the typhoidal species/serovars (*S.* Typhi and *S.* Paratyphi) and

the remaining non-typhoidal species/serovars. Symptoms of non-typhoidal gastroenteritis appear from 6 to 72 hours after ingestion of contaminated food or water. Diarrhoea lasts 3–5 days and is accompanied by fever and abdominal pain. Usually the disease is self-limiting. The incubation period for typhoid fever can be 1–14 days but is usually 3–5 days. Typhoid fever is a more severe illness and can be fatal. Although typhoid is uncommon in areas with good sanitary systems, it is still prevalent elsewhere, and there are many millions of cases each year.

Source and occurrence

Salmonella spp. are widely distributed in the environment, but some species or serovars show host specificity. Notably, *S.* Typhi and generally *S.* Paratyphi are restricted to humans, although livestock can occasionally be a source of *S.* Paratyphi. A large number of serovars, including *S.* Typhimurium and *S.* Enteritidis, infect humans and also a wide range of animals, including poultry, cows, pigs, sheep, birds and even reptiles. The pathogens typically gain entry into water systems through faecal contamination from sewage discharges, livestock and wild animals. Contamination has been detected in a wide variety of foods and milk.

Routes of exposure

Salmonella is spread by the faecal–oral route. Infections with non-typhoidal serovars are primarily associated with person-to-person contact, the consumption of a variety of contaminated foods and exposure to animals. Infection by typhoid species is associated with the consumption of contaminated water or food, with direct person-to-person spread being uncommon.

Significance in drinking-water

Waterborne typhoid fever outbreaks have devastating public health implications. However, despite their widespread occurrence, non-typhoidal *Salmonella* spp. rarely cause drinking-water-borne outbreaks. Transmission, most commonly involving *S.* Typhimurium, has been associated with the consumption of contaminated groundwater and surface water supplies. In an outbreak of illness associated with a communal rainwater supply, bird faeces were implicated as a source of contamination. *Salmonella* spp. are relatively sensitive to disinfection. Within a water safety plan, control measures that can be applied to manage risk include protection of raw water supplies from human and animal waste, adequate treatment and protection of water during distribution. *Escherichia coli* (or, alternatively, thermotolerant coliforms) is a generally reliable indicator for *Salmonella* spp. in drinking-water supplies.

Selected bibliography

Angulo FJ et al. (1997) A community waterborne outbreak of salmonellosis and the effectiveness of a boil water order. *American Journal of Public Health*, 87:580–584.

Escartin EF et al. (2002) Potential *Salmonella* transmission from ornamental fountains. *Journal of Environmental Health*, 65:9–12.

Koplan JP et al. (1978) Contaminated roof-collected rainwater as a possible cause of an outbreak of salmonellosis. *Journal of Hygiene*, 81:303–309.

Tindall BJ et al. (2005) Nomenclature and taxonomy of the genus *Salmonella. International Journal of Systematic and Evolutionary Microbiology*, 5:521–524.

Shigella

General description

Shigella spp. are Gram-negative, non-spore-forming, non-motile, rod-like members of the family Enterobacteriaceae, which grow in the presence or absence of oxygen. Members of the genus have a complex antigenic pattern, and classification is based on their somatic O antigens, many of which are shared with other enteric bacilli, including *E. coli*. There are four species: *S. dysenteriae*, *S. flexneri*, *S. boydii* and *S. sonnei*.

Human health effects

Shigella spp. can cause serious intestinal diseases, including bacillary dysentery. Over 2 million infections occur each year, resulting in about 600 000 deaths, predominantly in developing countries. Most cases of *Shigella* infection occur in children under 10 years of age. The incubation period for shigellosis is usually 24–72 hours. Ingestion of as few as 10–100 organisms may lead to infection, which is substantially less than the infective dose of most other enteric bacteria. Abdominal cramps, fever and watery diarrhoea occur early in the disease. All species can produce severe disease, but illness due to *S. sonnei* is usually relatively mild and self-limiting. In the case of *S. dysenteriae*, clinical manifestations may proceed to an ulceration process, with bloody diarrhoea and high concentrations of neutrophils in the stool. The production of Shiga toxin by the pathogen plays an important role in this outcome. *Shigella* spp. seem to be better adapted to cause human disease than most other enteric bacterial pathogens.

Source and occurrence

Humans and other higher primates appear to be the only natural hosts for the shigellae. The bacteria remain localized in the intestinal epithelial cells of their hosts. Epidemics of shigellosis occur in crowded communities and where hygiene is poor. Many cases of shigellosis are associated with day-care centres, prisons and psychiatric institutions. Military field groups and travellers to areas with poor sanitation are also prone to infection.

Routes of exposure

Shigella spp. are enteric pathogens predominantly transmitted by the faecal–oral route through person-to-person contact, contaminated food and water. Flies have also been identified as a transmission vector from contaminated faecal waste.

Significance in drinking-water

A number of large waterborne outbreaks of shigellosis have been recorded. As the organisms are not particularly stable in water environments, their presence in drinking-water indicates recent human faecal pollution. Available data on prevalence in water supplies may be an underestimate, because detection techniques generally used can have a relatively low sensitivity and reliability. The control of *Shigella* spp. in drinking-water supplies is of special public health importance in view of the severity of the disease caused. *Shigella* spp. are relatively sensitive to disinfection. Within a water safety plan, control measures that can be applied to manage potential risk include protection of raw water supplies from human waste, adequate treatment and protection of water

during distribution. *Escherichia coli* (or, alternatively, thermotolerant coliforms) is a generally reliable indicator for *Shigella* spp. in drinking-water supplies.

Selected bibliography

Alamanos Y et al. (2000) A community waterborne outbreak of gastro-enteritis attributed to *Shigella sonnei*. *Epidemiology and Infection*, 125:499–503.

Pegram GC, Rollins N, Espay Q (1998) Estimating the cost of diarrhoea and epidemic dysentery in Kwa-Zulu-Natal and South Africa. *Water SA*, 24:11–20.

Staphylococcus aureus

General description

Staphylococcus aureus is an aerobic or anaerobic, non-motile, non-spore-forming, catalase- and coagulase-positive, Gram-positive coccus, usually arranged in grapelike irregular clusters. The genus *Staphylococcus* contains at least 15 different species. Apart from *S. aureus*, the species *S. epidermidis* and *S. saprophyticus* are also associated with disease in humans.

Human health effects

Although *Staphylococcus aureus* is a common member of the human microflora, it can produce disease through two different mechanisms. One is based on the ability of the organisms to multiply and spread widely in tissues, and the other is based on the ability of the organisms to produce extracellular enzymes and toxins. Infections based on the multiplication of the organisms are a significant problem in hospitals and other health-care facilities. Multiplication in tissues can result in manifestations such as boils, skin sepsis, post-operative wound infections, enteric infections, septicaemia, endocarditis, osteomyelitis and pneumonia. The onset of clinical symptoms for these infections is relatively long, usually several days. Gastrointestinal disease (enterocolitis or food poisoning) is caused by a heat-stable staphylococcal enterotoxin and characterized by projectile vomiting, diarrhoea, fever, abdominal cramps, electrolyte imbalance and loss of fluids. Onset of disease in this case has a characteristic short incubation period of 1–8 hours. The same applies to the toxic shock syndrome caused by toxic shock syndrome toxin-1.

Source and occurrence

Staphylococcus aureus is relatively widespread in the environment but is found mainly on the skin and mucous membranes of animals. The organism is a member of the normal microbial flora of the human skin and is found in the nasopharynx of 20–30% of adults at any one time. Staphylococci are occasionally detected in the gastrointestinal tract and can be detected in sewage. *Staphylococcus aureus* can be released by human contact into water environments such as swimming pools, spa pools and other recreational waters. It has also been detected in drinking-water supplies.

Routes of exposure

Hand contact is by far the most common route of transmission. Inadequate hygiene can lead to contamination of food. Foods such as ham, poultry and potato and egg salads kept at room or higher temperature offer an ideal environment for the

multiplication of *S. aureus* and the release of toxins. The consumption of foods containing *S. aureus* toxins can lead to enterotoxin food poisoning within a few hours.

Significance in drinking-water

Although *S. aureus* can occur in drinking-water supplies, there is no evidence of transmission through the consumption of such water. Although staphylococci are slightly more resistant to chlorine residuals than *E. coli*, their presence in water is readily controlled by conventional treatment and disinfection processes. As faecal material is not their usual source, *E. coli* (or, alternatively, thermotolerant coliforms) is not a suitable indicator for *S. aureus* in drinking-water supplies.

Selected bibliography

Antai SP (1987) Incidence of *Staphylococcus aureus*, coliforms and antibiotic-resistant strains of *Escherichia coli* in rural water supplies in Port Harcourt. *Journal of Applied Bacteriology*, 62:371–375.

LeChevallier MW, Seidler RJ (1980) *Staphylococcus aureus* in rural drinking-water. *Applied and Environmental Microbiology*, 39:739–742.

Tsukamurella

General description

The genus *Tsukamurella* belongs to the family Nocardiaceae. *Tsukamurella* spp. are Gram-positive, weakly or variably acid-fast, non-motile, obligate aerobic, irregular rod-shaped bacteria. They are actinomycetes related to *Rhodococcus*, *Nocardia* and *Mycobacterium*. The genus was created in 1988 to accommodate a group of chemically unique organisms characterized by a series of very long chain (68–76 carbons), highly unsaturated mycolic acids, *meso*-diaminopimelic acid and arabinogalactan, common to the genus *Corynebacterium*. The type species is *T. paurometabola*, and the following additional species were proposed in the 1990s: *T. wratislaviensis*, *T. inchonensis*, *T. pulmonis*, *T. tyrosinosolvens* and *T. strandjordae*.

Human health effects

Tsukamurella spp. cause disease mainly in immunocompromised individuals. Infections with these microorganisms have been associated with chronic lung diseases, immune suppression (leukaemia, tumours, HIV/AIDS infection) and post-operative wound infections. *Tsukamurella* were reported in four cases of catheter-related bacteraemia and in individual cases including chronic lung infection, necrotizing tenosynovitis with subcutaneous abscesses, cutaneous and bone infections, meningitis and peritonitis.

Source and occurrence

Tsukamurella spp. exist primarily as environmental saprophytes in soil, water and foam (thick stable scum on aeration vessels and sedimentation tanks) of activated sludge. *Tsukamurella* are represented in HPC populations in drinking-water.

Routes of exposure

Tsukamurella spp. appear to be transmitted through devices such as catheters or lesions. The original source of the contaminating organisms is unknown.

Significance in drinking-water

Tsukamurella organisms have been detected in drinking-water supplies, but the significance is unclear. There is no evidence of a link between organisms in water and illness. As *Tsukamurella* is an environmental organism, *E. coli* (or, alternatively, thermotolerant coliforms) is not a suitable indicator for this organism.

Selected bibliography

Bartram J et al., eds (2003) *Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health*. London, IWA Publishing (WHO Emerging Issues in Water and Infectious Disease Series).

Kattar MM et al. (2001) *Tsukamurella strandjordae* sp. nov., a proposed new species causing sepsis. *Journal of Clinical Microbiology*, 39:1467–1476.

Larkin JA et al. (1999) Infection of a knee prosthesis with *Tsukamurella* species. *Southern Medical Journal*, 92:831–832.

Vibrio

General description

Vibrio spp. are small, curved (comma-shaped), Gram-negative bacteria with a single polar flagellum. Species are typed according to their O antigens. There are a number of pathogenic species, including *V. cholerae*, *V. parahaemolyticus* and *V. vulnificus*. *Vibrio cholerae* is the only pathogenic species of significance from freshwater environments. Although a number of serotypes can cause diarrhoea, only O1 and O139 currently cause the classical cholera symptoms in which a proportion of cases suffer fulminating and severe watery diarrhoea. The O1 serovar has been further divided into "classical" and "El Tor" biotypes. The latter is distinguished by features such as the ability to produce a dialysable heat-labile haemolysin, active against sheep and goat red blood cells. The classical biotype is considered responsible for the first six cholera pandemics, whereas the El Tor biotype is responsible for the seventh pandemic that commenced in 1961. Strains of *V. cholerae* O1 and O139 that cause cholera produce an enterotoxin (cholera toxin) that alters the ionic fluxes across the intestinal mucosa, resulting in substantial loss of water and electrolytes in liquid stools. Other factors associated with infection are an adhesion factor and an attachment pilus. Not all strains of serotypes O1 or O139 possess the virulence factors, and they are rarely possessed by non-O1/O139 strains.

Human health effects

Cholera outbreaks continue to occur in many areas of the developing world. Symptoms are caused by heat-labile cholera enterotoxin carried by toxigenic strains of *V. cholerae* O1/O139. A large percentage of infected persons do not develop illness; about 60% of the classical and 75% of the El Tor group infections are asymptomatic. Symptomatic illness ranges from mild or moderate to severe disease. The initial symptoms of cholera are an increase in peristalses followed by loose, watery and mucus-flecked "rice-water" stools that may cause a patient to lose as much as 10–15 litres of liquid per day. Decreasing gastric acidity by administration of sodium bicarbonate reduces the infective dose of *V. cholerae* O1 from more than 10^8 to about 10^4 organisms. Case

fatality rates vary according to facilities and preparedness. As many as 60% of untreated patients may die as a result of severe dehydration and loss of electrolytes, but well-established diarrhoeal disease control programmes can reduce fatalities to less than 1%. Non-toxigenic strains of *V. cholerae* can cause self-limiting gastroenteritis, wound infections and bacteraemia.

Source and occurrence

Non-toxigenic *V. cholerae* is widely distributed in water environments, but toxigenic strains are not distributed as widely. Humans are an established source of toxigenic *V. cholerae*; in the presence of disease, the organism can be detected in sewage. Although *V. cholerae* O1 can be isolated from water in areas without disease, the strains are not generally toxigenic. Toxigenic *V. cholerae* has also been found in association with live copepods as well as other aquatic organisms, including molluscs, crustaceans, plants, algae and cyanobacteria. Numbers associated with these aquatic organisms are often higher than in the water. Non-toxigenic *V. cholerae* has been isolated from birds and herbivores in areas far away from marine and coastal waters. The prevalence of *V. cholerae* decreases as water temperatures fall below 20 °C.

Routes of exposure

Cholera is typically transmitted by the faecal–oral route, and the infection is predominantly contracted by the ingestion of faecally contaminated water and food. The high numbers required to cause infection make person-to-person contact an unlikely route of transmission.

Significance in drinking-water

Contamination of water due to poor sanitation is largely responsible for transmission, but this does not fully explain the seasonality of recurrence, and factors other than poor sanitation must play a role. The presence of the pathogenic *V. cholerae* O1 and O139 serotypes in drinking-water supplies is of major public health importance and can have serious health and economic implications in the affected communities. *Vibrio cholerae* is highly sensitive to disinfection processes. Within a water safety plan, control measures that can be applied to manage potential risk from toxigenic *V. cholerae* include protection of raw water supplies from human waste, adequate treatment and protection of water during distribution. *Vibrio cholerae* O1 and non-O1 have been detected in the absence of *E. coli*, and this organism (or, alternatively, thermotolerant coliforms) is not a reliable indicator for *V. cholerae* in drinking-water.

Selected bibliography

Kaper JB, Morris JG, Levine MM (1995) Cholera. *Clinical Microbiology Reviews*, 8:48–86.

Ogg JE, Ryder RA, Smith HL (1989) Isolation of *Vibrio cholerae* from aquatic birds in Colorado and Utah. *Applied and Environmental Microbiology*, 55:95–99.

Rhodes JB, Schweitzer D, Ogg JE (1985) Isolation of non-O1 *Vibrio cholerae* associated with enteric disease of herbivores in western Colorado. *Journal of Clinical Microbiology*, 22:572–575.

WHO (2002) *Vibrio cholerae*. In: *Guidelines for drinking-water quality*, 2nd ed. *Addendum: Microbiological agents in drinking water*. Geneva, World Health Organization, pp. 119–142.

Yersinia

General description

The genus *Yersinia* is classified in the family Enterobacteriaceae and comprises seven species. The species *Y. pestis*, *Y. pseudotuberculosis* and certain serotypes of *Y. enterocolitica* are pathogens for humans. *Yersinia pestis* is the cause of bubonic plague through contact with rodents and their fleas. *Yersinia* spp. are Gram-negative rods that are motile at 25 °C but not at 37 °C.

Human health effects

Yersinia enterocolitica penetrates cells of the intestinal mucosa, causing ulcerations of the terminal ilium. Yersiniosis generally presents as an acute gastroenteritis with diarrhoea, fever and abdominal pain. Other clinical manifestations include greatly enlarged painful lymph nodes referred to as "buboes". The disease seems to be more acute in children than in adults.

Source and occurrence

Domestic and wild animals are the principal reservoir for *Yersinia* spp.; pigs are the major reservoir of pathogenic *Y. enterocolitica*, whereas rodents and small animals are the major reservoir of *Y. pseudotuberculosis*. Pathogenic *Y. enterocolitica* has been detected in sewage and polluted surface waters. However, *Y. enterocolitica* strains detected in drinking-water are more commonly non-pathogenic strains of probable environmental origin. At least some species and strains of *Yersinia* seem to be able to replicate in water environments if at least trace amounts of organic nitrogen are present, even at temperatures as low as 4 °C.

Routes of exposure

Yersinia spp. are transmitted by the faecal–oral route, with the major source of infection considered to be foods, particularly meat and meat products, milk and dairy products. Ingestion of contaminated water is also a potential source of infection. Direct transmission from person to person and from animals to humans is also known to occur.

Significance in drinking-water

Although most *Yersinia* spp. detected in water are probably non-pathogenic, circumstantial evidence has been presented to support transmission of *Y. enterocolitica* and *Y. pseudotuberculosis* to humans from untreated drinking-water. The most likely source of pathogenic *Yersinia* spp. is human or animal waste. The organisms are sensitive to disinfection processes. Within a water safety plan, control measures that can be used to minimize the presence of pathogenic *Yersinia* spp. in drinking-water supplies include protection of raw water supplies from human and animal waste, adequate disinfection and protection of water during distribution. Owing to the long survival and/or growth of some strains of *Yersinia* spp. in water, *E. coli* (or, alternatively, thermotolerant coliforms) is not a suitable indicator for the presence/absence of these organisms in drinking-water.

Selected bibliography

Aleksic S, Bockemuhl J (1988) Serological and biochemical characteristics of 416 *Yersinia* strains from well water and drinking water plants in the Federal Republic of Germany: Lack of evidence that these strains are of public health significance. *Zentralblatt für Bakteriologie, Mikrobiologie und Hygiene B*, 185:527–533.

Inoue M et al. (1988) Three outbreaks of *Yersinia pseudotuberculosis* infection. *Zentralblatt für Bakteriologie, Mikrobiologie und Hygiene B*, 186:504–511.

Ostroff SM et al. (1994) Sources of sporadic *Yersinia enterocolitica* infections in Norway: A prospective case control study. *Epidemiology and Infection*, 112:133–141.

Waage AS et al. (1999) Detection of low numbers of pathogenic *Yersinia enterocolitica* in environmental water and sewage samples by nested polymerase chain reaction. *Journal of Applied Microbiology*, 87:814–821.

11.2 Viral pathogens

Viruses associated with waterborne transmission are predominantly those that can infect the gastrointestinal tract and are excreted in the faeces of infected humans (enteric viruses). With the exception of hepatitis E virus, humans are considered to be the only source of human infectious species. Enteric viruses typically cause acute disease with a short incubation period. Water may also play a role in the transmission of other viruses with different modes of action. As a group, viruses can cause a wide variety of infections and symptoms involving different routes of transmission, routes and sites of infection and routes of excretion. The combination of these routes and sites of infection can vary and will not always follow expected patterns. For example, viruses that are considered to primarily cause respiratory infections and symptoms are usually transmitted by person-to-person spread of respiratory droplets. However, some of these respiratory viruses may be discharged in faeces, leading to potential contamination of water and subsequent transmission through aerosols and droplets. Another example is viruses excreted in urine, such as polyomaviruses, which could contaminate and then be potentially transmitted by water, with possible long-term health effects, such as cancer, that are not readily associated epidemiologically with waterborne transmission.

Adenoviruses

General description

The family Adenoviridae is classified into the two genera *Mastadenovirus* (mammal hosts) and *Aviadenovirus* (avian hosts). Adenoviruses are widespread in nature, infecting birds, mammals and amphibians. To date, 51 antigenic types of human adenoviruses have been described. Human adenoviruses have been classified into six groups (A–F) on the basis of their physical, chemical and biological properties. Adenoviruses consist of a double-stranded DNA genome in a non-enveloped icosahedral capsid with a diameter of about 80 nm and unique fibres. The subgroups A–E grow readily in cell culture, but serotypes 40 and 41 are fastidious and do not grow well. Identification of serotypes 40 and 41 in environmental samples is generally based on polymerase chain reaction (PCR) techniques with or without initial cell culture amplification.

Human health effects

Human adenoviruses cause a wide range of infections with a spectrum of clinical manifestations. These include infections of the gastrointestinal tract (gastroenteritis), the respiratory tract (acute respiratory diseases, pneumonia, pharyngoconjunctival fever), the urinary tract (cervicitis, urethritis, haemorrhagic cystitis) and the eyes (epidemic keratoconjunctivitis, also known as "shipyard eye"; pharyngoconjunctival fever, also known as "swimming pool conjunctivitis"). Different serotypes are associated with specific illnesses; for example, types 40 and 41 are the main causes of enteric illness. Adenoviruses are an important source of childhood gastroenteritis. In general, infants and children are most susceptible to adenovirus infections, and many infections are asymptomatic. High attack rates in outbreaks imply that infecting doses are low.

Source and occurrence

Adenoviruses are excreted in large numbers in human faeces and are known to occur in sewage, raw water sources and treated drinking-water supplies worldwide. Although the subgroup of enteric adenoviruses (mainly types 40 and 41) is a major cause of gastroenteritis worldwide, notably in developing communities, little is known about the prevalence of these enteric adenoviruses in water sources. The limited availability of information on enteric adenoviruses is largely due to the fact that they are not detectable by conventional cell culture isolation.

Routes of exposure

Owing to the diverse epidemiology of the wide spectrum of human adenoviruses, exposure and infection are possible by a variety of routes. Person-to-person contact plays a major role in the transmission of illness; depending on the nature of the illness, this can include faecal–oral, oral–oral and hand–eye contact transmission, as well as indirect transfer through contaminated surfaces or shared utensils. There have been numerous outbreaks associated with hospitals, military establishments, childcare centres and schools. Symptoms recorded in most outbreaks were acute respiratory disease, keratoconjunctivitis and conjunctivitis. Outbreaks of gastroenteritis have also been reported. The consumption of contaminated food or water may be an important source of enteric illness, although there is no substantial evidence supporting this route of transmission. Eye infections may be contracted by the exposure of eyes to contaminated water, the sharing of towels at swimming pools or the sharing of goggles, as in the case of "shipyard eye". Confirmed outbreaks of adenovirus infections associated with water have been limited to pharyngitis or conjunctivitis, with exposure arising from use of swimming pools.

Significance in drinking-water

Human adenoviruses have been shown to occur in substantial numbers in raw water sources and treated drinking-water supplies. In one study, the incidence of human adenoviruses in such waters was exceeded only by the group of enteroviruses among viruses detectable by PCR-based techniques. In view of their prevalence as an enteric pathogen and detection in water, contaminated drinking-water represents a likely but unconfirmed source of human adenovirus infections. Human adenoviruses are also

considered important because they are exceptionally resistant to some water treatment and disinfection processes, notably ultraviolet (UV) light irradiation. Human adenoviruses have been detected in drinking-water supplies that met accepted specifications for treatment, disinfection and conventional indicator organisms. Within a water safety plan, control measures to reduce potential risk from human adenoviruses should focus on prevention of source water contamination by human waste, followed by adequate treatment and disinfection. The effectiveness of treatment processes used to remove human adenoviruses will require validation. Drinking-water supplies should also be protected from contamination during distribution. Because of the high resistance of the viruses to disinfection, *E. coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator of the presence/absence of human adenoviruses in drinking-water supplies.

Selected bibliography

Chapron CD et al. (2000) Detection of astroviruses, enteroviruses and adenoviruses types 40 and 41 in surface waters collected and evaluated by the information collection rule and integrated cell culture–nested PCR procedure. *Applied and Environmental Microbiology*, 66:2520–2525.

D'Angelo LJ et al. (1979) Pharyngoconjunctival fever caused by adenovirus type 4: Report of a swimming pool–related outbreak with recovery of virus from pool water. *Journal of Infectious Diseases*, 140:42–47.

Grabow WOK, Taylor MB, de Villiers JC (2001) New methods for the detection of viruses: Call for review of drinking water quality guidelines. *Water Science and Technology*, 43:1–8.

Puig M et al. (1994) Detection of adenoviruses and enteroviruses in polluted water by nested PCR amplification. *Applied and Environmental Microbiology*, 60:2963–2970.

Astroviruses

General description

Human and animal strains of astroviruses are single-stranded ribonucleic acid (RNA) viruses classified in the family Astroviridae. Astroviruses consist of a single-stranded RNA genome in a non-enveloped icosahedral capsid with a diameter of about 28 nm. In a proportion of the particles, a distinct surface star-shaped structure can be seen by electron microscopy. Eight different serotypes of human astroviruses have been described. The most commonly identified is human astrovirus serotype 1. Human astroviruses can be detected in environmental samples using PCR techniques with or without initial cell culture amplification.

Human health effects

Human astroviruses cause gastroenteritis, predominantly diarrhoea, mainly in children under 5 years of age, although it has also been reported in adults. Seroprevalence studies showed that more than 80% of children between 5 and 10 years of age have antibodies against human astroviruses. Occasional outbreaks in schools, nurseries and families have been reported. The illness is self-limiting, is of short duration and has a peak incidence in the winter. Human astroviruses are the cause of only a small proportion of reported gastroenteritis infections. However, the number of infections may be underestimated, as the illness is usually mild, and many cases will go unreported.

Source and occurrence

Infected individuals generally excrete large numbers of human astroviruses in faeces; hence, the viruses will be present in sewage. Human astroviruses have been detected in water sources and in drinking-water supplies.

Routes of exposure

Human astroviruses are transmitted by the faecal–oral route. Person-to-person spread is considered the most common route of transmission, and clusters of cases are seen in child-care centres, paediatric wards, families, homes for the elderly and military establishments. Ingestion of contaminated food or water could also be important.

Significance in drinking-water

The presence of human astroviruses in treated drinking-water supplies has been confirmed. As the viruses are typically transmitted by the faecal–oral route, transmission by drinking-water seems likely, but has not been confirmed. Human astroviruses have been detected in drinking-water supplies that met accepted specifications for treatment, disinfection and conventional indicator organisms. Within a water safety plan, control measures to reduce potential risk from human astroviruses should focus on prevention of source water contamination by human waste, followed by adequate treatment and disinfection. The effectiveness of treatment processes used to remove human astroviruses will require validation. Drinking-water supplies should also be protected from contamination during distribution. Owing to the higher resistance of the viruses to disinfection, *E. coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator of the presence/absence of human astroviruses in drinking-water supplies.

Selected bibliography

Grabow WOK, Taylor MB, de Villiers JC (2001) New methods for the detection of viruses: Call for review of drinking water quality guidelines. *Water Science and Technology*, 43:1–8.

Nadan S et al. (2003) Molecular characterization of astroviruses by reverse transcriptase PCR and sequence analysis: Comparison of clinical and environmental isolates from South Africa. *Applied and Environmental Microbiology*, 69:747–753.

Pintó RM et al. (2001) Astrovirus detection in wastewater. *Water Science and Technology*, 43: 73–77.

Caliciviruses

General description

The family Caliciviridae consists of four genera of single-stranded RNA viruses with a non-enveloped capsid (diameter 35–40 nm), which generally displays a typical surface morphology resembling cup-like structures. Human caliciviruses include the genera *Norovirus* (Norwalk-like viruses) and *Sapovirus* (Sapporo-like viruses). *Sapovirus* spp. demonstrate the typical calicivirus morphology and are called classical caliciviruses. Noroviruses generally fail to reveal the typical morphology and were in the past referred to as small round-structured viruses. The remaining two genera of the family contain viruses that infect animals other than humans. Human caliciviruses cannot be propagated in available cell culture systems. The viruses were originally

discovered by electron microscopy. Some *Norovirus* spp. can be detected by enzyme-linked immunosorbent assay using antibodies raised against baculovirus-expressed *Norovirus* capsid proteins. Several reverse transcriptase PCR procedures have been described for the detection of human caliciviruses.

Human health effects

Human caliciviruses are a major cause of acute viral gastroenteritis in all age groups. Symptoms include nausea, vomiting and abdominal cramps. Usually about 40% of infected individuals present with diarrhoea; some have fever, chills, headache and muscular pain. As some cases present with vomiting only and no diarrhoea, the condition is also known as "winter vomiting disease". Infections by human caliciviruses induce a short-lived immunity. The symptoms are usually relatively mild and rarely last for more than 3 days. High attack rates in outbreaks indicate that the infecting dose is low.

Source and occurrence

Human caliciviruses are excreted in faeces of infected individuals and will therefore be present in domestic wastewaters as well as faecally contaminated food and water, including drinking-water supplies.

Routes of exposure

The epidemiology of the disease indicates that person-to-person contact and the inhalation of contaminated aerosols and dust particles, as well as airborne particles of vomitus, are the most common routes of transmission. Drinking-water and a wide variety of foods contaminated with human faeces have been confirmed as major sources of exposure. Numerous outbreaks have been associated with contaminated drinking-water, ice, water on cruise ships and recreational waters. Shellfish harvested from sewage-contaminated waters have also been identified as a source of outbreaks.

Significance in drinking-water

Many human calicivirus outbreaks have been epidemiologically linked to contaminated drinking-water supplies. Within a water safety plan, control measures to reduce potential risk from human caliciviruses should focus on prevention of source water contamination by human waste, followed by adequate treatment and disinfection. The effectiveness of treatment processes used to remove human caliciviruses will require validation. Drinking-water supplies should also be protected from contamination during distribution. Owing to the higher resistance of the viruses to disinfection, *E. coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator of the presence/absence of human caliciviruses in drinking-water supplies.

Selected bibliography

Berke T et al. (1997) Phylogenetic analysis of the Caliciviridae. *Journal of Medical Virology*, 52:419–424.

Jiang X et al. (1999) Design and evaluation of a primer pair that detects both Norwalk- and Sapporo-like caliciviruses by RT-PCR. *Journal of Virological Methods*, 83:145–154.

Mauer AM, Sturchler DA (2000) A waterborne outbreak of small round-structured virus, *Campylobacter* and *Shigella* co-infections in La Neuveville, Switzerland, 1998. *Epidemiology and Infection*, 125:325–332.

Monroe SS, Ando T, Glass R (2000) Introduction: Human enteric caliciviruses—An emerging pathogen whose time has come. *Journal of Infectious Diseases*, 181(Suppl. 2):S249–251.

Enteroviruses

General description

The genus *Enterovirus* is a member of the family Picornaviridae. This genus consists of 69 serotypes (species) that infect humans: poliovirus types 1–3, coxsackievirus types A1–A24, coxsackievirus types B1–B6, echovirus types 1–33 and the numbered enterovirus types EV68–EV73. Members of the genus are collectively referred to as enteroviruses. Other species of the genus infect animals other than humans—for instance, the bovine group of enteroviruses. Enteroviruses are among the smallest known viruses and consist of a single-stranded RNA genome in a non-enveloped icosahedral capsid with a diameter of 20–30 nm. Some members of the genus, notably poliovirus, coxsackievirus B, echovirus and enterovirus, are readily isolated by cytopathogenic effect in cell cultures.

Human health effects

Enteroviruses are one of the most common causes of human infections. They have been estimated to cause about 30 million infections in the USA each year. The spectrum of diseases caused by enteroviruses is broad and ranges from a mild febrile illness to myocarditis, meningoencephalitis, poliomyelitis, herpangina, hand-foot-and-mouth disease and neonatal multi-organ failure. The persistence of the viruses in chronic conditions such as polymyositis, dilated cardiomyopathy and chronic fatigue syndrome has been described. Most infections, particularly in children, are asymptomatic, but still lead to the excretion of large numbers of the viruses, which may cause clinical disease in other individuals.

Source and occurrence

Enteroviruses are excreted in the faeces of infected individuals. Among the types of viruses detectable by conventional cell culture isolation, enteroviruses are generally the most numerous in sewage, water resources and treated drinking-water supplies. The viruses are also readily detected in many foods.

Routes of exposure

Person-to-person contact and inhalation of airborne viruses or viruses in respiratory droplets are considered to be the predominant routes of transmission of enteroviruses in communities. Transmission from drinking-water could also be important, but this has not yet been confirmed. Waterborne transmission of enteroviruses (coxsackievirus A16 and B5) has been epidemiologically confirmed for only two outbreaks, and these were associated with children bathing in lake water in the 1970s.

Significance in drinking-water

Enteroviruses have been shown to occur in substantial numbers in raw water sources and treated drinking-water supplies. In view of their prevalence, drinking-water represents a likely, although unconfirmed, source of enterovirus infection. The limited

knowledge on the role of waterborne transmission could be related to a number of factors, including the wide range of clinical symptoms, frequent asymptomatic infection, the diversity of serotypes and the dominance of person-to-person spread. Enteroviruses have been detected in drinking-water supplies that met accepted specifications for treatment, disinfection and conventional indicator organisms. Within a water safety plan, control measures to reduce potential risk from enteroviruses should focus on prevention of source water contamination by human waste, followed by adequate treatment and disinfection. The effectiveness of treatment processes used to remove enteroviruses will require validation. Drinking-water supplies should also be protected from contamination during distribution. Owing to the higher resistance of the viruses to disinfection, *E. coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator of the presence/absence of enteroviruses in drinking-water supplies.

Selected bibliography

Grabow WOK, Taylor MB, de Villiers JC (2001) New methods for the detection of viruses: Call for review of drinking water quality guidelines. *Water Science and Technology*, 43:1–8.

Hawley HB et al. (1973) Coxsackie B epidemic at a boys' summer camp. *Journal of the American Medical Association*, 226:33–36.

Hepatitis A virus

General description

Hepatitis A virus (HAV) is the only species of the genus *Hepatovirus* in the family Picornaviridae. The virus shares basic structural and morphological features with other members of the family, as described for enteroviruses. Human and simian HAVs are genotypically distinguishable. HAV cannot be readily detected or cultivated in conventional cell culture systems, and identification in environmental samples is based on the use of PCR techniques.

Human health effects

HAV is highly infectious, and the infecting dose is considered to be low. The virus causes the disease hepatitis A, commonly known as "infectious hepatitis". Like other members of the group enteric viruses, HAV enters the gastrointestinal tract by ingestion, where it infects epithelial cells. From here, the virus enters the bloodstream and reaches the liver, where it may cause severe damage to liver cells. In as many as 90% of cases, particularly in children, there is little, if any, liver damage, and the infection passes without clinical symptoms and elicits lifelong immunity. In general, the severity of illness increases with age. The damage to liver cells results in the release of liver-specific enzymes such as aspartate aminotransferase, which are detectable in the bloodstream and used as a diagnostic tool. The damage also results in the failure of the liver to remove bilirubin from the bloodstream; the accumulation of bilirubin causes the typical symptoms of jaundice and dark urine. After a relatively long incubation period of 28–30 days on average, there is a characteristic sudden onset of illness, including symptoms such as fever, malaise, nausea, anorexia, abdominal discomfort and eventually jaundice. Although mortality is generally less than 1%, repair of the liver

damage is a slow process that may keep patients incapacitated for 6 weeks or longer. This has substantial burden of disease implications. Mortality is higher in those over 50 years of age.

Source and occurrence

HAV occurs worldwide, but the prevalence of clinical disease has typical geographically based characteristics. HAV is excreted in faecal material of infected people, and there is strong epidemiological evidence that faecally contaminated food and water are common sources of the virus. In areas with poor sanitation, children are often infected at a very early age and become immune for life without clinical symptoms of disease. In areas with good sanitation, infection tends to occur later in life.

Routes of exposure

Person-to-person spread is probably the most common route of transmission, but contaminated food and water are important sources of infection. There is stronger epidemiological evidence for waterborne transmission of HAV than for any other virus. Foodborne outbreaks are also relatively common, with sources of infection including infected food handlers, shellfish harvested from contaminated water and contaminated produce. Travel of people from areas with good sanitation to those with poor sanitation provides a high risk of infection. Infection can also be spread in association with injecting and non-injecting drug use.

Significance in drinking-water

The transmission of HAV by drinking-water supplies is well established, and the presence of HAV in drinking-water constitutes a substantial health risk. Within a water safety plan, control measures to reduce potential risk from HAV should focus on prevention of source water contamination by human waste, followed by adequate treatment and disinfection. The effectiveness of treatment processes used to remove HAV will require validation. Drinking-water supplies should also be protected from contamination during distribution. Owing to the higher resistance of the viruses to disinfection, *E. coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator of the presence/absence of HAV in drinking-water supplies.

Selected bibliography

Cuthbert JA (2001) Hepatitis A: Old and new. *Clinical Microbiology Reviews*, 14:38–58.

WHO (2002) Enteric hepatitis viruses. In: *Guidelines for drinking-water quality*, 2nd ed. *Addendum: Microbiological agents in drinking water*. Geneva, World Health Organization, pp. 18–39.

Hepatitis E virus

General description

Hepatitis E virus (HEV) consists of a single-stranded RNA genome in a non-enveloped icosahedral capsid with a diameter of 27–34 nm. HEV shares properties with a number of viruses, and classification is a challenge. At one stage, HEV was classified as a member of the family Caliciviridae, but most recently it has been placed in a separate family called hepatitis E–like viruses. There are indications of antigenic variation,

and possibly even differences in serotypes of the virus, whereas human HAV consists of only one clearly defined serotype. HEV cannot be readily detected or cultivated in conventional cell culture systems, and identification in environmental samples is based on the use of PCR techniques.

Human health effects

HEV causes hepatitis that is in many respects similar to that caused by HAV. However, the incubation period tends to be longer (average 40 days), and infections typically have a mortality rate of up to 25% in pregnant women. In endemic regions, first infections are typically seen in young adults rather than young children. Despite evidence of antigenic variation, single infection appears to provide lifelong immunity to HEV. Global prevalence has a characteristic geographic distribution. HEV is endemic and causes clinical diseases in certain developing parts of the world, such as India, Nepal, central Asia, Mexico and parts of Africa. In many of these areas, HEV is the most important cause of viral hepatitis. Although seroprevalence can be high, clinical cases and outbreaks are rare in certain parts of the world, such as Japan, South Africa, the United Kingdom, North and South America, Australasia and central Europe. The reason for the lack of clinical cases in the presence of the virus is unknown.

Source and occurrence

HEV is excreted in faeces of infected people, and the virus has been detected in raw and treated sewage. Contaminated water has been associated with very large outbreaks. HEV is distinctive, in that it is the only enteric virus with a meaningful animal reservoir, including domestic animals, particularly pigs, as well as cattle, goats and even rodents.

Routes of exposure

Secondary transmission of HEV from cases to contacts and particularly nursing staff has been reported, but appears to be much less common than for HAV. The lower level of person-to-person spread suggests that faecally polluted water could play a much more important role in the spread of HEV than of HAV. Waterborne outbreaks involving thousands of cases are on record. These include one outbreak in 1954 with approximately 40 000 cases in Delhi, India; one with more than 100 000 cases in 1986–1988 in the Xinjiang Uighar region of China; and one in 1991 with some 79 000 cases in Kanpur, India. Animal reservoirs may also serve as a route of exposure, but the extent to which humans contract HEV infection from animals remains to be elucidated.

Significance in drinking-water

The role of contaminated water as a source of HEV has been confirmed, and the presence of the virus in drinking-water constitutes a major health risk. There is no laboratory information on the resistance of the virus to disinfection processes, but data on waterborne outbreaks suggest that HEV may be as resistant as other enteric viruses. Within a water safety plan, control measures to reduce potential risk from HEV should focus on prevention of source water contamination by human and animal waste, followed by adequate treatment and disinfection. The effectiveness of treatment processes used to remove HEV will require validation. Drinking-water supplies

should also be protected from contamination during distribution. Owing to the likelihood that the virus has a higher resistance to disinfection, *E. coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator of the presence/absence of HEV in drinking-water supplies.

Selected bibliography

Pina S et al. (1998) Characterization of a strain of infectious hepatitis E virus isolated from sewage in an area where hepatitis E is not endemic. *Applied and Environmental Microbiology*, 64:4485–4488.

Van der Poel WHM et al. (2001) Hepatitis E virus sequence in swine related to sequences in humans, the Netherlands. *Emerging Infectious Diseases*, 7:970–976.

WHO (2002) Enteric hepatitis viruses. In: *Guidelines for drinking-water quality*, 2nd ed. *Addendum: Microbiological agents in drinking water.* Geneva, World Health Organization, pp. 18–39.

Rotaviruses and orthoreoviruses

General description

Members of the genus *Rotavirus* consist of a segmented double-stranded RNA genome in a non-enveloped icosahedral capsid with a diameter of 50–65 nm. This capsid is surrounded by a double-layered shell, giving the virus the appearance of a wheel—hence the name rotavirus. The diameter of the entire virus is about 80 nm. *Rotavirus* and *Orthoreovirus* are the two genera of the family Reoviridae typically associated with human infection. Orthoreoviruses are readily isolated by cytopathogenic effect on cell cultures. The genus *Rotavirus* is serologically divided into seven groups, A–G, each of which consists of a number of subgroups; some of these subgroups specifically infect humans, whereas others infect a wide spectrum of animals. Groups A–C are found in humans, with group A being the most important human pathogens. Wild-type strains of rotavirus group A are not readily grown in cell culture, but there are a number of PCR-based detection methods available for testing environmental samples.

Human health effects

Human rotaviruses are the most important single cause of infant death in the world. Typically, 50–60% of cases of acute gastroenteritis of hospitalized children throughout the world are caused by human rotaviruses. The viruses infect cells in the villi of the small intestine, with disruption of sodium and glucose transport. Acute infection has an abrupt onset of severe watery diarrhoea with fever, abdominal pain and vomiting; dehydration and metabolic acidosis may develop, and the outcome may be fatal if the infection is not appropriately treated. The burden of disease of rotavirus infections is extremely high. Members of the genus *Orthoreovirus* infect many humans, but they are typical "orphan viruses" and not associated with any meaningful disease.

Source and occurrence

Human rotaviruses are excreted by patients in numbers up to 10^{11} per gram of faeces for periods of about 8 days. This implies that domestic sewage and any environments

polluted with the human faeces are likely to contain large numbers of human rotaviruses. The viruses have been detected in sewage, rivers, lakes and treated drinking-water. Orthoreoviruses generally occur in wastewater in substantial numbers.

Routes of exposure

Human rotaviruses are transmitted by the faecal–oral route. Person-to-person transmission and the inhalation of airborne human rotaviruses or aerosols containing the viruses would appear to play a much more important role than ingestion of contaminated food or water. This is confirmed by the spread of infections in children's wards in hospitals, which takes place much faster than can be accounted for by the ingestion of food or water contaminated by the faeces of infected patients. The role of contaminated water in transmission is lower than expected, given the prevalence of human rotavirus infections and presence in contaminated water. However, occasional waterborne and foodborne outbreaks have been described. Two large outbreaks in China in 1982–1983 were linked to contaminated water supplies.

Significance in drinking-water

Although ingestion of drinking-water is not the most common route of transmission, the presence of human rotaviruses in drinking-water constitutes a public health risk. There is some evidence that the rotaviruses are more resistant to disinfection than other enteric viruses. Within a water safety plan, control measures to reduce potential risk from human rotaviruses should focus on prevention of source water contamination by human waste, followed by adequate treatment and disinfection. The effectiveness of treatment processes used to remove human rotaviruses will require validation. Drinking-water supplies should also be protected from contamination during distribution. Owing to a higher resistance of the viruses to disinfection, *E. coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator of the presence/absence of human rotaviruses in drinking-water supplies.

Selected bibliography

Baggi F, Peduzzi R (2000) Genotyping of rotaviruses in environmental water and stool samples in southern Switzerland by nucleotide sequence analysis of 189 base pairs at the 5′ end of the VP7 gene. *Journal of Clinical Microbiology*, 38:3681–3685.

Gerba CP et al. (1996) Waterborne rotavirus: A risk assessment. *Water Research*, 30:2929–2940.

Hopkins RS et al. (1984) A community waterborne gastroenteritis outbreak: Evidence for rotavirus as the agent. *American Journal of Public Health*, 74:263–265.

Hung T et al. (1984) Waterborne outbreak of rotavirus diarrhoea in adults in China caused by a novel rotavirus. *Lancet*, i:1139–1142.

Sattar SA, Raphael RA, Springthorpe VS (1984) Rotavirus survival in conventionally treated drinking water. *Canadian Journal of Microbiology*, 30:653–656.

11.3 Protozoan pathogens

Protozoa and helminths are among the most common causes of infection and disease in humans and animals. The diseases have a major public health and socioeconomic impact. Water plays an important role in the transmission of some of these pathogens. The control of waterborne transmission presents real challenges, because most of the pathogens produce cysts, oocysts or eggs that are extremely resistant to processes

generally used for the disinfection of water and in some cases can be difficult to remove by filtration processes. Some of these organisms cause "emerging diseases". In the last 30 years, the most notable example of an emerging disease caused by a protozoan pathogen is cryptosporidiosis. Other examples are diseases caused by microsporidia and *Cyclospora*. As evidence for waterborne transmission of "emerging diseases" has been reported relatively recently, some questions about their epidemiology and behaviour in water treatment and disinfection processes remain to be elucidated. It would appear that the role of water in the transmission of this group of pathogens may increase substantially in importance and complexity as human and animal populations grow and the demands for potable drinking-water escalate.

Further information on emerging diseases is provided in *Emerging issues in water and infectious disease* (WHO, 2003) and associated texts.

Acanthamoeba

General description

Acanthamoeba spp. are free-living amoebae (10–50 μm in diameter) common in aquatic environments and one of the prominent protozoa in soil. The genus contains some 20 species, of which *A. castellanii*, *A. polyphaga* and *A. culbertsoni* are known to be human pathogens. However, the taxonomy of the genus may change substantially when evolving molecular biological knowledge is taken into consideration. *Acanthamoeba* has a feeding, replicative trophozoite, which, under unfavourable conditions, such as an anaerobic environment, will develop into a dormant cyst that can withstand extremes of temperature (−20 °C to 56 °C), disinfection and desiccation.

Human health effects

Acanthamoeba culbertsoni causes granulomatous amoebic encephalitis, whereas *A. castellanii* and *A. polyphaga* are associated with acanthamoebic keratitis and acanthamoebic uveitis.

Granulomatous amoebic encephalitis is a multifocal, haemorrhagic and necrotizing encephalitis that is generally seen only in debilitated or immunodeficient persons. It is a rare, but usually fatal, disease. Early symptoms include drowsiness, personality changes, intense headaches, stiff neck, nausea, vomiting, sporadic low fevers, focal neurological changes, hemiparesis and seizures. This is followed by an altered mental status, diplopia, paresis, lethargy, cerebellar ataxia and coma. Death follows within a week to a year after the appearance of the first symptoms, usually as a result of bronchopneumonia. Associated disorders of granulomatous amoebic encephalitis include skin ulcers, liver disease, pneumonitis, renal failure and pharyngitis.

Acanthamoebic keratitis is a painful infection of the cornea and can occur in healthy individuals, especially among contact lens wearers. It is a rare disease that may lead to impaired vision, permanent blindness and loss of the eye. The prevalence of antibodies to *Acanthamoeba* and the detection of the organism in the upper airways of healthy persons suggest that infection may be common with few apparent symptoms in the vast majority of cases.

Source and occurrence

The wide distribution of *Acanthamoeba* in the natural environment makes soil, airborne dust and water all potential sources. *Acanthamoeba* can be found in many types of aquatic environments, including surface water, tap water, swimming pools and contact lens solutions. Depending on the species, *Acanthamoeba* can grow over a wide temperature range in water, with the optimum temperature for pathogenic species being 30 °C. Trophozoites can exist and replicate in water while feeding on bacteria, yeasts and other organisms.

Routes of exposure

Acanthamoebic keratitis has been associated with contact lenses being washed with contaminated home-made saline solutions or contamination of the contact lens containers. Although the source of the contaminating organisms has not been established, tap water is one possibility. Warnings have been issued by a number of health agencies that only sterile water should be used to prepare wash solutions for contact lenses. The mode of transmission of granulomatous amoebic encephalitis has not been established, but water is not considered to be a source of infection. The more likely routes of transmission are via the blood from other sites of colonization, such as skin lesions or lungs.

Significance in drinking-water

Cases of acanthamoebic keratitis have been associated with drinking-water due to use of tap water in preparing solutions for washing contact lenses. Cleaning of contact lenses is not considered to be a normal use for tap water, and a higher-quality water may be required. Compared with *Cryptosporidium* oocysts and *Giardia* cysts, *Acanthamoeba* cysts are relatively large and amenable to removal from raw water by filtration. Reducing the presence of biofilm organisms is likely to reduce food sources and growth of the organism in distribution systems, but the cyst is highly resistant to disinfection. However, as normal uses of drinking-water lack significance as a source of infection, setting a health-based target for *Acanthamoeba* spp. is not warranted.

Selected bibliography

Marshall MM et al. (1997) Waterborne protozoan pathogens. *Clinical Microbiology Reviews*, 10:67–85.

Yagita K, Endo T, De Jonckheere JF (1999) Clustering of *Acanthamoeba* isolates from human eye infections by means of mitochondrial DNA digestion patterns. *Parasitology Research*, 85:284–289.

Balantidium coli

General description

Balantidium coli is a unicellular protozoan parasite with a length up to 200 µm, making it the largest of the human intestinal protozoa. The trophozoites are oval in shape and covered with cilia for motility. The cysts are 60–70 µm in length and resistant to unfavourable environmental conditions, such as pH and temperature extremes. *Balantidium coli* belongs to the largest protozoan group, the ciliates, with about 7200 species, of which only *B. coli* is known to infect humans.

Human health effects

Infections in humans are relatively rare, and most are asymptomatic. The trophozoites invade the mucosa and submucosa of the large intestine and destroy the host cells when multiplying. The multiplying parasites form nests and small abscesses that break down into oval, irregular ulcers. Clinical symptoms may include dysentery similar to amoebiasis, colitis, diarrhoea, nausea, vomiting, headache and anorexia. The infections are generally self-limiting, with complete recovery.

Source and occurrence

Humans seem to be the most important host of *B. coli*, and the organism can be detected in domestic sewage. Animal reservoirs, particularly swine, also contribute to the prevalence of the cysts in the environment. The cysts have been detected in water sources, but the prevalence in tap water is unknown.

Routes of exposure

Transmission of *B. coli* is by the faecal–oral route, from person to person, from contact with infected swine or by consumption of contaminated water or food. One waterborne outbreak of balantidiasis has been reported. This outbreak occurred in 1971 when a drinking-water supply was contaminated with stormwater runoff containing swine faeces after a typhoon.

Significance in drinking-water

Although water does not appear to play an important role in the spread of this organism, one waterborne outbreak is on record. *Balantidium coli* is large and amenable to removal by filtration, but cysts are highly resistant to disinfection. Within a water safety plan, control measures to reduce potential risk from *B. coli* should focus on prevention of source water contamination by human and swine waste, followed by adequate treatment. Owing to resistance to disinfection, *E. coli* (or, alternatively, thermotolerant coliforms) is not a reliable indicator for the presence/absence of *B. coli* in drinking-water supplies.

Selected bibliography

Garcia LS (1999) Flagellates and ciliates. *Clinics in Laboratory Medicine*, 19:621–638.

Walzer PD et al. (1973) Balantidiasis outbreak in Truk. *American Journal of Tropical Medicine and Hygiene*, 22:33–41.

Blastocystis

General description

Blastocystis is a common anaerobic intestinal parasite that was first described in the early 1900s. Despite this long history, there are large gaps in knowledge about the organism, and the issue of pathogenicity remains a subject of some debate. *Blastocystis* spp. have been detected in a range of animal hosts, with isolates from humans identified as *Blastocystis hominis*. However, molecular studies suggest that there is considerable antigenic and genetic heterogeneity within *B. hominis* and *Blastocystis* spp. *Blastocystis hominis* lives in the colon and has several morphological forms, including a faecal cyst that is believed to be the infective form.

Human health effects

Blastocystis hominis is probably the most common protozoan detected in human faecal samples worldwide. Infection occurs in both immunocompetent and immunocompromised individuals. Reported prevalence ranges from 2% to 50%, with the highest rates reported for developing countries with poor environmental hygiene. Infection appears to be more common in adults than in children. However, one study showed that peak infection occurs at 10 years of age and then later in life. Pathogenicity of *B. hominis* is controversial because of the nonspecific symptoms and prevalence of asymptomatic infections. Some case–control studies of individuals with and without symptoms show no difference in the prevalence of *B. hominis*. Symptoms attributed to *B. hominis* include watery or loose stools, diarrhoea, abdominal pain, anal itching, weight loss and excess gas. Duration of infection is not well known; some infections can last for weeks, months or years. In some patients, the symptoms resolve, even though *Blastocystis* can still be detected in stools. It has been suggested that *B. hominis* may be a commensal organism that becomes pathogenic when the host is immunosuppressed, is malnourished or has other infections.

Source and occurrence

The source of human infectious *Blastocystis* is uncertain. *Blastocystis* occurs in many animals, including insects, reptiles, birds and mammals. Some evidence suggests that *Blastocystis* may not be host specific and that animal-to-human transmission is possible. A recent survey in Malaysia showed that animal handlers and abattoir workers were at greater risk of infection than a control group of high-rise city dwellers. *Blastocystis* is excreted as a cyst, which could be environmentally persistent, but there are no data on its survival in the environment. *Blastocystis* has been identified in sewage samples.

Routes of exposure

The routes of transmission have not been established, but the faecal–oral route is considered to be the main mode of transmission. Studies of transmission between mice indicate infection after oral inoculation of faecal cysts. Water and foodborne transmission have been suggested, but not confirmed.

Significance in drinking-water

The role of drinking-water as a source of *Blastocystis* infections has not been established. However, an investigation in Thailand provided evidence of waterborne transmission, and identification in sewage samples suggests potential for this to occur. Within a water safety plan, control measures focused on prevention of source water contamination by human and animal waste should reduce potential risks. There is little information on the removal and/or inactivation of *Blastocystis* by water and wastewater treatment processes. The morphology of *Blastocystis* varies over a broad range, and size estimates vary. Faecal cysts can be as small as 3–10 μm in diameter, and these are likely to be removed by conventional granular media-based filtration methods in a similar manner to *Cryptosporidium* oocysts that are 4–6 μm in diameter. It has been reported that *Blastocystis* cysts are relatively resistant to chlorine. Because of this resistance, *E. coli* (or, alternatively, thermotolerant coliforms) should

not be relied upon as an indicator of the presence/absence of *Blastocystis* in drinking-water sources.

Selected bibliography

Leelayoova S et al. (2004) Evidence of waterborne transmission of *Blastocystis hominis*. *American Journal of Tropical Medicine and Hygiene*, 70:658–662.

Rajah SH et al. (1999) *Blastocystis* in animal handlers. *Parasitology Research*, 85:1032–1033.

Stenzel DJ, Boreham PFL (1996) *Blastocystis hominis* revisited. *Clinical Microbiology Reviews*, 9(4):563–584.

Suresh K, Smith HV, Tan TC (2005) Viable *Blastocystis* cysts in Scottish and Malaysian sewage samples. *Applied and Environmental Microbiology*, 71:5619–5620.

Tan KSW, Singh M, Yap EH (2002) Recent advances in *Blastocystis hominis* research: Hot spots in terra incognita. *International Journal of Parasitology*, 32:789–804.

Cryptosporidium

General description

Cryptosporidium is an obligate, intracellular, coccidian parasite with a complex life cycle including sexual and asexual replication. Thick-walled oocysts with a diameter of 4–6 μm are shed in faeces. The genus *Cryptosporidium* has about 13 species, with human infections predominantly caused by *C. hominis* and the cattle genotype of *C. parvum*. Other *Cryptosporidium* species have been reported to cause infrequent infections. *Cryptosporidium* was discovered to infect humans in 1976, and waterborne transmission was confirmed for the first time in 1984.

Human health effects

Cryptosporidium generally causes self-limiting diarrhoea, sometimes including nausea, vomiting and fever, which usually resolves within a week in normally healthy people, but can last for a month or more. Severity of cryptosporidiosis varies according to age and immune status, and infections in severely immunocompromised people can be life-threatening. The impact of cryptosporidiosis outbreaks is relatively high due to the large numbers of people that may be involved and the associated socioeconomic implications. The total cost of illness associated with the 1993 outbreak in Milwaukee, USA, has been estimated at US$ 96.2 million.

Source and occurrence

A large range of animals are reservoirs of *C. hominis/parvum*, but humans and livestock, particularly young animals, are the most significant source of human infectious organisms. Calves can excrete 10^{10} oocysts per day. Concentrations of oocysts as high as 14 000 per litre for raw sewage and 5800 per litre for surface water have been reported. Oocysts can survive for weeks to months in fresh water. *Cryptosporidium* oocysts have been detected in many drinking-water supplies. However, in most cases, there is little information about whether human infectious species were present. The currently available standard analytical techniques provide an indirect measure of viability and no indication of human infectivity. Oocysts also occur in recreational waters.

Routes of exposure

Cryptosporidium is transmitted by the faecal–oral route. The major route of infection is person-to-person contact. Other sources of infection include the consumption of contaminated food and water and direct contact with infected farm animals and possibly domestic pets. Contaminated drinking-water, recreational water and, to a lesser extent, food have been associated with outbreaks. In 1993, *Cryptosporidium* caused the largest waterborne outbreak of disease on record, when more than 400 000 people were infected by the drinking-water supply of Milwaukee, USA. The infectivity of *Cryptosporidium* oocysts is relatively high. Studies on healthy human volunteers revealed that ingestion of fewer than 10 oocysts can lead to infection.

Significance in drinking-water

The role of drinking-water in the transmission of *Cryptosporidium*, including in large outbreaks, is well established. Attention to these organisms is therefore important. The oocysts are extremely resistant to oxidizing disinfectants such as chlorine, but investigations based on assays for infectivity have shown that UV light irradiation inactivates oocysts. Within a water safety plan, control measures to reduce potential risk from *Cryptosporidium* should focus on prevention of source water contamination by human and livestock waste, adequate treatment and protection of water during distribution. Because of their relatively small size, the oocysts represent a challenge for removal by conventional granular media–based filtration processes. Acceptable removal requires well-designed and well-operated systems. Membrane filtration processes that provide a direct physical barrier may represent a viable alternative for the effective removal of *Cryptosporidium* oocysts. Owing to the exceptional resistance of the oocysts to disinfectants, *E. coli* (or, alternatively, thermotolerant coliforms) cannot be relied upon as an indicator for the presence/absence of *Cryptosporidium* oocysts in drinking-water supplies.

Selected bibliography

Corso PS et al. (2003) Cost of illness in the 1993 waterborne *Cryptosporidium* outbreak, Milwaukee, Wisconsin. *Emerging Infectious Diseases*, 9:426–431.

Haas CN et al. (1996) Risk assessment of *Cryptosporidium parvum* oocysts in drinking water. *Journal of the American Water Works Association*, 88:131–136.

Leav BA, Mackay M, Ward HD (2003) *Cryptosporidium* species: New insight and old challenges. *Clinical Infectious Diseases*, 36:903–908.

Linden KG, Shin G, Sobsey MD (2001) Comparative effectiveness of UV wavelengths for the inactivation of *Cryptosporidium parvum* oocysts in water. *Water Science and Technology*, 43:171–174.

Medema G et al. (2009) *Risk assessment of* Cryptosporidium *in drinking water.* Geneva, World Health Organization (WHO/HSE/WSH/09.04).

Okhuysen PC et al. (1999) Virulence of three distinct *Cryptosporidium parvum* isolates for healthy adults. *Journal of Infectious Diseases*, 180:1275–1281.

Cyclospora cayetanensis

General description

Cyclospora cayetanensis is a single-celled, obligate, intracellular, coccidian protozoan parasite, which belongs to the family Eimeriidae. It produces thick-walled oocysts of

8–10 μm in diameter that are excreted in the faeces of infected individuals. *Cyclospora cayetanensis* is considered an emerging waterborne pathogen.

Human health effects

Sporozoites are released from the oocysts when ingested and penetrate epithelial cells in the small intestine of susceptible individuals. Clinical symptoms of cyclosporiasis include watery diarrhoea, abdominal cramping, weight loss, anorexia, myalgia and occasionally vomiting and/or fever. Relapsing illness often occurs.

Source and occurrence

Humans are the only host identified for this parasite. The unsporulated oocysts pass into the external environment with faeces and undergo sporulation, which is complete in 7–12 days, depending on environmental conditions. Only the sporulated oocysts are infectious. Owing to the lack of a quantification technique, there is limited information on the prevalence of *Cyclospora* in water environments. However, *Cyclospora* has been detected in sewage and water sources.

Routes of exposure

Cyclospora cayetanensis is transmitted by the faecal–oral route. Person-to-person transmission is virtually impossible, because the oocysts must sporulate outside the host to become infectious. The primary routes of exposure are contaminated water and food. The initial source of organisms in foodborne outbreaks has generally not been established, but consumption of food crops irrigated with contaminated water has been implicated in several cases. Drinking-water has also been implicated as a cause of outbreaks. The first report was among staff of a hospital in Chicago, USA, in 1990. The infections were associated with drinking tap water that had possibly been contaminated with stagnant water from a rooftop storage reservoir. Another outbreak was reported from Nepal, where drinking-water consisting of a mixture of river and municipal water was associated with infections in 12 of 14 soldiers.

Significance in drinking-water

Transmission of the pathogens by drinking-water has been confirmed. The oocysts are resistant to disinfection and are not inactivated by chlorination practices generally applied in the production of drinking-water. Within a water safety plan, control measures that can be applied to manage potential risk from *Cyclospora* include prevention of source water contamination by human waste, followed by adequate treatment and protection of water during distribution. Owing to the resistance of the cysts to disinfectants, *E. coli* (or, alternatively, thermotolerant coliforms) cannot be relied upon as an indicator of the presence/absence of *Cyclospora* in drinking-water supplies.

Selected bibliography

Curry A, Smith HV (1998) Emerging pathogens: *Isospora*, *Cyclospora* and microsporidia. *Parasitology*, 117:S143–159.

Dowd SE et al. (2003) Confirmed detection of *Cyclospora cayetanensis*, *Encephalitozoon intestinalis* and *Cryptosporidium parvum* in water used for drinking. *Journal of Water and Health*, 1:117–123.

Goodgame R (2003) Emerging causes of traveller's diarrhea: *Cryptosporidium*, *Cyclospora*, *Isospora* and microsporidia. *Current Infectious Disease Reports*, 5:66–73.

Herwaldt BL (2000) *Cyclospora cayetanensis*: A review, focusing on the outbreaks of cyclosporiasis in the 1990s. *Clinical Infectious Diseases*, 31:1040–1057.

Rabold JG et al. (1994) *Cyclospora* outbreak associated with chlorinated drinking-water [letter]. *Lancet*, 344:1360–1361.

WHO (2002) Protozoan parasites (*Cryptosporidium*, *Giardia*, *Cyclospora*). In: *Guidelines for drinking-water quality*, 2nd ed. *Addendum: Microbiological agents in drinking water*. Geneva, World Health Organization, pp. 70–118.

Entamoeba histolytica

General description

Entamoeba histolytica is the most prevalent intestinal protozoan pathogen worldwide and belongs to the superclass Rhizopoda in the subphylum Sarcodina. *Entamoeba* has a feeding, replicative trophozoite (diameter 10–60 μm), which, under unfavourable conditions, will develop into a dormant cyst (diameter 10–20 μm). Infection is contracted by the ingestion of cysts. Recent studies with RNA and DNA probes demonstrated genetic differences between pathogenic and non-pathogenic *E. histolytica*; the latter has been separated and reclassified as *E. dispar*.

Human health effects

About 85–95% of human infections with *E. histolytica* are asymptomatic. Acute intestinal amoebiasis has an incubation period of 1–14 weeks. Clinical disease results from the penetration of the epithelial cells in the gastrointestinal tract by the amoebic trophozoites. Approximately 10% of infected individuals present with dysentery or colitis. Symptoms of amoebic dysentery include diarrhoea with cramping, lower abdominal pain, low-grade fever and the presence of blood and mucus in the stool. The ulcers produced by the invasion of the trophozoites may deepen into the classic flask-shaped ulcers of amoebic colitis. *Entamoeba histolytica* may invade other parts of the body, such as the liver, lungs and brain, sometimes with fatal outcome.

Source and occurrence

Humans are the reservoir of infection, and there would not appear to be other meaningful animal reservoirs of *E. histolytica*. In the acute phase of infection, patients excrete only trophozoites that are not infectious. Chronic cases and asymptomatic carriers who excrete cysts are more important sources of infection and can discharge up to 1.5×10^7 cysts daily. *Entamoeba histolytica* can be present in sewage and contaminated water. Cysts may remain viable in suitable aquatic environments for several months at low temperature. The potential for waterborne transmission is greater in the tropics, where the carrier rate sometimes exceeds 50%, compared with more temperate regions, where the prevalence in the general population may be less than 10%.

Routes of exposure

Person-to-person contact and contamination of food by infected food handlers appear to be the most significant means of transmission, although contaminated water

also plays a substantial role. Ingestion of faecally contaminated water and consumption of food crops irrigated with contaminated water can both lead to transmission of amoebiasis. Sexual transmission, particularly among male homosexuals, has also been documented.

Significance in drinking-water

The transmission of *E. histolytica* by contaminated drinking-water has been confirmed. The cysts are relatively resistant to disinfection and may not be inactivated by chlorination practices generally applied in the production of drinking-water. Within a water safety plan, control measures that can be applied to manage potential risk from *E. histolytica* include prevention of source water contamination by human waste, followed by adequate treatment and protection of water during distribution. Owing to the resistance of the cysts to disinfectants, *E. coli* (or, alternatively, thermotolerant coliforms) cannot be relied upon as an indicator of the presence/absence of *E. histolytica* in drinking-water supplies.

Selected bibliography

Marshall MM et al. (1997) Waterborne protozoan pathogens. *Clinical Microbiology Reviews*, 10:67–85.

Giardia intestinalis

General description

Giardia spp. are flagellated protozoa that parasitize the gastrointestinal tract of humans and certain animals. The genus *Giardia* consists of a number of species, but human infection (giardiasis) is usually assigned to *G. intestinalis*, also known as *G. lamblia* or *G. duodenalis*. *Giardia* has a relatively simple life cycle consisting of a flagellate trophozoite that multiplies in the gastrointestinal tract and an infective thick-walled cyst that is shed intermittently but in large numbers in faeces. The trophozoites are bilaterally symmetrical and ellipsoidal in shape. The cysts are ovoid in shape and 8–12 μm in diameter.

Human health effects

Giardia has been known as a human parasite for 200 years. After ingestion and excystation of cysts, the trophozoites attach to surfaces of the gastrointestinal tract. Infections in both children and adults may be asymptomatic. In day-care centres, as many as 20% of children may carry *Giardia* and excrete cysts without clinical symptoms. The symptoms of giardiasis may result from damage caused by the trophozoites, although the mechanisms by which *Giardia* causes diarrhoea and intestinal malabsorption remain controversial. Symptoms generally include diarrhoea and abdominal cramps; in severe cases, however, malabsorption deficiencies in the small intestine may be present, mostly among young children. Giardiasis is self-limiting in most cases, but it may be chronic in some patients, lasting more than 1 year, even in otherwise healthy people. Studies on human volunteers revealed that fewer than 10 cysts constitute a meaningful risk of infection.

Source and occurrence

Giardia can multiply in a wide range of animal species and humans, which excrete cysts into the environment. Numbers of cysts as high as 88 000 per litre in raw sewage and 240 per litre in surface water resources have been reported. These cysts are robust and can survive for weeks to months in fresh water. The presence of cysts in raw water sources and drinking-water supplies has been confirmed. However, there is no information on whether human infectious species were present. The currently available standard analytical techniques provide an indirect measure of viability and no indication of human infectivity. Cysts also occur in recreational waters and contaminated food.

Routes of exposure

By far the most common route of transmission of *Giardia* is person-to-person contact, particularly between children. Contaminated drinking-water, recreational water and, to a lesser extent, food have been associated with outbreaks. Animals have been implicated as a source of human infectious *G. intestinalis*, but further investigations are required to determine their role.

Significance in drinking-water

Waterborne outbreaks of giardiasis have been associated with drinking-water supplies for over 30 years; at one stage, *Giardia* was the most commonly identified cause of waterborne outbreaks in the USA. *Giardia* cysts are more resistant than enteric bacteria to oxidative disinfectants such as chlorine, but they are not as resistant as *Cryptosporidium* oocysts. The time required for 90% inactivation at a free chlorine residual of 1 mg/l is about 25–30 minutes. Within a water safety plan, control measures that can be applied to manage potential risk from *Giardia* include prevention of source water contamination by human and animal waste, followed by adequate treatment and disinfection and protection of water during distribution. Owing to the resistance of the cysts to disinfectants, *E. coli* (or, alternatively, thermotolerant coliforms) cannot be relied upon as an indicator of the presence/absence of *Giardia* in drinking-water supplies.

Selected bibliography

LeChevallier MW, Norton WD, Lee RG (1991) Occurrence of *Giardia* and *Cryptosporidium* species in surface water supplies. *Applied and Environmental Microbiology*, 57:2610–2616.

Ong C et al. (1996) Studies of *Giardia* spp. and *Cryptosporidium* spp. in two adjacent watersheds. *Applied and Environmental Microbiology*, 62:2798–2805.

Rimhanen-Finne R et al. (2002) An IC-PCR method for detection of *Cryptosporidium* and *Giardia* in natural surface waters in Finland. *Journal of Microbiological Methods*, 50:299–303.

Slifko TR, Smith HV, Rose JB (2000) Emerging parasite zoonoses associated with water and food. *International Journal for Parasitology*, 30:1379–1393.

Stuart JM et al. (2003) Risk factors for sporadic giardiasis: A case–control study in southwestern England. *Emerging Infectious Diseases*, 9:229–233.

WHO (2002) Protozoan parasites (*Cryptosporidium*, *Giardia*, *Cyclospora*). In: *Guidelines for drinking-water quality*, 2nd ed. *Addendum: Microbiological agents in drinking water*. Geneva, World Health Organization, pp. 70–118.

Isospora belli

General description

Isospora is a coccidian, single-celled, obligate parasite related to *Cryptosporidium* and *Cyclospora*. There are many species of *Isospora* that infect animals, but only *I. belli* is known to infect humans, the only known host for this species. *Isospora belli* is one of the few coccidia that undergo sexual reproduction in the human intestine. Sporulated oocysts are ingested, and, after complete asexual and sexual life cycles in the mucosal epithelium of the upper small intestine, unsporulated oocysts are released in faeces.

Human health effects

Illness caused by *I. belli* is similar to that caused by *Cryptosporidium* and *Giardia*. About 1 week after ingestion of viable oocysts, a low-grade fever, lassitude and malaise may appear, followed soon by mild diarrhoea and vague abdominal pain. The infection is usually self-limited after 1–2 weeks, but occasionally diarrhoea, weight loss and fever may last for 6 weeks to 6 months. Symptomatic isosporiasis is more common in children than in adults. Infection is often associated with immunocompromised patients, in whom symptoms are more severe and likely to be recurrent or chronic, leading to malabsorption and weight loss. Infections are usually sporadic and most common in the tropics and subtropics, although they also occur elsewhere, including industrialized countries. They have been reported from Central and South America, Africa and south-east Asia.

Source and occurrence

Unsporulated oocysts are excreted in the faeces of infected individuals. The oocysts sporulate within 1–2 days in the environment to produce the potentially infectious form of the organism. Few data are available on numbers of oocysts in sewage and raw and treated water sources. This is largely because sensitive and reliable techniques for the quantitative enumeration of oocysts in water environments are not available. Little is known about the survival of oocysts in water and related environments.

Routes of exposure

Poor sanitation and faecally contaminated food and water are the most likely sources of infection, but waterborne transmission has not been confirmed. The oocysts are less likely than *Cryptosporidium* oocysts or *Giardia* cysts to be transmitted directly from person to person, because freshly shed *I. belli* oocysts require 1–2 days in the environment to sporulate before they are capable of infecting humans.

Significance in drinking-water

The characteristics of *I. belli* suggest that illness could be transmitted by contaminated drinking-water supplies, but this has not been confirmed. No information is available on the effectiveness of water treatment processes for removal of *I. belli*, but it is likely that the organism is relatively resistant to disinfectants. It is considerably larger than *Cryptosporidium* and should be easier to remove by filtration. Within a water safety plan, control measures that can be applied to manage potential risk from

I. belli include prevention of source water contamination by human waste, followed by adequate treatment and disinfection and protection of water during distribution. Owing to the likely resistance of the oocysts to disinfectants, *E. coli* (or, alternatively, thermotolerant coliforms) cannot be relied upon as an indicator of the presence/absence of *I. belli* in drinking-water supplies.

Selected bibliography

Ballal M et al. (1999) *Cryptosporidium* and *Isospora belli* diarrhoea in immunocompromised hosts. *Indian Journal of Cancer*, 36:38–42.

Bialek R et al. (2002) Comparison of autofluorescence and iodine staining for detection of *Isospora belli* in feces. *American Journal of Tropical Medicine and Hygiene*, 67:304–305.

Curry A, Smith HV (1998) Emerging pathogens: *Isospora*, *Cyclospora* and microsporidia. *Parasitology*, 117:S143–159.

Goodgame R (2003) Emerging causes of traveller's diarrhea: *Cryptosporidium*, *Cyclospora*, *Isospora* and microsporidia. *Current Infectious Disease Reports*, 5:66–73.

Microsporidia

General description

Microsporidia are eukaryotic obligate intracellular parasites belonging to the phylum Microspora. Although microsporidia were initially considered to be protozoa, the scientific classification is uncertain, with recent studies indicating that they could be classified as fungi. More than 100 microsporidial genera and almost 1000 species have been identified. Infections occur in every major animal group, including vertebrates and invertebrates. A number of genera have been implicated in human infections, including *Enterocytozoon*, *Encephalitozoon* (including *Septata*), *Nosema*, *Pleistophora*, *Vittaforma* and *Trachipleistophora*, as well as a collective group of unclassified microsporidia referred to as microsporidium. Microsporidia are among the smallest eukaryotes. They produce unicellular spores with a diameter of 1.0–4.5 μm and a characteristic coiled polar filament for injecting the sporoplasm into a host cell to initiate infection. Within an infected cell, a complex process of multiplication takes place, and new spores are produced and released in faeces, urine, respiratory secretions or other body fluids, depending on the type of species and the site of infection.

Human health effects

Microsporidia are emerging human pathogens identified predominantly in persons with AIDS, but their ability to cause disease in immunologically normal hosts has been recognized. Reported human infections are globally dispersed and have been documented in persons from all continents. The most common clinical manifestation in AIDS patients is a severe enteritis involving chronic diarrhoea, dehydration and weight loss. Prolonged illness for up to 48 months has been reported. Infections in the general population are less pronounced. *Enterocytozoon* infection generally appears to be limited to intestinal enterocytes and biliary epithelium. *Encephalitozoon* spp. infect a variety of cells, including epithelial and endothelial cells, fibroblasts, kidney tubule cells, macrophages and possibly other cell types. Unusual complications include keratoconjunctivitis, myositis and hepatitis.

Source and occurrence

The sources of microsporidia infecting humans are uncertain. Spores are likely to be excreted in faeces and are also excreted in urine and respiratory secretions. Owing to the lack of a quantification technique, there is limited information on the prevalence of microsporidia spores in water environments. However, microsporidia have been detected in sewage and water sources. Indications are that their numbers in raw sewage may be similar to those of *Cryptosporidium* and *Giardia*, and they may survive in certain water environments for many months. Certain animals, notably swine, may serve as a host for human infectious species.

Routes of exposure

Little is known about transmission of microsporidia. Person-to-person contact and ingestion of spores in water or food contaminated with human faeces or urine are probably important routes of exposure. A waterborne outbreak of microsporidiosis has been reported involving about 200 cases in Lyon, France, during the summer of 1995. However, the source of the organism and faecal contamination of the drinking-water supply were not demonstrated. Transmission by the inhalation of airborne spores or aerosols containing spores seems possible. The role of animals in transmission to humans remains unclear. Epidemiological and experimental studies in mammals suggest that *Encephalitozoon* spp. can be transmitted transplacentally from mother to offspring. No information is available on the infectivity of the spores. However, in view of the infectivity of spores of closely related species, the infectivity of microsporidia may be high.

Significance in drinking-water

Waterborne transmission has been reported, and infection arising from contaminated drinking-water is plausible but unconfirmed. Little is known about the response of microsporidia to water treatment processes. One study has suggested that the spores may be susceptible to chlorine. The small size of the organism is likely to make them difficult to remove by filtration processes. Within a water safety plan, control measures that can be applied to manage potential risk from microsporidia include prevention of source water contamination by human and animal waste, followed by adequate treatment and disinfection and protection of water during distribution. Owing to the lack of information on sensitivity of infectious species of microsporidia to disinfection, the reliability of *E. coli* (or, alternatively, thermotolerant coliforms) as an indicator for the presence/absence of these organisms from drinking-water supplies is unknown.

Selected bibliography

Coote L et al. (2000) Waterborne outbreak of intestinal microsporidiosis in persons with and without human immunodeficiency virus infection. *Journal of Infectious Diseases*, 180:2003–2008.

Dowd SE et al. (2003) Confirmed detection of *Cyclospora cayetanensis*, *Encephalitozoon intestinalis* and *Cryptosporidium parvum* in water used for drinking. *Journal of Water and Health*, 1:117–123.

Goodgame R (2003) Emerging causes of traveller's diarrhea: *Cryptosporidium*, *Cyclospora*, *Isospora* and microsporidia. *Current Infectious Disease Reports*, 5:66–73.

Joynson DHM (1999) Emerging parasitic infections in man. *The Infectious Disease Review*, 1:131–134.

Slifko TR, Smith HV, Rose JB (2000) Emerging parasite zoonoses associated with water and food. *International Journal for Parasitology*, 30:1379–1393.

Naegleria fowleri

General description

Naegleria are free-living amoeboflagellates distributed widely in the environment. There are several species of *Naegleria*, of which *N. fowleri* is the primary infectious species. *Naegleria* spp. exist as a trophozoite, a flagellate and a cyst stage. The trophozoite (10–20 μm) moves by eruptive pseudopod formation, feeding on bacteria, and reproduces by binary fission. The trophozoite can transform into a flagellate stage with two anterior flagella. The flagellate does not divide but reverts to the trophozoite stage. Under adverse conditions, the trophozoite transforms into a circular cyst (7–15 μm), which is resistant to unfavourable conditions.

Human health effects

Naegleria fowleri causes primary amoebic meningoencephalitis in healthy individuals. The amoeba enters the brain by penetrating the olfactory mucosa and cribiform plate. The disease is acute, and patients often die within 5–10 days and before the infectious agent can be diagnosed. Treatment is difficult. Although the infection is rare, new cases are reported every year.

Source and occurrence

Naegleria fowleri is thermophilic and grows well at temperatures up to 45 °C. It occurs naturally in fresh water of suitable temperature, and prevalence is only indirectly related to human activity, inasmuch as such activity may modify temperature or promote bacterial (food source) production. The pathogen has been reported from many countries, usually associated with thermally polluted water environments such as geothermal water or heated swimming pools. However, the organism has been detected in drinking-water supplies, particularly where water temperature can exceed 25–30 °C. Water is the only known source of infection. The first cases of amoebic meningitis were diagnosed in 1965 in Australia and Florida. Since that time, about 100 cases of primary amoebic meningoencephalitis have been reported throughout the world.

Routes of exposure

Infection with *N. fowleri* is almost exclusively contracted by exposure of the nasal passages to contaminated water. Infection is predominantly associated with recreational use of water, including swimming pools and spas, as well as surface waters naturally heated by the sun, industrial cooling waters and geothermal springs. In a limited number of cases, a link to recreational water exposure is lacking. The occurrence of primary amoebic meningoencephalitis is highest during hot summer months, when many people engage in water recreation and when the temperature of water is conducive to growth of the organism. Consumption of contaminated water or food and person-to-person spread have not been reported as routes of transmission.

Significance in drinking-water

Naegleria fowleri has been detected in drinking-water supplies. Although unproven, a direct or indirect role of drinking-water-derived organisms—for example, through use of drinking-water in swimming pools—is possible. Any water supply that seasonally exceeds 30 °C or that continually exceeds 25 °C can potentially support the growth of *N. fowleri*. In such cases, a periodic prospective study would be valuable. Free chlorine or monochloramine residuals in excess of 0.5 mg/l have been shown to control *N. fowleri*, providing the disinfectant persists through the water distribution system. In addition to maintaining persistent disinfectant residuals, other control measures aimed at limiting the presence of biofilm organisms will reduce food sources and hence growth of the organism in distribution systems. Owing to the environmental nature of this amoeba, *E. coli* (or, alternatively, thermotolerant coliforms) cannot be relied upon as an indicator for the presence/absence of *N. fowleri* in drinking-water supplies.

Selected bibliography

Behets J et al. (2003) Detection of *Naegleria* spp. and *Naegleria fowleri*: a comparison of flagellation tests, ELISA and PCR. *Water Science and Technology*, 47:117–122.

Cabanes P-A et al. (2001) Assessing the risk of primary amoebic meningoencephalitis from swimming in the presence of environmental *Naegleria fowleri*. *Applied and Environmental Microbiology*, 67:2927–2931.

Dorsch MM, Cameron AS, Robinson BS (1983) The epidemiology and control of primary amoebic meningoencephalitis with particular reference to South Australia. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 77:372–377.

Martinez AJ, Visvesvara GS (1997) Free-living amphizoic and opportunistic amebas. *Brain Pathology*, 7:583–598.

Parija SC, Jayakeerthee SR (1999) *Naegleria fowleri*: a free living amoeba of emerging medical importance. *Communicable Diseases*, 31:153–159.

Toxoplasma gondii

General description

Toxoplasma gondii is a coccidian parasite, and the cat is the definitive host. Felid animals harbour the parasite in the intestinal tract, where sexual reproduction takes place. The actively multiplying asexual form in the human host is an obligate, intracellular parasite (diameter 3–6 μm) called a tachyzoite. A chronic phase of the disease develops as the tachyzoites transform into slowly replicating bradyzoites, which eventually become cysts in the host tissue. In the natural cycle, mice and rats containing infective cysts are eaten by cats, which host the sexual stage of the parasite. The cyst wall is digested, and bradyzoites penetrate epithelial cells of the small intestine. Several generations of intracellular multiplication lead to the development of microgametes and macrogametes. Fertilization of the latter leads to the development of oocysts that are excreted in faeces as early as 5 days after a cat has ingested the cysts. Oocysts require 1–5 days to sporulate in the environment. Sporulated oocysts and tissue-borne cysts can both cause infections in susceptible hosts.

Human health effects

Toxoplasmosis is usually asymptomatic in humans. In a small percentage of cases, flu-like symptoms, lymphadenopathy and hepatosplenomegaly present 5–23 days after

the ingestion of cysts or oocysts. Dormant cysts, formed in organ tissue after primary infection, can be reactivated when the immune system becomes suppressed, producing disseminated disease involving the central nervous system and lungs and leading to severe neurological disorders or pneumonia. When these infection sites are involved, the disease can be fatal in immunocompromised patients. Congenital toxoplasmosis is mostly asymptomatic, but can produce chorioretinitis, cerebral calcifications, hydrocephalus, severe thrombocytopenia and convulsions. Primary infection during early pregnancy can lead to spontaneous abortion, stillbirth or fetal abnormality.

Source and occurrence

Toxoplasmosis is found worldwide. Estimates indicate that in many parts of the world, 15–30% of lamb and pork meat is infected with cysts. The prevalence of oocyst-shedding cats may be 1%. By the third decade of life, about 50% of the European population is infected, and in France this proportion is close to 80%. *Toxoplasma gondii* oocysts may occur in water sources and supplies contaminated with the faeces of infected cats. Owing to a lack of practical methods for the detection of *T. gondii* oocysts, there is little information on the prevalence of the oocysts in raw and treated water supplies. Details on the survival and behaviour of the oocysts in water environments are also not available. However, qualitative evidence of the presence of oocysts in faecally polluted water has been reported, and results suggest that *T. gondii* oocysts may be as resistant to unfavourable conditions in water environments as the oocysts of related parasites.

Routes of exposure

Both *T. gondii* oocysts that sporulate after excretion by cats and tissue-borne cysts are potentially infectious. Humans can become infected by ingestion of oocysts excreted by cats by direct contact or through contact with contaminated soil or water. Two outbreaks of toxoplasmosis have been associated with consumption of contaminated water. In Panama, creek water contaminated by oocysts from jungle cats was identified as the most likely source of infection, whereas in 1995, an outbreak in Canada was associated with a drinking-water reservoir being contaminated by excreta from domestic or wild cats. A study in Brazil during 1997–1999 identified the consumption of unfiltered drinking-water as a risk factor for *T. gondii* seropositivity. More commonly, humans contract toxoplasmosis through the consumption of undercooked or raw meat and meat products containing *T. gondii* cysts. Transplacental infection also occurs.

Significance in drinking-water

Contaminated drinking-water has been identified as a source of toxoplasmosis outbreaks. Little is known about the response of *T. gondii* to water treatment processes. The oocysts are larger than *Cryptosporidium* oocysts and should be amenable to removal by filtration. Within a water safety plan, control measures to manage potential risk from *T. gondii* should be focused on prevention of source water contamination by wild and domesticated cats. If necessary, the organisms can be removed by filtration. Owing to the lack of information on sensitivity of *T. gondii* to disinfection, the reliability of *E. coli* (or, alternatively, thermotolerant coliforms) as an indicator for the presence/absence of these organisms in drinking-water supplies is unknown.

Selected bibliography

Aramini JJ et al. (1999) Potential contamination of drinking water with *Toxoplasma gondii* oocysts. *Epidemiology and Infection*, 122:305–315.

Bahia-Oliveira LMG et al. (2003) Highly endemic, waterborne toxoplasmosis in North Rio de Janeiro State, Brazil. *Emerging Infectious Diseases*, 9:55–62.

Bowie WR et al. (1997) Outbreak of toxoplasmosis associated with municipal drinking water. The BC Toxoplasma Investigation Team. *Lancet*, 350:173–177.

Kourenti C et al. (2003) Development and application of different methods for the detection of *Toxoplasma gondii* in water. *Applied and Environmental Microbiology*, 69:102–106.

11.4 Helminth pathogens

The word "helminth" comes from the Greek word meaning "worm" and refers to all types of worms, both free-living and parasitic. The major parasitic worms are classified primarily in the phylum Nematoda (roundworms) and the phylum Platyhelminthes (flatworms including trematodes and cestodes). Helminth parasites infect a large number of people and animals worldwide. For most helminths, drinking-water is not a significant route of transmission. There are two exceptions: *Dracunculus medinensis* (guinea worm) and *Fasciola* spp. (*F. hepatica* and *F. gigantica*) (liver flukes). Dracunculiasis and fascioliasis both require intermediate hosts to complete their life cycles but are transmitted through drinking-water by different mechanisms. Other helminthiases can be transmitted through water contact (schistosomiasis) or are associated with the use of untreated wastewater in agriculture (ascariasis, trichuriasis, hookworm infections and strongyloidiasis) but are not usually transmitted through drinking-water.

Dracunculus medinensis

Dracunculus medinensis, commonly known as "guinea worm", belongs to the phylum Nematoda and is the only nematode associated with significant transmission by drinking-water.

The eradication of guinea worm infection from the world by 1995 was a target of the International Drinking Water Supply and Sanitation Decade (1981–1990), and the World Health Assembly formally committed itself to this goal in 1991. The Dracunculus Eradication Programme has achieved a massive reduction in the number of cases. There were an estimated 3.3 million cases in 1986, 625 000 cases in 1990, fewer than 60 000 cases in 2002 and only 3190 cases in 2009, with the majority occurring in Sudan. Dracunculiasis is restricted to a central belt of countries in sub-Saharan Africa.

General description

The *D. medinensis* worms inhabit the cutaneous and subcutaneous tissues of infected individuals, the female reaching a length of up to 700 mm, and the male, 25 mm. When the female is ready to discharge larvae (embryos), its anterior end emerges from a blister or ulcer, usually on the foot or lower limb, and releases large numbers of rhabditiform larvae when the affected part of the body is immersed in water. The larvae can move about in water for approximately 3 days and during that time can

be ingested by many species of *Cyclops* (cyclopoid Copepoda, Crustacea). The larvae penetrate into the haemocoelom, moult twice and are infective to a new host in about 2 weeks. If the *Cyclops* (0.5–2.0 mm) are swallowed in drinking-water, the larvae are released in the stomach, penetrate the intestinal and peritoneal walls and inhabit the subcutaneous tissues.

Human health effects

The onset of symptoms occurs just prior to the local eruption of the worm. The early manifestations of urticaria, erythema, dyspnoea, vomiting, pruritus and giddiness are of an allergic nature. In about 50% of cases, the whole worm is extruded in a few weeks; the lesion then heals rapidly, and disability is of limited duration. In the remaining cases, however, complications ensue, and the track of the worm becomes secondarily infected, leading to a severe inflammatory reaction that may result in abscess formation with disabling pain that lasts for months. Mortality is extremely rare, but permanent disability can result from contractures of tendons and chronic arthritis. The economic impact can be substantial. One study reported an 11% annual reduction in rice production from an area of eastern Nigeria, at a cost of US$ 20 million.

Source and occurrence

Infection with guinea worm is geographically limited to a central belt of countries in sub-Saharan Africa. Drinking-water containing infected *Cyclops* is the only source of infection with *Dracunculus*. The disease typically occurs in rural areas where piped water supplies are not available. Transmission tends to be highly seasonal, depending on changes in water sources. For instance, transmission is highest in the early rainy season in a dry savannah zone of Mali with under 800 mm annual rainfall but in the dry season in the humid savannah area of southern Nigeria with over 1300 mm annual rainfall. The eradication strategy combines a variety of interventions, including integrated surveillance systems, intensified case containment measures, provision of safe water and health education.

Routes of exposure

The only route of exposure is the consumption of drinking-water containing *Cyclops* spp. carrying infectious *Dracunculus* larvae.

Significance in drinking-water

Dracunculus medinensis is the only human parasite that may be eradicated in the near future by the provision of safe drinking-water. Infection can be prevented by a number of relatively simple control measures. These include intervention strategies to prevent the release of *D. medinensis* larvae from female worms in infected patients into water and control of *Cyclops* spp. in water resources by means of fish. Prevention can also be achieved through the provision of boreholes and safe wells. Wells and springs should be surrounded by cement curbings, and bathing and washing in these waters should be avoided. Other control measures include filtration of water carrying infectious *Dracunculus* larvae through a fine mesh cloth to remove *Cyclops* spp. or inactivation of *Cyclops* spp. in drinking-water by treatment with chlorine.

Selected bibliography

Cairncross S, Muller R, Zagaria N (2002) Dracunculiasis (guinea worm disease) and the eradication initiative. *Clinical Microbiology Reviews*, 15:223–246.

Hopkins DR, Ruiz-Tiben E (1991) Strategies for dracunculiasis eradication. *Bulletin of the World Health Organization*, 69:533–540.

Fasciola spp.

Fascioliasis is caused by two trematode species of the genus *Fasciola*: *F. hepatica*, present in Europe, Africa, Asia, the Americas and Oceania, and *F. gigantica*, mainly distributed in Africa and Asia. Human fascioliasis was considered a secondary zoonotic disease until the mid-1990s. In most regions, fascioliasis is a foodborne disease. However, the discovery of floating metacercariae in hyperendemic regions (including the Andean Altiplano region in South America) indicates that drinking-water may be a significant transmission route for fascioliasis in certain locations.

General description

The life cycle of *F. hepatica* and *F. gigantica* takes about 14–23 weeks and requires two hosts. The life cycle comprises four phases. In the first phase, the definitive host ingests metacercariae. The metacercariae excyst in the intestinal tract and then migrate to the liver and bile ducts. After 3–4 months, the flukes attain sexual maturity and produce eggs, which are excreted into the bile and intestine. Adult flukes can live for 9–14 years in the host. In the second phase, the eggs are excreted by the human or animal. Once in fresh water, a miracidium develops inside. In the third phase, miracidia penetrate a snail host and develop into cercaria, which are released into the water. In the fourth and final phase, cercariae swim for a short period of time until they reach a suitable attachment site (aquatic plants), where they encyst to form metacercariae, which become infective within 24 hours. Some metacercariae do not attach to plants but remain floating in the water.

Human health effects

The parasites inhabit the large biliary passages and the gall-bladder. Disease symptoms are different for the acute and chronic phases of the infection. The invasive or acute phase may last from 2 to 4 months and is characterized by symptoms such as dyspepsia, nausea and vomiting, abdominal pain and a high fever (up to 40 °C). Anaemia and allergic responses (e.g. pruritis, urticaria) may also occur. In children, the acute infection can be accompanied by severe symptoms and sometimes causes death. The obstructive or chronic phase (after months to years of infection) may be characterized by painful liver enlargement and in some cases obstructive jaundice, chest pains, loss of weight and cholelithiasis. The most important pathogenic sequelae are hepatic lesions and fibrosis and chronic inflammation of the bile ducts. Immature flukes may deviate during migration, enter other organs and cause ectopic fascioliasis in a range of subcutaneous tissues. Fascioliasis can be treated with triclabendazole.

Source and occurrence

Human cases have been increasing in 51 countries on five continents. Estimates of the numbers of humans with fascioliasis range from 2.4 to 17 million people or even higher, depending on unquantified prevalence in many African and Asian countries.

Analysis of the geographical distribution of human cases shows that the correlation between human fascioliasis and fascioliasis in animals occurs only at a basic level. High prevalences in humans are not necessarily related to areas where fascioliasis is a great veterinary problem. Major health problems associated with fascioliasis occur in Andean countries (the Plurinational State of Bolivia, Peru, Chile, Ecuador), the Caribbean (Cuba), northern Africa (Egypt), the Near East (the Islamic Republic of Iran and neighbouring countries) and western Europe (Portugal, France and Spain).

Routes of exposure

Humans can contract fascioliasis when they ingest infective metacercariae by eating raw aquatic plants (and, in some cases, terrestrial plants, such as lettuce, irrigated with contaminated water), drinking contaminated water, using utensils washed in contaminated water or eating raw liver infected with immature flukes.

Significance in drinking-water

Water is often cited as a human infection source. In the Bolivian Altiplano, 13% of metacercariae isolates are floating. Untreated drinking-water in hyperendemic regions often contains floating metacercariae; for example, a small stream crossing in the Altiplano region of the Plurinational State of Bolivia contained up to 7 metacercariae per 500 ml. The importance of fascioliasis transmission through water is supported by indirect evidence. There are significant positive associations between liver fluke infection and infection by other waterborne protozoans and helminths in Andean countries and in Egypt. In many human hyperendemic areas of the Americas, people do not have a history of eating watercress or other water plants. In the Nile Delta region, people living in houses with piped water had a higher infection risk. Metacercariae are likely to be resistant to chlorine disinfection but should be removed by various filtration processes. For example, in Tiba, Egypt, human prevalence was markedly decreased after filtered water was supplied to specially constructed washing units.

Selected bibliography

Mas-Coma S (2004) Human fascioliasis. In: Cotruvo JA et al., eds. *Waterborne zoonoses: Identification, causes, and controls*. IWA Publishing, London, on behalf of the World Health Organization, Geneva.

Mas-Coma S, Esteban JG, Bargues MD (1999) Epidemiology of human fascioliasis: A review and proposed new classification. *Bulletin of the World Health Organization*, 77(4):340–346.

WHO (1995) *Control of foodborne trematode infections.* Geneva, World Health Organization (WHO Technical Report Series, No. 849).

Free-living nematodes

General description

Nematodes are the most numerous metazoan (many-celled) animals on Earth. Many of them are parasites of insects, plants or animals, including humans. Free-living species are abundant in aquatic environments, both freshwater and saltwater, and soil habitats. Not only are the vast majority of species encountered poorly understood biologically, but there may be thousands more unknown species of nematodes yet to be discovered. Nematodes are structurally simple, with the digestive tract run-

ning from the mouth on the anterior end to the posterior opening near the tail, being characterized as a tube in a tube. Nematodes found in drinking-water systems range in size from 0.1 mm to over 0.6 mm.

About 20 different orders have been distinguished within the phylum Nematoda. Four of these orders (Rhabditida, Tylenchida, Aphelenchida and Dorylaimida) are particularly common in soil. Non-pathogenic free-living nematodes that have been found in drinking-water include *Cheilobus*, *Diplogaster*, *Tobrilus*, *Aphelenchus* and *Rhabditis*.

Human health effects

The presence of free-living nematodes in drinking-water does not necessarily indicate a direct health threat. It has largely been regarded by water suppliers as an "aesthetic" problem, either directly or through their association with discoloured water. High concentrations of nematodes in drinking-water have been reported to impart an unpleasant taste to the drinking-water. The presence of free-living nematodes in drinking-water reduces its acceptability to the consumer.

It has been suggested that free-living nematodes could carry pathogenic bacteria in their gut. Such bacteria would be protected from chlorine disinfection and might therefore present a health hazard. Enterobacteriaceae have been isolated from the microflora in the guts of nematodes taken from a treated water supply and from the raw water from which it was derived. However, they were of non-pathogenic genera. Opportunistic pathogens such as *Nocardia* and *Mycobacterium* may also be carried in the gut of the free-living nematodes. There is no reason to suppose that pathogens would be selectively favoured. The microorganisms present in the gut of the free-living nematodes are much more likely to reflect those in the sediments and biofilms where they are feeding.

In some cases, the motile larvae of parasitic nematodes such as hookworms (*Necator americanus* and *Ancylostoma duodenale*) and threadworms (*Strongyloides stercoralis*) are capable of moving themselves through sand filters or may be introduced into drinking-water during distribution as the result of faecal contamination. There are also some other species of nematodes that theoretically could infect humans through ingestion of contaminated water. Such a source of infection, however, is difficult to prove. *Dracunculus medinensis* is a noticeable parasitic nematode that may occur in drinking-water. This parasite is reported elsewhere in this section.

Source and occurrence

Because free-living nematodes are ubiquitous, they, as an egg or free-living larval or adult form, can enter the drinking-water supply at the storage, treatment, distribution or household level. The concentration of free-living nematodes in the raw water source generally corresponds to the turbidity of the water. The higher the turbidity, the larger the concentration of free-living nematodes there will be.

In warm or even temperate weather, slow sand filters may discharge nematodes—and Oligochaetes (e.g. *Aeolosoma* spp.), insect larvae (e.g. *Chironomus* spp.) and mosquitoes (*Culex* spp.)—by drawdown into the filtered water. Aquatic animals that successfully penetrate drinking-water treatment processes are largely benthic species, living on the bottoms or margins of water bodies.

Routes of exposure

Potential health concerns arise from exposure to the nematodes through ingestion of drinking-water, during recreation and potentially through consumption of fresh vegetables fertilized with sewage that received non-lethal treatment. Distinguishing pathogenic larvae of the hookworm and threadworm from free-living non-pathogenic nematodes in water is difficult and requires special knowledge of nematology.

Significance in drinking-water

Large numbers of nematodes are not normally found in well-maintained, piped drinking-water systems. Eggs or infective larvae from species parasitic to humans (*Ascaris, Trichuris, Ancylostoma, Necator* and *Strongyloides*) and the many non-pathogenic nematodes are not usually present in protected groundwater sources or are generally removed during treatment processes.

In some circumstances, when the water contains a high nutrient or organic matter content and the ambient temperatures are appropriate, it may be possible for free-living nematodes to feed on microbial growth in the biofilms or slimes in treatment processes or in water mains and thus multiply within the system. This is particularly true if drinking-water sources have not been adequately protected, treatment systems are not adequate or not operated and maintained properly, the distribution system is leaking or there are many stagnant areas or "dead zones" in the distribution system. Detection of large numbers of nematodes (live and dead) in drinking-water indicates that there is a problem that needs to be resolved, without necessarily implying a direct health risk.

Selected bibliography

Ainsworth R, ed. (2004) *Safe piped water: Managing microbial water quality in piped distribution systems*. Geneva, World Health Organization.

Brusca RC, Brusca GJ (2002) *Invertebrates,* 2nd ed. Sunderland, MA, Sinauer Associates Inc.

Chang SL, Woodward RL, Kabler PW (1960) Survey of free-living nematodes and amebas in municipal supplies. *Journal of the American Water Works Association,* 52:613.

Endo T, Morishima Y (2004) Major helminth zoonoses in water. In: Cotruvo JA et al., eds. *Waterborne zoonoses: Identification, causes, and controls*. IWA Publishing, London, on behalf of the World Health Organization, Geneva, pp. 291–304.

Evins C, Greaves GF (1979) *Penetration of water treatment works by animals.* Medmenham, Water Research Centre (Technical Report TR 115).

Lupi E, Ricci V, Burrini D (1995) Recovery of bacteria in nematodes from a drinking water supply. *Journal of Water Supply: Research and Technology – Aqua*, 44:212–218.

McSorley R (2007) *Soil-inhabiting nematodes, Phylum Nematoda*. Gainesville, FL, University of Florida, Institute of Food and Agricultural Sciences, Department of Entomology and Nematology.

Mott JB, Mulamoottil G, Harrison AD (1981) A 13-month survey of nematodes at three water treatment plants in southern Ontario, Canada. *Water Research,* 15:729.

Tombes AS et al. (1979) The relationship between rainfall and nematode density in drinking water. *Water Research*, 13:619.

Schistosoma spp.

General description

The genus *Schistosoma* is a member of the class Trematoda, commonly known as trematodes or blood flukes. The life cycle takes about 3–4 months and requires two

hosts. There are about 20 species of *Schistosoma*, and adult flukes are found in humans, other mammals and birds. Unlike other trematode species, *Schistosoma* has two distinct sexual forms. In the most important human schistosomes, adult flukes are 12–20 mm in length and 0.3–0.6 mm in width; male flukes are shorter and thicker than the females. Adult worms of schistosomes reside in the mesenteric blood vessels of the definitive host. Once the worms mature, they mate, and the females produce eggs that are round or oval and vary in length from 50 to 200 μm. Depending on the infecting species, a large number of eggs released by the females reach either the intestine or the bladder and are excreted in faeces or urine, respectively. The eggs hatch in fresh water, and the larvae (miracidia) invade snail hosts, where they undergo asexual reproduction and develop into the infective larvae (cercariae). Cercariae have pear-shaped heads and forked tails and are 400–600 μm in length. They emerge into the water from snails and invade the final hosts, including humans.

Human health effects

Schistosomiasis, also known as bilharzia, is a group of infectious diseases caused by five major species of *Schistosoma* in humans. Intestinal schistosomiasis is caused by *Schistosoma mansoni*, *S. japonicum*, *S. mekongi* and *S. intercalatum*, whereas urinary schistosomiasis is caused by *S. haematobium*. Most of the symptoms of schistosomiasis are the manifestation of the body's reaction to the eggs laid and are due to the intensity of the immune response of the host, not to the worms themselves. Therefore, the symptoms depend on the amount and location of eggs in the human host, and light infections can be asymptomatic. In some people, an initial allergic reaction (Katayama fever), including fever, chills, muscle pains and cough, can begin within 1–2 months of infection immediately before and during initial egg deposition. Chronic infections with *S. mansoni*, *S. japonicum*, *S. intercalatum* and *S. mekongi* result primarily in intestinal and hepatic symptoms, including bloody diarrhoea (bilharzial dysentery), abdominal pains and hepatosplenomegaly, whereas *S. haematobium* infection leads to urinary manifestation, including dysuria and haematuria. Important life-threatening complications that arise from chronic infections include liver fibrosis and portal hypertension. Later development of bladder cancer and renal failure is associated with urinary schistosomiasis. Rarely, eggs are found in the brain or spinal cord and can cause cerebral symptoms, such as seizures and paralysis. Anaemia and malnutrition are also found in young infected cases. Impaired growth, impaired development and poor cognition are signs of morbidity in infected school-age children. In total, more than 200 million people are infected in 75 countries. The number of deaths associated with schistosomiasis is estimated at 20 000 annually. Schistosomiasis is of great public health and socioeconomic importance in developing countries where it is endemic.

Source and occurrence

Schistosomes occur in tropical and subtropical freshwater sources. *Schistosoma mansoni* is found in Africa, the Arabian Peninsula, Brazil, Suriname, the Bolivarian Republic of Venezuela and some Caribbean islands; *S.haematobium* is found in Africa and the Middle East; *S. japonicum* is found in China, the Philippines and the Sulawesi

Island of Indonesia; *S. intercalatum* is found in some countries of Central Africa; and *S. mekongi* is limited to the Mekong River in Cambodia and the Lao People's Democratic Republic. Water resource development projects, including dam construction, have been identified as potential sources of elevated rates of schistosomiasis as a result of the production of increased habitats for freshwater snails. Humans are the principal reservoirs of *S. haematobium*, *S. intercalatum* and *S. mansoni*, although the latter has been reported in rodents. Various animals, such as humans, dogs, cats, rodents, pigs, cattle and water buffalo, are potential reservoirs of *S. japonicum*, whereas humans and dogs are potential reservoirs of *S. mekongi.*

Routes of exposure

Infection occurs through skin penetration when people are exposed to free-swimming cercariae in infested water used for agricultural, domestic and recreational activities. Infection does not occur through consumption of drinking-water. Cercariae of human infectious schistosomes penetrate the skin rapidly and transform into schistosomules, which migrate to the lungs through the circulatory system and develop into adult flukes in the mesenteric veins. If cercariae of non-human infectious schistosomes come in contact with human skin, they do not survive but can cause an inflammatory response, especially in hosts that have been exposed previously. Papular rash, known as schistosome cercarial dermatitis, can result at points of penetration of cercariae. The cercariae of avian schistosomes and probably bovine schistosomes are responsible for a majority of cases of this dermatitis, which has been reported throughout the world. Person-to-person transmission does not occur.

Significance in drinking-water

Most infections occur in poor communities without access to safe drinking-water and adequate sanitation. Ready availability of safe drinking-water contributes to disease prevention by replacing use of infested water for domestic purposes. Within a water safety plan, control measures include prevention of source water contamination by human waste, snail control programmes and adequate treatment. *Schistosoma* cercariae can be removed by filtration and inactivated by chlorination.

Selected bibliography

Boulanger D et al. (1999) The oral route as a potential way of transmission of *Schistosoma bovis* in goats. *Journal of Parasitology*, 85:464–467.

Esrey SA et al. (1991) Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bulletin of the World Health Organization*, 69:609–621.

Giver H et al. (1999) Peroral infection of pigs with *Schistosoma japonicum* cercariae. *Veterinary Parasitology*, 83:161–165.

Hunter JM et al. (1993) *Parasitic diseases in water resources development: The need for intersectoral negotiation.* Geneva, World Health Organization.

Noda S et al. (1997) Effect of piped water supply on human water contact patterns in a *Schistosoma haematobium*–endemic area in Coast Province, Kenya. *American Journal of Tropical Medicine and Hygiene*, 56:118–126.

Steinmann P et al. (2006) Schistosomiasis and water resources development: Systematic review, meta-analysis, and estimates of people at risk. *Lancet Infectious Diseases*, 6:411–425.

Table 11.1 Cyanotoxins produced by cyanobacteria

Toxic species	Cyanotoxins
Anabaena spp.	Microcystins, saxitoxins, anatoxin-a, anatoxin-a(s)
Aphanizomenon spp.	Anatoxin-a, saxitoxins, cylindrospermopsins
Cylindrospermum spp.	Cylindrospermopsins, saxitoxins, anatoxin-a
Lyngbya spp.	Cylindrospermopsins, saxitoxins, lyngbyatoxins
Microcystis spp.	Microcystins, anatoxin-a (minor amounts)
Nodularia spp.	Nodularins
Nostoc spp.	Microcystins
Oscillatoria spp.	Anatoxin-a, microcystins
Planktothrix spp.	Anatoxin-a, homoanatoxin-a, microcystins
Raphidiopsis curvata	Cylindrospermopsins
Umezakia natans	Cylindrospermopsins

11.5 Toxic cyanobacteria

Detailed information on toxic cyanobacteria is available in the supporting document *Toxic cyanobacteria in water* (Annex 1).

General description

Cyanobacteria are photosynthetic bacteria that share some properties with algae. Notably, they possess chlorophyll *a* and liberate oxygen during photosynthesis. The species used for early nomenclature were blue-green in colour; hence, a common term for these organisms is blue-green algae. However, owing to the production of different pigments, there are a large number that are not blue-green, and they can range in colour from blue-green to yellow-brown to red. Most cyanobacteria are phototrophs, but some exhibit heterotrophic growth. They may grow as separate cells or in multicellular filaments or colonies. They can be identified by their morphology to genus or even to species level under a microscope. Some species form surface blooms or scums, whereas others are evenly dispersed throughout the mixed layers of the water body or are bottom dwelling (benthic). Some cyanobacteria possess the ability to regulate their buoyancy via intracellular gas vacuoles, and some species can fix elemental nitrogen dissolved in water. The most notable feature of cyanobacteria in terms of public health impact is that a range of species can produce toxins.

Human health effects

Many cyanobacteria produce potent toxins, as shown in Table 11.1. Cyanobacterial toxins are also discussed in section 8.5.1. Each toxin has specific properties, with distinct concerns including liver damage, neurotoxicity and tumour promotion. Acute symptoms reported after exposure include gastrointestinal disorders, fever and irritations of the skin, ears, eyes, throat and respiratory tract. Cyanobacteria do not multiply in the human body and hence are not infectious.

Source and occurrence

Cyanobacteria are widespread and found in a diverse range of environments, including soils, seawater and, most notably, freshwater environments. Some environmental

conditions, including sunlight, high nutrient levels, low turbulence and warm weather, can promote growth. Depending on the species, this may result in greenish discoloration of water due to a high density of suspended cells and, in some cases, the formation of surface scums. Such cell accumulations may lead to high toxin concentrations.

Routes of exposure

Potential health concerns arise from exposure to the toxins through ingestion of drinking-water, during recreation, through showering and potentially through consumption of algal food supplement tablets. Repeated or chronic exposure is the primary concern for many of the cyanotoxins; in some cases, however, acute toxicity is more important (e.g. lyngbyatoxins and the neurotoxins saxitoxin and anatoxin). Human fatalities have occurred through use of inadequately treated water containing high cyanotoxin levels for renal dialysis. Dermal exposure may lead to irritation of the skin and mucous membranes and possibly also to allergic reactions.

Significance in drinking-water

Cyanobacteria occur in low cell density in most surface waters. However, under environmental conditions supporting their proliferation, high-density "blooms" can occur. Eutrophication (increased biological growth associated with increased nutrients) can support the development of cyanobacterial blooms. Control measures to reduce the potential for "blooms" include catchment management to minimize nutrient inputs to source waters, maintaining flow in regulated rivers and water mixing techniques, both to eliminate stratification and to reduce nutrient release from sediments in reservoirs.

Selected bibliography

Backer LC (2002) Cyanobacterial harmful algal blooms (CyanoHABs): Developing a public health response. *Lake and Reservoir Management*, 18:20–31.

Chorus I, Bartram J, eds (1999) *Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management*. Published by E & FN Spon, London, on behalf of the World Health Organization, Geneva.

Lahti K et al. (2001) Occurrence of microcystins in raw water sources and treated drinking water of Finnish waterworks. *Water Science and Technology*, 43:225–228.

11.6 Indicator organisms

Indicator organisms are used for a range of purposes, including as indicators of:

- faecal pollution in verification and surveillance monitoring;
- the effectiveness of processes such as filtration or disinfection in validation;
- integrity and cleanliness of distribution systems in operational monitoring.

Further discussion on indicator organisms is contained in section 7.4 and the supporting document *Assessing microbial safety of drinking water* (Annex 1).

Total coliform bacteria

General description

Total coliform bacteria include a wide range of aerobic and facultatively anaerobic, Gram-negative, non-spore-forming bacilli capable of growing in the presence of

relatively high concentrations of bile salts with the fermentation of lactose and production of acid or aldehyde within 24 hours at 35–37 °C. *Escherichia coli* and thermotolerant coliforms are a subset of the total coliform group that can ferment lactose at higher temperatures (see below). As part of lactose fermentation, total coliforms produce the enzyme β-galactosidase. Traditionally, coliform bacteria were regarded as belonging to the genera *Escherichia*, *Citrobacter*, *Klebsiella* and *Enterobacter*, but the group is more heterogeneous and includes a wider range of genera, such as *Serratia* and *Hafnia*. The total coliform group includes both faecal and environmental species.

Indicator value

Total coliforms include organisms that can survive and grow in water. Hence, they are not useful as an indicator of faecal pathogens, but they can be used to assess the cleanliness and integrity of distribution systems and the potential presence of biofilms. However, there are better indicators for these purposes. It has been proposed that total coliforms could be used as a disinfection indicator. However, the test for total coliforms is far slower and less reliable than direct measurement of disinfectant residual. In addition, total coliforms are far more sensitive to disinfection than are enteric viruses and protozoa. HPC measurements detect a wider range of microorganisms and are generally considered a better indicator of distribution system integrity and cleanliness.

Source and occurrence

Total coliform bacteria (excluding *E. coli*) occur in both sewage and natural waters. Some of these bacteria are excreted in the faeces of humans and animals, but many coliforms are heterotrophic and able to multiply in water and soil environments. Total coliforms can also survive and grow in water distribution systems, particularly in the presence of biofilms.

Application in practice

Total coliforms are generally measured in 100 ml samples of water. A variety of relatively simple procedures are available based on the production of acid from lactose or the production of the enzyme β-galactosidase. The procedures include membrane filtration followed by incubation of the membranes on selective media at 35–37 °C and counting of colonies after 24 hours. Alternative methods include most probable number procedures using tubes or microtitre plates and presence/absence tests. Field test kits are available.

Significance in drinking-water

Total coliforms should be absent immediately after disinfection, and the presence of these organisms indicates inadequate treatment. The presence of total coliforms in distribution systems and stored water supplies can reveal regrowth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants.

Selected bibliography

Ashbolt NJ, Grabow WOK, Snozzi M (2001) Indicators of microbial water quality. In: Fewtrell L, Bartram J, eds. *Water quality—Guidelines, standards and health: Assessment of risk and*

risk management for water-related infectious disease. London, IWA Publishing, pp. 289–315 (WHO Water Series).

Grabow WOK (1996) Waterborne diseases: Update on water quality assessment and control. *Water SA*, 22:193–202.

Sueiro RA et al. (2001) Evaluation of Coli-ID and MUG Plus media for recovering *Escherichia coli* and other coliform bacteria from groundwater samples. *Water Science and Technology*, 43:213–216.

Escherichia coli and thermotolerant coliform bacteria

General description

Total coliform bacteria that are able to ferment lactose at 44–45 °C are known as thermotolerant coliforms. In most waters, the predominant genus is *Escherichia*, but some types of *Citrobacter*, *Klebsiella* and *Enterobacter* are also thermotolerant. *Escherichia coli* can be differentiated from the other thermotolerant coliforms by the ability to produce indole from tryptophan or by the production of the enzyme β-glucuronidase. *Escherichia coli* is present in very high numbers in human and animal faeces and is rarely found in the absence of faecal pollution, although there is some evidence for growth in tropical soils. Thermotolerant coliform species other than *E. coli* can include environmental organisms.

Indicator value

Escherichia coli is considered the most suitable indicator of faecal contamination. In most circumstances, populations of thermotolerant coliforms are composed predominantly of *E. coli*; as a result, this group is regarded as a less reliable but acceptable indicator of faecal pollution. *Escherichia coli* (or, alternatively, thermotolerant coliforms) is the first organism of choice in monitoring programmes for verification, including surveillance of drinking-water quality. These organisms are also used as disinfection indicators, but testing is far slower and less reliable than direct measurement of disinfectant residual. In addition, *E. coli* is far more sensitive to disinfection than are enteric viruses and protozoa.

Source and occurrence

Escherichia coli occurs in high numbers in human and animal faeces, sewage and water subject to recent faecal pollution. Water temperatures and nutrient conditions present in drinking-water distribution systems are highly unlikely to support the growth of these organisms.

Application in practice

Escherichia coli (or, alternatively, thermotolerant coliforms) are generally measured in 100 ml samples of water. A variety of relatively simple procedures are available based on the production of acid and gas from lactose or the production of the enzyme β-glucuronidase. The procedures include membrane filtration followed by incubation of the membranes on selective media at 44–45 °C and counting of colonies after 24 hours. Alternative methods include most probable number procedures using tubes or microtitre plates and presence/absence tests, some for volumes of water larger than 100 ml. Field test kits are available.

Significance in drinking-water

The presence of *E. coli* (or, alternatively, thermotolerant coliforms) provides evidence of recent faecal contamination, and detection should lead to consideration of further action, which could include further sampling and investigation of potential sources such as inadequate treatment or breaches in distribution system integrity.

Selected bibliography

Ashbolt NJ, Grabow WOK, Snozzi M (2001) Indicators of microbial water quality. In: Fewtrell L, Bartram J, eds. *Water quality—Guidelines, standards and health: Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing, pp. 289–315 (WHO Water Series).

George I et al. (2001) Use of rapid enzymatic assays to study the distribution of faecal coliforms in the Seine river (France). *Water Science and Technology*, 43:77–80.

Grabow WOK (1996) Waterborne diseases: Update on water quality assessment and control. *Water SA*, 22:193–202.

Sueiro RA et al. (2001) Evaluation of Coli-ID and MUG Plus media for recovering *Escherichia coli* and other coliform bacteria from groundwater samples. *Water Science and Technology*, 43:213–216.

Heterotrophic plate counts

A substantial review of the use of HPC is available (see the supporting document *Heterotrophic plate counts and drinking-water safety*; Annex 1).

General description

HPC measurement detects a wide spectrum of heterotrophic microorganisms, including bacteria and fungi, based on the ability of the organisms to grow on rich growth media, without inhibitory or selective agents, over a specified incubation period and at a defined temperature. The spectrum of organisms detected by HPC testing includes organisms sensitive to disinfection processes, such as coliform bacteria; organisms resistant to disinfection, such as spore formers; and organisms that rapidly proliferate in treated water in the absence of residual disinfectants. The tests detect only a small proportion of the microorganisms that are present in water. The population recovered will differ according to the method and conditions applied. Although standard methods have been developed, there is no single universal HPC measurement. A range of media is available, incubation temperatures used vary from 20 °C to 37 °C and incubation periods range from a few hours to 7 days or more.

Indicator value

The test has little value as an indicator of pathogen presence but can be useful in operational monitoring as a treatment and disinfectant indicator, where the objective is to keep numbers as low as possible. In addition, HPC measurement can be used in assessing the cleanliness and integrity of distribution systems and the presence of biofilms.

Source and occurrence

Heterotrophic microorganisms include both members of the natural (typically non-hazardous) microbial flora of water environments and organisms present in a range

of pollution sources. They occur in large numbers in raw water sources. The actual organisms detected by HPC tests vary widely between locations and between consecutive samples. Some drinking-water treatment processes, such as coagulation and sedimentation, reduce the number of HPC organisms in water. However, the organisms proliferate in other treatment processes, such as biologically active carbon and sand filtration. Numbers of HPC organisms are reduced significantly by disinfection practices, such as chlorination, ozonation and UV light irradiation. However, in practice, none of the disinfection processes sterilizes water; under suitable conditions, such as the absence of disinfectant residuals, HPC organisms can grow rapidly. HPC organisms can grow in water and on surfaces in contact with water as biofilms. The principal determinants of growth or "regrowth" are temperature, availability of nutrients, including assimilable organic carbon, lack of disinfectant residual and stagnation.

Application in practice

No sophisticated laboratory facilities or highly trained staff are required. Results on simple aerobically incubated agar plates are available within hours to days, depending on the characteristics of the procedure used.

Significance in drinking-water

After disinfection, numbers would be expected to be low; for most uses of HPC test results, however, actual numbers are of less value than changes in numbers at particular locations. In distribution systems, increasing numbers can indicate a deterioration in cleanliness, possibly stagnation and the potential development of biofilms. HPC can include potentially "opportunistic" pathogens such as *Acinetobacter*, *Aeromonas*, *Flavobacterium*, *Klebsiella*, *Moraxella*, *Serratia*, *Pseudomonas* and *Xanthomonas*. However, there is no evidence of an association of any of these organisms with gastrointestinal infection through ingestion of drinking-water in the general population.

Selected bibliography

Ashbolt NJ, Grabow WOK, Snozzi M (2001) Indicators of microbial water quality. In: Fewtrell L, Bartram J, eds. *Water quality—Guidelines, standards and health: Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing, pp. 289–315 (WHO Water Series).

Bartram J et al., eds (2003) *Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health*. London, IWA Publishing (WHO Emerging Issues in Water and Infectious Disease Series).

Intestinal enterococci

General description

Intestinal enterococci are a subgroup of the larger group of organisms defined as faecal streptococci, comprising species of the genus *Streptococcus*. These bacteria are Gram-positive and relatively tolerant of sodium chloride and alkaline pH levels. They are facultatively anaerobic and occur singly, in pairs or as short chains. Faecal streptococci including intestinal enterococci all give a positive reaction with Lancefield's

Group D antisera and have been isolated from the faeces of warm-blooded animals. The subgroup intestinal enterococci consists of the species *Enterococcus faecalis*, *E. faecium*, *E. durans* and *E. hirae.* This group was separated from the rest of the faecal streptococci because they are relatively specific for faecal pollution. However, some intestinal enterococci isolated from water may occasionally also originate from other habitats, including soil, in the absence of faecal pollution.

Indicator value

The intestinal enterococci group can be used as an indicator of faecal pollution. Most species do not multiply in water environments. The numbers of intestinal enterococci in human faeces are generally about an order of magnitude lower than those of *E. coli.* Important advantages of this group are that they tend to survive longer in water environments than *E. coli* (or thermotolerant coliforms), are more resistant to drying and are more resistant to chlorination. Intestinal enterococci have been used in testing of raw water as an indicator of faecal pathogens that survive longer than *E. coli* and in drinking-water to augment testing for *E. coli*. In addition, they have been used to test water quality after repairs to distribution systems or after new mains have been laid.

Source and occurrence

Intestinal enterococci are typically excreted in the faeces of humans and other warm-blooded animals. Some members of the group have also been detected in soil in the absence of faecal contamination. Intestinal enterococci are present in large numbers in sewage and water environments polluted by sewage or wastes from humans and animals.

Application in practice

Enterococci are detectable by simple, inexpensive cultural methods that require basic bacteriology laboratory facilities. Commonly used methods include membrane filtration with incubation of membranes on selective media and counting of colonies after incubation at 35–37 °C for 48 hours. Other methods include a most probable number technique using microtitre plates where detection is based on the ability of intestinal enterococci to hydrolyse 4-methyl-umbelliferyl-β-D-glucoside in the presence of thallium acetate and nalidixic acid within 36 hours at 41 °C.

Significance in drinking-water

The presence of intestinal enterococci provides evidence of recent faecal contamination, and detection should lead to consideration of further action, which could include further sampling and investigation of potential sources such as inadequate treatment or breaches in distribution system integrity.

Selected bibliography

Ashbolt NJ, Grabow WOK, Snozzi M (2001) Indicators of microbial water quality. In: Fewtrell L, Bartram J, eds. *Water quality—Guidelines, standards and health: Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing, pp. 289–315 (WHO Water Series).

Grabow WOK (1996) Waterborne diseases: Update on water quality assessment and control. *Water SA*, 22:193–202.

Junco TT et al. (2001) Identification and antibiotic resistance of faecal enterococci isolated from water samples. *International Journal of Hygiene and Environmental Health*, 203:363–368.

Pinto B et al. (1999) Characterization of "faecal streptococci" as indicators of faecal pollution and distribution in the environment. *Letters in Applied Microbiology*, 29:258–263.

Clostridium perfringens

General description

Clostridium spp. are Gram-positive, anaerobic, sulfite-reducing bacilli. They produce spores that are exceptionally resistant to unfavourable conditions in water environments, including UV irradiation, temperature and pH extremes, and disinfection processes, such as chlorination. The characteristic species of the genus, *C. perfringens*, is a member of the normal intestinal flora of 13–35% of humans and other warm-blooded animals. Other species are not exclusively of faecal origin. Like *E. coli*, *C. perfringens* does not multiply in most water environments and is a highly specific indicator of faecal pollution.

Indicator value

In view of the exceptional resistance of *C. perfringens* spores to disinfection processes and other unfavourable environmental conditions, *C. perfringens* has been proposed as an indicator of protozoa in treated drinking-water supplies. In addition, *C. perfringens* can serve as an indicator of faecal pollution that took place previously and hence can indicate sources liable to intermittent contamination. The evidence that *Clostridium* is a reliable indicator for enteric viruses is limited and inconsistent, largely based on one study of reductions by drinking-water treatment. Results should be treated with some caution, as the exceptionally long survival times of its spores are likely to far exceed those of enteric pathogens. *Clostridium perfringens* spores are smaller than protozoan (oo)cysts and may be useful indicators of the effectiveness of filtration processes.

Source and occurrence

Clostridium perfringens and its spores are virtually always present in sewage. The organism does not multiply in water environments. *Clostridium perfringens* is present more often and in higher numbers in the faeces of some animals, such as dogs, than in the faeces of humans and less often in the faeces of many other warm-blooded animals. The numbers excreted in faeces are normally substantially lower than those of *E. coli*.

Application in practice

Vegetative cells and spores of *C. perfringens* are usually detected by membrane filtration techniques in which membranes are incubated on selective media under strict anaerobic conditions. These detection techniques are not as simple and inexpensive as those for other indicators, such as *E. coli* and intestinal enterococci.

Significance in drinking-water

The presence of *C. perfringens* in drinking-water can be an indicator of intermittent faecal contamination. Potential sources of contamination should be investigated.

Filtration processes designed to remove enteric viruses or protozoa should also remove *C. perfringens*. Detection in water immediately after treatment should lead to investigation of filtration plant performance.

Selected bibliography

Araujo M et al. (2001) Evaluation of fluorogenic TSC agar for recovering *Clostridium perfringens* in groundwater samples. *Water Science and Technology*, 43:201–204.

Ashbolt NJ, Grabow WOK, Snozzi M (2001) Indicators of microbial water quality. In: Fewtrell L, Bartram J, eds. *Water quality—Guidelines, standards and health: Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing, pp. 289–315 (WHO Water Series).

Nieminski EC, Bellamy WD, Moss LR (2000) Using surrogates to improve plant performance. *Journal of the American Water Works Association*, 92(3):67–78.

Payment P, Franco E (1993) *Clostridium perfringens* and somatic coliphages as indicators of the efficiency of drinking-water treatment for viruses and protozoan cysts. *Applied and Environmental Microbiology*, 59:2418–2424.

Coliphages

General description

Bacteriophages (phages) are viruses that use only bacteria as hosts for replication. Coliphages use *E. coli* and closely related species as hosts and hence can be released by these bacterial hosts into the faeces of humans and other warm-blooded animals. Coliphages used in water quality assessment are divided into the major groups of somatic coliphages and F-RNA coliphages. Differences between the two groups include the route of infection.

Somatic coliphages initiate infection by attaching to receptors permanently located on the cell wall of hosts. They replicate more frequently in the gastrointestinal tract of warm-blooded animals but can also replicate in water environments. Somatic coliphages consist of a wide range of phages (members of the phage families Myoviridae, Siphoviridae, Podoviridae and Microviridae) with a spectrum of morphological types.

F-RNA coliphages initiate infection by attaching to fertility (F-, sex) fimbriae on *E. coli* hosts. These F-fimbriae are produced only by bacteria carrying the fertility (F-) plasmid. As F-fimbriae are produced only in the logarithmic growth phase at temperatures above 30 °C, F-RNA phages are not likely to replicate in environments other than the gastrointestinal tract of warm-blooded animals. F-RNA coliphages comprise a restricted group of closely related phages, which belong to the family Leviviridae, and consist of a single-stranded RNA genome and an icosahedral capsid that is morphologically similar to that of picornaviruses. F-RNA coliphages have been divided into serological types I–IV, which can be identified as genotypes by molecular techniques such as gene probe hybridization. Members of groups I and IV have to date been found exclusively in (non-human) animal faeces, and group III in human faeces. Group II phages have been detected in human faeces and no animal faeces other than about 28% of porcine faeces. This specificity, which is not fully understood, offers a potential tool to distinguish between faecal pollution of human and animal origin under certain conditions and limitations.

Indicator value

Phages share many properties with human viruses, notably composition, morphology, structure and mode of replication. As a result, coliphages are useful models or surrogates to assess the behaviour of enteric viruses in water environments and the sensitivity to treatment and disinfection processes. In this regard, they are superior to faecal bacteria and could be considered for inclusion in verification and surveillance monitoring where source waters are known to be affected by human faecal waste. However, there is no direct correlation between numbers of coliphages and numbers of enteric viruses. In addition, coliphages cannot be absolutely relied upon as an indicator for enteric viruses. This has been confirmed by the isolation of enteric viruses from treated and disinfected drinking-water supplies that yielded negative results in conventional tests for coliphages.

F-RNA coliphages provide a more specific indicator of faecal pollution than somatic phages. In addition, F-RNA coliphages are better indicators of the behaviour of enteric viruses in water environments and their response to treatment and disinfection processes than are somatic coliphages. This has been confirmed by studies in which the behaviour and survival of F-RNA coliphages, somatic phages, faecal bacteria and enteric viruses have been compared. Available data indicate that the specificity of F-RNA serogroups (genotypes) for human and animal excreta may prove useful in the distinction between faecal pollution of human and animal origin. However, there are shortcomings and conflicting data that need to be resolved, and the extent to which this tool can be applied in practice remains to be elucidated. Owing to the limitations of coliphages, they are best used in laboratory investigations, pilot trials and possibly validation testing. They are not suitable for operational or verification (including surveillance) monitoring.

Source and occurrence

Coliphages are excreted by humans and animals in relatively low numbers. As a result of their respective modes of replication and host specificity, somatic coliphages are generally excreted by most humans and animals, whereas F-RNA coliphages are excreted by a variable and generally lower percentage of humans and animals. Available data indicate that in some communities, F-RNA phages are detectable in 10% of human, 45% of bovine, 60% of porcine and 70% of poultry faecal specimens. Somatic coliphages have been found to generally outnumber F-RNA phages in water environments by a factor of about 5 and cytopathogenic human viruses by a factor of about 500, although these ratios vary considerably. Sewage contains somatic coliphages in numbers of the order of 10^6–10^8 per litre; in one study, slaughterhouse wastewater was found to contain somatic coliphages in numbers up to 10^{10} per litre. There are indications that they may multiply in sewage, and somatic coliphages may multiply in natural water environments using saprophytic hosts. Somatic phages and F-RNA phages have been detected in numbers up to 10^5 per litre in lake and river water.

Application in practice

Somatic coliphages are detectable by relatively simple and inexpensive plaque assays, which yield results within 24 hours. Plaque assays for F-RNA coliphages are not quite

as simple, because the culture of host bacteria has to be in the logarithmic growth phase at a temperature above 30 °C to ensure that F-fimbriae are present. Plaque assays using large petri dishes have been designed for the quantitative enumeration of plaques in 100 ml samples, and presence/absence tests have been developed for volumes of water of 500 ml or more.

Significance in drinking-water

As coliphages typically replicate in the gastrointestinal tract of humans and warm-blooded animals, their presence in drinking-water provides an indicator of faecal pollution and hence the potential presence of enteric viruses and possibly also other pathogens. The presence of coliphages in drinking-water also indicates shortcomings in treatment and disinfection processes designed to remove enteric viruses. F-RNA coliphages provide a more specific indicator for faecal pollution. The absence of coliphages from treated drinking-water supplies does not confirm the absence of pathogens such as enteric viruses and protozoan parasites.

Selected bibliography

Ashbolt NJ, Grabow WOK, Snozzi M (2001) Indicators of microbial water quality. In: Fewtrell L, Bartram J, eds. *Water quality—Guidelines, standards and health: Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing, pp. 289–315 (WHO Water Series).

Grabow WOK (2001) Bacteriophages: Update on application as models for viruses in water. *Water SA*, 27:251–268.

Mooijman KA et al. (2001) Optimisation of the ISO-method on enumeration of somatic coliphages (draft ISO 10705-2). *Water Science and Technology*, 43:205–208.

Schaper M et al. (2002) Distribution of genotypes of F-specific RNA bacteriophages in human and non-human sources of faecal pollution in South Africa and Spain. *Journal of Applied Microbiology*, 92:657–667.

Storey MV, Ashbolt NJ (2001) Persistence of two model enteric viruses (B40-8 and MS-2 bacteriophages) in water distribution pipe biofilms. *Water Science and Technology*, 43:133–138.

Bacteroides fragilis phages

General description

The bacterial genus *Bacteroides* inhabits the human gastrointestinal tract in greater numbers than *E. coli*. Faeces can contain 10^9–10^{10} *Bacteroides* per gram compared with 10^6–10^8 *E. coli* per gram. *Bacteroides* are rapidly inactivated by environmental oxygen levels, but *Bacteroides* bacteriophages are resistant to unfavourable conditions. Two groups of *B. fragilis* phages are used as indicators in water quality assessment. One is a restricted group of phages that specifically uses *B. fragilis* strain HSP40 as host. This group of phages appears unique, because it is found only in human faeces and not in faeces of animals. The numbers of these phages in sewage appear to be relatively low, and they are almost absent in some geographical areas. The *B. fragilis* HSP40 phages belong to the family Siphoviridae, with flexible non-contractile tails, double-stranded DNA and capsids with a diameter of up to 60 nm. The second group of *Bacteroides* phages used as indicators is those that use *B. fragilis* strain RYC2056 as a host. This

group includes a substantially wider spectrum of phages, occurring in the faeces of humans and many animals. The numbers of these phages in sewage are generally substantially higher than those of *B. fragilis* HSP40 phages.

Indicator value

Bacteroides bacteriophages have been proposed as a possible indicator of faecal pollution as a result of their specific association with faecal material and exceptional resistance to environmental conditions. In particular, *B. fragilis* HSP40 phages are found only in human faeces. *Bacteroides fragilis* phage B40-8, a typical member of the group of *B. fragilis* HSP40 phages, has been found to be more resistant to inactivation by chlorine than poliovirus type 1, simian rotavirus SA11, coliphage f2, *E. coli* and *Streptococcus faecalis*. *Bacteroides fragilis* strain RYC2056 phages seem to be likewise relatively resistant to disinfection. Indicator shortcomings of *B. fragilis* phages include relatively low numbers in sewage and polluted water environments. This applies in particular to *B. fragilis* HSP40 phages. Human enteric viruses have been detected in drinking-water supplies that yielded negative results in conventional tests for *B. fragilis* HSP40 phages. Owing to the limitations of *Bacteroides* bacteriophages, they are best used in laboratory investigations, pilot trials and possibly validation testing.

Source and occurrence

Bacteroides fragilis HSP40 phages are excreted by about 10–20% of humans in certain parts of the world; consequently, their numbers in sewage are substantially lower than those of somatic and even F-RNA coliphages. A mean count of 67 *B. fragilis* HSP40 phages per litre in a sewage-polluted river has been reported. In some parts of the world, *B. fragilis* HSP40 phages would appear not to be detectable in sewage at all. Phages using *B. fragilis* RYC2056 as host are excreted in larger numbers and seem to occur more universally. On average, these phages are excreted by more than 25% of humans. In a survey of water environments, *B. fragilis* HSP40 phages have been found to outnumber cytopathogenic enteric viruses on average by only about 5-fold. Theoretically, wastewaters could be expected to contain higher levels of *B. fragilis* phages than those detected. The reason for the discrepancy may be due to failure in maintaining sufficiently anaerobic conditions during the performance of plaque assays. Improvement of detection methods may result in the recording of higher numbers of *B. fragilis* phages in sewage and polluted water environments.

Application in practice

Disadvantages of *B. fragilis* phages are that the detection methods are more complex and expensive than those for coliphages. Costs are increased by the need to use antibiotics for purposes of selection and to incubate cultures and plaque assays under absolute anaerobic conditions. Results of plaque assays are usually available after about 24 hours compared with about 8 hours for coliphages.

Significance in drinking-water

The presence of *B. fragilis* phages in drinking-water is sound evidence of faecal pollution as well as shortcomings in water treatment and disinfection processes. In addition, the presence of *B. fragilis* HSP40 phages strongly indicates faecal pollution of

human origin. However, *B. fragilis* phages occur in relatively low numbers in sewage, polluted water environments and drinking-water supplies. This implies that the absence of *B. fragilis* phages from treated drinking-water supplies does not confirm the absence of pathogens such as enteric viruses and protozoan parasites.

Selected bibliography

Bradley G et al. (1999) Distribution of the human faecal bacterium *Bacteroides fragilis* and their relationship to current sewage pollution indicators in bathing waters. *Journal of Applied Microbiology*, 85(Suppl.):90S–100S.

Grabow WOK (2001) Bacteriophages: Update on application as models for viruses in water. *Water SA*, 27:251–268.

Puig A et al. (1999) Diversity of *Bacteroides fragilis* strains in their capacity to recover phages from human and animal wastes and from fecally polluted wastewater. *Applied and Environmental Microbiology*, 65:1772–1776.

Storey MV, Ashbolt NJ (2001) Persistence of two model enteric viruses (B40-8 and MS-2 bacteriophages) in water distribution pipe biofilms. *Water Science and Technology*, 43:133–138.

Tartera C, Lucena F, Jofre J (1989) Human origin of *Bacteroides fragilis* bacteriophages present in the environment. *Applied and Environmental Microbiology*, 10:2696–2701.

Enteric viruses

General description

The viruses referred to here are a combined group of those that infect the human gastrointestinal tract and are predominantly transmitted by the faecal–oral route. Well-known members of this group include the enteroviruses, astroviruses, enteric adenoviruses, orthoreoviruses, rotaviruses, caliciviruses and hepatitis A and E viruses. The enteric viruses cover a wide spectrum of viruses, members of which are a major cause of morbidity and mortality worldwide. Members of the group of enteric viruses differ with regard to structure, composition, nucleic acid and morphology. There are also differences in the numbers and frequency of excretion, survival in the environment and resistance to water treatment processes. Enteric viruses have robust capsids that enable them to survive unfavourable conditions in the environment as well as allowing passage through the acidic and proteolytic conditions in the stomach on their way to the duodenum, where they infect susceptible epithelial cells.

Indicator value

The use of enteric viruses as indicator organisms is based on the shortcomings of the existing choices. The survival of faecal bacteria in water environments and the sensitivity to treatment and disinfection processes differ substantially from those of enteric viruses. Monitoring based on one or more representatives of the large group of enteric viruses themselves would therefore be more valuable for assessment of the presence of any of the enteric viruses in water and the response to control measures.

Source and occurrence

Enteric viruses are excreted by individuals worldwide at a frequency and in numbers that result in many of these viruses being universally present in substantial numbers

in wastewater. However, the prevalence of individual members may vary to a large extent as a result of variations in rates of infection and excretion. Much higher numbers would be present during outbreaks.

Application in practice

Practical methods are not yet available for the routine monitoring of water supplies for a broad spectrum of enteric viruses. Viruses that are more readily detectable include members of the enterovirus, adenovirus and orthoreovirus groups. These viruses occur in polluted environments in relatively high numbers and can be detected by reasonably practical and moderate-cost techniques based on cytopathogenic effect in cell culture that yield results within 3–12 days (depending on the type of virus). In addition, progress in technology and expertise is decreasing costs. The cost for the recovery of enteric viruses from large volumes of drinking-water has been reduced extensively. Some techniques—for instance, those based on glass wool adsorption–elution—are inexpensive. The cost of cell culture procedures has also been reduced. Consequently, the cost of testing drinking-water supplies for cytopathogenic viruses has become acceptable for certain purposes. Testing could be used to validate the effectiveness of treatment processes and, in certain circumstances, as part of specific investigations to verify the performance of processes. The incubation times, cost and relative complexity of testing mean that enteric virus testing is not suitable for operational or verification (including surveillance) monitoring. Orthoreoviruses, and at least the vaccine strains of polioviruses detected in many water environments, also have the advantage of not constituting a health risk to laboratory workers.

Significance in drinking-water

The presence of any enteric viruses in drinking-water should be regarded as an indicator for the potential presence of other enteric viruses, is conclusive evidence of faecal pollution and also provides evidence of shortcomings in water treatment and disinfection processes.

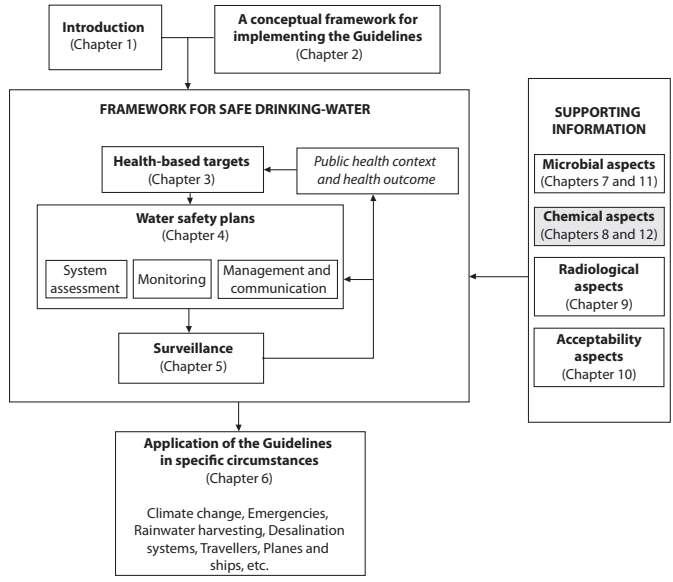
Selected bibliography

Ashbolt NJ, Grabow WOK, Snozzi M (2001) Indicators of microbial water quality. In: Fewtrell L, Bartram J, eds. *Water quality—Guidelines, standards and health: Assessment of risk and risk management for water-related infectious disease*. London, IWA Publishing, pp. 289–315 (WHO Water Series).

Grabow WOK, Taylor MB, de Villiers JC (2001) New methods for the detection of viruses: Call for review of drinking-water quality guidelines. *Water Science and Technology,* 43:1–8.

12
Chemical fact sheets

The background documents referred to in this chapter (as the principal reference for each fact sheet) may be found on the Water, Sanitation, Hygiene and Health web site at http://www.who.int/water_sanitation_health/dwq/chemicals/en/index.html. A complete list of references cited in this chapter, including the background documents for each chemical, is provided in Annex 2.



12.1 Chemical contaminants in drinking-water

Acrylamide

Residual acrylamide monomer occurs in polyacrylamide coagulants used in the treatment of drinking-water. In general, the maximum authorized dose of polymer is 1 mg/l. At a monomer content of 0.05%, this corresponds to a maximum theoretical concentration of 0.5 µg/l of the monomer in water. Practical concentrations may be lower by a factor of 2–3. This applies to the anionic and non-ionic polyacrylamides, but residual levels from cationic polyacrylamides may be higher. Polyacrylamides are also used as grouting agents in the construction of drinking-water reservoirs and wells. Human exposure is much greater from food than from drinking-water, owing to the formation of acrylamide in foods (e.g. breads, fried and roasted foods) cooked at high temperatures.

Guideline value	0.0005 mg/l (0.5 µg/l)
Occurrence	Concentrations up to a few micrograms per litre occasionally detected in tap water
Basis of guideline value derivation	Combined mammary, thyroid and uterine tumours observed in female rats in a drinking-water study, and using the linearized multistage model
Limit of detection	0.032 µg/l by gas chromatography (GC); 0.2 µg/l by high-performance liquid chromatography (HPLC); 10 µg/l by HPLC with ultraviolet (UV) detection
Treatment performance	Conventional treatment processes do not remove acrylamide. Acrylamide concentrations in drinking-water are usually controlled by limiting either the acrylamide content of polyacrylamide flocculants or the dose used, or both. Advances in analytical techniques are also beginning to allow control by direct measurement (see background document).
Additional comments	Every effort should be made to limit free acrylamide monomer in polyacrylamide used for water treatment, and water suppliers should also make every effort to ensure that residual acrylamide in drinking-water is kept as low as is technically feasible. In particular, if acrylamide is controlled by limiting the amount dosed, overdosing should always be avoided.
Assessment date	2011
Principal references	FAO/WHO (2011) *Evaluation of certain contaminants in food* WHO (2011) *Acrylamide in drinking-water*

Following ingestion, acrylamide is readily absorbed from the gastrointestinal tract and widely distributed in body fluids. Acrylamide can cross the placenta. It is neurotoxic, affects germ cells and impairs reproductive function. In mutagenicity assays, acrylamide was negative in the Ames test but induced gene mutations in mammalian cells and chromosomal aberrations in vitro and in vivo. In a long-term carcinogenicity study in rats exposed via drinking-water, acrylamide induced scrotal, thyroid and adrenal tumours in males and mammary, thyroid and uterine tumours in females. The International Agency for Research on Cancer (IARC) has placed acrylamide in Group 2A (probably carcinogenic to humans). The Joint Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Expert Committee on Food Additives (JECFA) has recently noted concerns regarding the carcinogenicity and neurotoxicity of acrylamide and concluded that dietary exposure should be reduced to as low a level as technically achievable. Recent data have shown that exposure to acrylamide from cooked food is much higher than previously thought. As it is difficult to control the intake of acrylamide from food, it is very important that the acrylamide content of polyacrylamide used as a coagulant aid in water treatment, the most important source of drinking-water contamination by acrylamide, be as low as possible and that polyacrylamide not be overdosed in an attempt to take a shortcut to improving coagulation.

Alachlor

Alachlor (Chemical Abstracts Service [CAS] No. 15972-60-8) is a pre-emergence and post-emergence herbicide used to control annual grasses and many broad-leaved weeds

in maize and a number of other crops. It is lost from soil mainly through volatilization, photodegradation and biodegradation. Many alachlor degradation products have been identified in soil. Alachlor was included in the Prior Informed Consent procedure of the Rotterdam Convention on the basis of the final regulatory actions taken by the European Community and by Canada to ban alachlor as a pesticide.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Has been detected in groundwater and surface water; has also been detected in drinking-water at levels below 0.002 mg/l
Basis of guideline value derivation	Calculated by applying the linearized multistage model to data on the incidence of nasal tumours in rats
Limit of detection	0.1 µg/l by gas–liquid chromatography with electrolytic conductivity detection in the nitrogen mode or by capillary column GC with a nitrogen–phosphorus detector
Treatment performance	0.001 mg/l should be achievable using granular activated carbon (GAC)
Assessment date	1993
Principal reference	WHO (2003) *Alachlor in drinking-water*

On the basis of available experimental data, evidence for the genotoxicity of alachlor is considered to be equivocal. However, a metabolite of alachlor, 2,6-diethylaniline, has been shown to be mutagenic. Available data from two studies in rats clearly indicate that alachlor is carcinogenic, causing benign and malignant tumours of the nasal turbinate, malignant stomach tumours and benign thyroid tumours.

Aldicarb

Aldicarb (CAS No. 116-06-3) is a systemic pesticide used to control nematodes in soil and insects and mites on a variety of crops. It is very soluble in water and highly mobile in soil. It degrades mainly by biodegradation and hydrolysis, persisting for weeks to months.

Guideline value	0.01 mg/l (10 µg/l)
Occurrence	Frequently found as a contaminant in groundwater in the vicinity of application areas, particularly when associated with sandy soil; concentrations in well water as high as 500 µg/l have been measured; aldicarb sulfoxide and aldicarb sulfone residues are found in an approximately 1:1 ratio in groundwater
Acceptable daily intake (ADI)	0–0.003 mg/kg body weight based on cholinesterase depression in a single oral dose study in human volunteers
Limit of detection	0.001 mg/l by reversed-phase HPLC with fluorescence detection
Treatment performance	0.001 mg/l should be achievable using GAC or ozonation
Guideline value derivation	
• allocation to water	10% of upper limit of ADI
• weight	60 kg adult
• consumption	2 litres/day

Additional comments	The guideline value derived from the 1992 assessment of the Joint FAO/WHO Meeting on Pesticide Residues (JMPR) was very similar to the guideline value derived in the second edition, which was therefore retained.
Assessment date	2003
Principal references	FAO/WHO (1993) *Pesticide residues in food—1992 evaluations* WHO (2003) *Aldicarb in drinking-water*

Aldicarb is one of the most acutely toxic pesticides in use, although the only consistently observed toxic effect with both long-term and single-dose administration is acetylcholinesterase inhibition. It is converted to the sulfoxide and sulfone. Aldicarb sulfoxide is a more potent inhibitor of acetylcholinesterase than aldicarb itself, whereas aldicarb sulfone is considerably less toxic than either aldicarb or the sulfoxide. The weight of evidence indicates that aldicarb, aldicarb sulfoxide and aldicarb sulfone are not genotoxic or carcinogenic. IARC has concluded that aldicarb is not classifiable as to its carcinogenicity (Group 3).

Aldrin and dieldrin

Aldrin (CAS No. 309-00-2) and dieldrin (CAS No. 60-57-1) are chlorinated pesticides that are used against soil-dwelling pests, for wood protection and, in the case of dieldrin, against insects of public health importance. Since the early 1970s, many countries have either severely restricted or banned the use of both compounds, particularly in agriculture. The two compounds are closely related with respect to their toxicology and mode of action. Aldrin is rapidly converted to dieldrin under most environmental conditions and in the body. Dieldrin is a highly persistent organochlorine compound that has low mobility in soil, can be lost to the atmosphere and bioaccumulates. Dietary exposure to aldrin/dieldrin is very low and decreasing.

Guideline value	*Aldrin and dieldrin (combined):* 0.000 03 mg/l (0.03 µg/l)
Occurrence	Seldom detected in drinking-water; concentrations of aldrin and dieldrin in drinking-water normally less than 0.01 µg/l; rarely present in groundwater
Provisional tolerable daily intake (PTDI)	0.1 µg/kg body weight (combined total for aldrin and dieldrin), based on no-observed-adverse-effect levels (NOAELs) of 1 mg/kg diet in the dog and 0.5 mg/kg diet in the rat, which are equivalent to 0.025 mg/kg body weight per day in both species, and applying an uncertainty factor of 250 based on concern about carcinogenicity observed in mice
Limit of detection	0.003 µg/l for aldrin and 0.002 µg/l for dieldrin by GC with electron capture detector (ECD)
Treatment performance	0.02 µg/l should be achievable using coagulation, GAC or ozonation
Guideline value derivation	
• allocation to water	1% of PTDI (In view of the reduction in exposure from food, this value is probably very conservative.)
• weight	60 kg adult
• consumption	2 litres/day

Additional comments	Aldrin and dieldrin are listed under the Stockholm Convention on Persistent Organic Pollutants. Hence, monitoring may occur in addition to that required by drinking-water guidelines.
Assessment date	2003
Principal references	FAO/WHO (1995) *Pesticide residues in food—1994 evaluations* WHO (2003) *Aldrin and dieldrin in drinking-water*

Both compounds are highly toxic in experimental animals, and cases of poisoning in humans have occurred. Aldrin and dieldrin have more than one mechanism of toxicity. The target organs are the central nervous system and the liver. In long-term studies, dieldrin was shown to produce liver tumours in both sexes of two strains of mice. It did not produce an increase in tumours in rats and does not appear to be genotoxic. IARC has classified aldrin and dieldrin in Group 3 (not classifiable as to its carcinogenicity to humans). Exposure through food has decreased significantly with the dramatic reduction in use.

Aluminium

Aluminium is the most abundant metallic element and constitutes about 8% of Earth's crust. Aluminium salts are widely used in water treatment as coagulants to reduce organic matter, colour, turbidity and microorganism levels. Such use may lead to increased concentrations of aluminium in finished water. Where residual concentrations are high, undesirable colour and turbidity may ensue. Concentrations of aluminium at which such problems may occur are highly dependent on a number of water quality parameters and operational factors at the water treatment plant. Aluminium intake from foods, particularly those containing aluminium compounds used as food additives, represents the major route of aluminium exposure for the general public. The contribution of drinking-water to the total oral exposure to aluminium is usually less than 5% of the total intake.

Reason for not establishing a guideline value	A health-based value of 0.9 mg/l could be derived from the JECFA provisional tolerable weekly intake (PTWI), but this value exceeds practicable levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants: 0.1 mg/l or less in large water treatment facilities and 0.2 mg/l or less in small facilities
Assessment date	2009
Principal references	FAO/WHO (2007) Aluminium (from all sources, including food additives) IPCS (1997) *Aluminium* WHO (2010) *Aluminium in drinking-water*

There is little indication that orally ingested aluminium is acutely toxic to humans despite the widespread occurrence of the element in foods, drinking-water and many antacid preparations. It has been hypothesized that aluminium exposure is a risk factor for the development or acceleration of onset of Alzheimer disease in humans. The 1997 WHO Environmental Health Criteria document for aluminium concludes that:

> On the whole, the positive relationship between aluminium in drinking-water and AD [Alzheimer disease], which was demonstrated in several epidemiological studies, cannot be totally dismissed. However, strong reservations about inferring a causal relationship are warranted in view of the failure of these studies to account for demonstrated confounding factors and for total aluminium intake from all sources.
>
> Taken together, the relative risks for AD from exposure to aluminium in drinking-water above 100 μg/l, as determined in these studies, are low (less than 2.0). But, because the risk estimates are imprecise for a variety of methodological reasons, a population-attributable risk cannot be calculated with precision. Such imprecise predictions may, however, be useful in making decisions about the need to control exposures to aluminium in the general population.

In 2007, JECFA developed a PTWI for aluminium from all sources of 1 mg/kg body weight. JECFA concluded the following:

> … the available studies have many limitations and are not adequate for defining the dose–response relationships. The Committee therefore based its evaluation on the combined evidence from several studies. The relevance of studies involving administration of aluminium compounds by gavage was unclear because the toxicokinetics after gavage were expected to differ from toxicokinetics after dietary administration, and the gavage studies generally did not report total aluminium exposure including basal levels in the feed. The studies conducted with dietary administration of aluminium compounds were considered most appropriate for the evaluation. The lowest LOELs [lowest-observed-effect levels] for aluminium in a range of different dietary studies in mice, rats and dogs were in the region of 50–75 mg/kg bw [body weight] per day expressed as Al.
>
> The Committee applied an uncertainty factor of 100 to the lower end of this range of LOELs (50 mg/kg bw per day expressed as Al) to allow for inter- and intraspecies differences. There are deficiencies in the database, notably the absence of NOELs [no-observed-effect levels] in the majority of the studies evaluated and the absence of long-term studies on the relevant toxicological end-points. The deficiencies are counterbalanced by the probable lower bioavailability of the less soluble aluminium species present in food. Overall, an additional uncertainty factor of three was considered to be appropriate. The Committee confirmed that the resulting health-based guidance value should be expressed as a PTWI, because of the potential for bioaccumulation. The Committee established a PTWI of 1 mg/kg bw for Al, which applies to all aluminium compounds in food, including additives.

A health-based value derived from the JECFA PTWI would be 0.9 mg/l (rounded value), based on an allocation of 20% of the PTWI to drinking-water and assuming a 60 kg adult drinking 2 litres of water per day. However, there remain uncertainties as to the extent of aluminium absorption from drinking-water, which depends on a number of parameters, such as the aluminium salt administered, pH (for aluminium speciation and solubility), bioavailability and dietary factors.

The beneficial effects of the use of aluminium as a coagulant in water treatment are recognized. Taking this into account, and considering the health concerns about aluminium (i.e. its potential neurotoxicity), a practicable level is derived, based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants, to minimize aluminium levels in finished water.

Several approaches are available for minimizing residual aluminium concentrations in treated water. These include use of optimum pH in the coagulation process, avoiding excessive aluminium dosage, good mixing at the point of application of the coagulant, optimum paddle speeds for flocculation and efficient filtration of the aluminium floc. Under good operating conditions, concentrations of aluminium of 0.1 mg/l or less are achievable in large water treatment facilities. Small facilities (e.g. those serving fewer than 10 000 people) might experience some difficulties in attaining this level, because the small size of the plant provides little buffering for fluctuation in operation; moreover, such facilities often have limited resources and limited access to the expertise needed to solve specific operational problems. For these small facilities, 0.2 mg/l or less is a practicable level for aluminium in finished water.

As indicated above, a health-based value derived from the JECFA PTWI would be 0.9 mg/l (rounded value) based on an allocation of 20% of the PTWI to drinking-water and assuming a 60 kg adult drinking 2 litres of water per day. However, as also noted above, practicable levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants are less than 0.1 mg/l in large water treatment facilities and less than 0.2 mg/l in small facilities. In view of the importance of optimizing coagulation to prevent microbial contamination and the need to minimize deposition of aluminium floc in distribution systems, it is important to ensure that average residuals do not exceed these values.

Ammonia

The term ammonia includes the non-ionized (NH_3) and ionized (NH_4^+) species. Ammonia in the environment originates from metabolic, agricultural and industrial processes and from disinfection with chloramine. Natural levels in groundwater and surface water are usually below 0.2 mg/l. Anaerobic groundwaters may contain up to 3 mg/l. Intensive rearing of farm animals can give rise to much higher levels in surface water. Ammonia contamination can also arise from cement mortar pipe linings. Ammonia in water is an indicator of possible bacterial, sewage and animal waste pollution.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	1993
Principal reference	WHO (2003) *Ammonia in drinking-water*

Ammonia is a major component of the metabolism of mammals. Exposure from environmental sources is insignificant in comparison with endogenous synthesis of ammonia. Toxicological effects are observed only at exposures above about 200 mg/kg body weight.

Ammonia in drinking-water is not of immediate health relevance, and therefore no health-based guideline value is proposed. However, ammonia can compromise disinfection efficiency, result in nitrite formation in distribution systems, cause the failure of filters for the removal of manganese and cause taste and odour problems (see also chapter 10).

Antimony

Elemental antimony forms very hard alloys with copper, lead and tin. Antimony compounds have various therapeutic uses. Antimony is used in solders as a replacement for lead, but there is little evidence of any significant contribution to drinking-water concentrations from this source. Total exposure from environmental sources, food and drinking-water is very low compared with occupational exposure.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Concentrations in groundwater less than 0.001 µg/l; concentrations in surface water less than 0.2 µg/l; concentrations in drinking-water appear to be less than 5 µg/l
Tolerable daily intake (TDI)	6 µg/kg body weight, based on a NOAEL of 6.0 mg/kg body weight per day for decreased body weight gain and reduced food and water intake in a 90-day study in which rats were administered potassium antimony tartrate in drinking-water, using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation, 10 for the short duration of the study)
Limit of detection	0.01 µg/l by electrothermal atomic absorption spectrometry (AAS); 0.1–1 µg/l by inductively coupled plasma mass spectrometry (ICP-MS); 0.8 µg/l by graphite furnace AAS; 5 µg/l by hydride generation AAS
Treatment performance	Conventional treatment processes do not remove antimony. However, antimony is not normally a raw water contaminant. As the most common source of antimony in drinking-water appears to be dissolution from metal plumbing and fittings, control of antimony from such sources would be by product control.
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	2003
Principal reference	WHO (2003) *Antimony in drinking-water*

There has been a significant increase in the toxicity data available since the previous review, although much of it pertains to the intraperitoneal route of exposure. The form of antimony in drinking-water is a key determinant of the toxicity, and it would appear that antimony leached from antimony-containing materials would be in the form of the antimony(V) oxo-anion, which is the less toxic form. The subchronic toxicity of antimony trioxide is lower than that of potassium antimony tartrate, which is the most soluble form. Antimony trioxide, owing to its low bioavailability, is genotoxic only in some in vitro tests, but not in vivo, whereas soluble antimony(III) salts exert genotoxic effects in vitro and in vivo. Animal experiments from which the carcinogenic potential of soluble or insoluble antimony compounds may be quantified are not available. IARC has concluded that antimony trioxide is possibly carcinogenic to humans (Group 2B) on the basis of an inhalation study in rats, but that antimony trisulfide was not classifiable as to its carcinogenicity to humans (Group 3). However,

chronic oral uptake of potassium antimony tartrate may not be associated with an additional carcinogenic risk, as antimony after inhalation exposure was carcinogenic only in the lung but not in other organs and is known to cause direct lung damage following chronic inhalation as a consequence of overload with insoluble particulates. Although there is some evidence for the carcinogenicity of certain antimony compounds by inhalation, there are no data to indicate carcinogenicity by the oral route.

Arsenic[1]

Arsenic is found widely in Earth's crust in oxidation states of –3, 0, +3 and +5, often as sulfides or metal arsenides or arsenates. In water, it is mostly present as arsenate (+5), but in anaerobic conditions, it is likely to be present as arsenite (+3). It is usually present in natural waters at concentrations of less than 1–2 µg/l. However, in waters, particularly groundwaters, where there are sulfide mineral deposits and sedimentary deposits deriving from volcanic rocks, the concentrations can be significantly elevated.

Arsenic is found in the diet, particularly in fish and shellfish, in which it is found mainly in the less toxic organic form. There are only limited data on the proportion of inorganic arsenic in food, but these indicate that approximately 25% is present in the inorganic form, depending on the type of food. Apart from occupational exposure, the most important routes of exposure are through food and drinking-water, including beverages that are made from drinking-water. Where the concentration of arsenic in drinking-water is 10 µg/l or greater, this will be the dominant source of intake. In circumstances where soups or similar dishes are a staple part of the diet, the drinking-water contribution through preparation of food will be even greater.

Provisional guideline value	0.01 mg/l (10 µg/l)
	The guideline value is designated as provisional on the basis of treatment performance and analytical achievability.
Occurrence	Levels in natural waters generally range between 1 and 2 µg/l, although concentrations may be elevated (up to 12 mg/l) in areas containing natural sources
Basis of guideline value derivation	There remains considerable uncertainty over the actual risks at low concentrations, and available data on mode of action do not provide a biological basis for using either linear or non-linear extrapolation. In view of the practical difficulties in removing arsenic from drinking-water, as well as the practical quantification limit in the region of 1–10 µg/l, the guideline value of 10 µg/l is retained and designated as provisional.
Limit of detection	0.1 µg/l by ICP-MS; 2 µg/l by hydride generation AAS or flame AAS
Treatment performance	It is technically feasible to achieve arsenic concentrations of 5 µg/l or lower using any of several possible treatment methods. However, this requires careful process optimization and control, and a more reasonable expectation is that 10 µg/l should be achievable by conventional treatment (e.g. coagulation).

[1] As arsenic is one of the chemicals of greatest health concern in some natural waters, its chemical fact sheet has been expanded.

Assessment date	2011
Principal references	FAO/WHO (2011) *Evaluation of certain contaminants in food* IARC (1987) *Overall evaluations of carcinogenicity* IPCS (2001) *Arsenic and arsenic compounds* ISO (1982) *Water quality—determination of total arsenic* USNRC (2001) *Arsenic in drinking water, 2001 update* WHO (2011) *Arsenic in drinking-water*

Both pentavalent and trivalent soluble arsenic compounds are rapidly and extensively absorbed from the gastrointestinal tract. Metabolism is characterized by 1) reduction of pentavalent to trivalent arsenic and 2) oxidative methylation of trivalent arsenic to form monomethylated, dimethylated and trimethylated products. Methylation of inorganic arsenic facilitates the excretion of inorganic arsenic from the body, as the end-products monomethylarsonic acid and dimethylarsinic acid are readily excreted in urine. There are major qualitative and quantitative interspecies differences in methylation, but in humans and most common laboratory animals, inorganic arsenic is extensively methylated, and the metabolites are excreted primarily in the urine. There is large interindividual variation in arsenic methylation in humans, probably due to a wide difference in the activity of methyltransferases and possible polymorphism. Ingested organoarsenicals are much less extensively metabolized and more rapidly eliminated in urine than inorganic arsenic.

Arsenic has not been demonstrated to be essential in humans. The acute toxicity of arsenic compounds in humans is predominantly a function of their rate of removal from the body. Arsine is considered to be the most toxic form, followed by the arsenites, the arsenates and organic arsenic compounds. Acute arsenic intoxication associated with the ingestion of well water containing very high concentrations (21.0 mg/l) of arsenic has been reported.

Signs of chronic arsenicism, including dermal lesions such as hyperpigmentation and hypopigmentation, peripheral neuropathy, skin cancer, bladder and lung cancers and peripheral vascular disease, have been observed in populations ingesting arsenic-contaminated drinking-water. Dermal lesions were the most commonly observed symptom, occurring after minimum exposure periods of approximately 5 years. Effects on the cardiovascular system were observed in children consuming arsenic-contaminated water (mean concentration 0.6 mg/l) for an average of 7 years.

Numerous epidemiological studies have examined the risk of cancers associated with arsenic ingestion through drinking-water. Many are ecological-type studies, and many suffer from methodological flaws, particularly in the measurement of exposure. However, there is overwhelming evidence that consumption of elevated levels of arsenic through drinking-water is causally related to the development of cancer at several sites. Nevertheless, there remain considerable uncertainty and controversy over both the mechanism of carcinogenicity and the shape of the dose–response curve at low intakes. The International Programme on Chemical Safety (IPCS) concluded that long-term exposure to arsenic in drinking-water is causally related to increased risks of cancer in the skin, lungs, bladder and kidney, as well as other skin changes, such

as hyperkeratosis and pigmentation changes. These effects have been demonstrated in many studies using different study designs. Exposure–response relationships and high risks have been observed for each of these end-points. The effects have been most thoroughly studied in Taiwan, China, but there is considerable evidence from studies on populations in other countries as well. Increased risks of lung and bladder cancer and of arsenic-associated skin lesions have been reported to be associated with ingestion of drinking-water at concentrations below 50 µg of arsenic per litre. There is a need for more analytical epidemiological studies to determine the dose–time response for skin lesions, as well as cancer, in order to assist in developing suitable interventions and determining practical intervention policies.

Inorganic arsenic compounds are classified by IARC in Group 1 (carcinogenic to humans) on the basis of sufficient evidence for carcinogenicity in humans and limited evidence for carcinogenicity in animals. Although there is a substantial database on the association between both internal and skin cancers and the consumption of arsenic in drinking-water, there remains considerable uncertainty over the actual risks at low concentrations. In its updated evaluation, the United States National Research Council concluded that "the available mode-of-action data on arsenic do not provide a biological basis for using either a linear or nonlinear extrapolation". The maximum likelihood estimates, using a linear extrapolation, for bladder and lung cancer for populations in the United States of America (USA) exposed to arsenic at concentrations of 10 µg/l in drinking-water are, respectively, 12 and 18 per 10 000 population for females and 23 and 14 per 10 000 population for males. The actual numbers indicated by these estimated risks would be very difficult to detect by current epidemiological methods. There is also uncertainty over the contribution of arsenic in food—a higher intake of inorganic arsenic from food would lead to a lower risk estimate for water—and the impact of factors such as variation in the metabolism of arsenic and nutritional status. Some studies in areas with arsenic concentrations somewhat above 50 µg/l have not detected arsenic-related adverse effects in the residents. It remains possible that the estimates of cancer risk associated with various arsenic intakes are overestimates. The concentration of arsenic in drinking-water below which no effects can be observed remains to be determined, and there is an urgent need for identification of the mechanism by which arsenic causes cancer, which appears to be the most sensitive toxicity end-point.

The practical quantification limit for arsenic is in the region of 1–10 µg/l, and removal of arsenic to concentrations below 10 µg/l is difficult in many circumstances. In view of the practical difficulties in removing arsenic from drinking-water, particularly from small supplies, and the practical quantification limit for arsenic, the guideline value of 10 µg/l is retained as a goal and designated as provisional.

The provisional guideline value of 10 µg/l was previously supported by a JECFA PTWI of 15 µg/kg body weight, assuming an allocation of 20% to drinking-water. However, JECFA recently re-evaluated arsenic and concluded that the existing PTWI was very close to the lower confidence limit on the benchmark dose for a 0.5% response ($BMDL_{0.5}$) calculated from epidemiological studies and was therefore no longer appropriate. The PTWI was therefore withdrawn. Nevertheless, given that, in many countries, even the provisional guideline value may not be attainable, it is retained on

the basis of treatment performance and analytical achievability with the proviso that every effort should be made to keep concentrations as low as reasonably possible.

Practical considerations

A silver diethyldithiocarbamate spectrophotometric method (ISO 6595:1982) is available for the determination of arsenic; the detection limit is about 1 μg/l. Graphite furnace AAS, hydride generation AAS and ICP-MS are more sensitive. HPLC in combination with ICP-MS can also be used to determine various arsenic species.

It is technically feasible to achieve arsenic concentrations of 5 μg/l or lower using any of several possible treatment methods. However, this requires careful process optimization and control, and a more reasonable expectation is that 10 μg/l should be achievable by conventional treatment (e.g. coagulation). For local non-piped water supplies, the first option is often substitution by, or dilution with, microbially safe low-arsenic sources. It may also be appropriate to use alternative sources for drinking and cooking but to use the contaminated sources for purposes such as washing and laundry. There are also an increasing number of effective small-scale treatment techniques, usually based around coagulation and precipitation or adsorption, available at relatively low cost for removal of arsenic from small supplies.

Asbestos

Asbestos is introduced into water by the dissolution of asbestos-containing minerals and ores as well as from industrial effluents, atmospheric pollution and asbestos-cement pipes in the distribution system. Exfoliation of asbestos fibres from asbestos-cement pipes is related to the aggressiveness of the water supply. Limited data indicate that exposure to airborne asbestos released from tap water during showers or humidification is negligible.

Reason for not establishing a guideline value	No consistent evidence that ingested asbestos is hazardous to health
Assessment date	1993
Principal reference	WHO (2003) *Asbestos in drinking-water*

Asbestos is a known human carcinogen by the inhalation route. Although it has been well studied, there is little convincing evidence of the carcinogenicity of ingested asbestos in epidemiological studies of populations with drinking-water supplies containing high concentrations of asbestos. Moreover, in extensive studies in experimental animal species, asbestos has not consistently increased the incidence of tumours of the gastrointestinal tract. There is therefore no consistent evidence that ingested asbestos is hazardous to health, and thus it is concluded that there is no need to establish a health-based guideline value for asbestos in drinking-water. The primary issue surrounding asbestos-cement pipes is for people working on the outside of the pipes (e.g. cutting pipe), because of the risk of inhalation of asbestos dust.

Atrazine and its metabolites

Atrazine is a selective systemic herbicide of the chlorotriazine class, used for the control of annual broadleaf and grassy weeds. Atrazine and its chloro-*s*-triazine metabolites—deethyl-atrazine, deisopropyl-atrazine and diaminochlorotriazine—have been found in surface water and groundwater as a result of the use of atrazine as a pre-emergent or early post-emergent herbicide. The metabolite hydroxyatrazine is more commonly detected in groundwater than in surface water.

Guideline values	*Atrazine and its chloro-s-triazine metabolites:* 0.1 mg/l (100 µg/l)
	Hydroxyatrazine: 0.2 mg/l (200 µg/l)
Occurrence	Concentrations rarely exceed 2 µg/l and are commonly well below 0.1 µg/l
Group ADI for atrazine and its chloro-*s*-triazine metabolites	0–0.02 mg/kg body weight based on the NOAEL for atrazine of 1.8 mg/kg body weight per day identified on the basis of luteinizing hormone surge suppression and subsequent disruption of the estrous cycle seen at 3.6 mg/kg body weight per day in a 6-month study in rats, using a safety factor of 100
ADI for hydroxyatrazine	0–0.04 mg/kg body weight based on the NOAEL of 1.0 mg/kg body weight per day identified on the basis of kidney toxicity at 7.8 mg/kg body weight per day in a 24-month study in rats, using a safety factor of 25, based on kinetic considerations
Limit of detection	*Atrazine:* 1 ng/l, isotope dilution MS with solid-phase extraction; 10 ng/l, GC-MS with solid-phase extraction; 50 ng/l, liquid chromatography (LC)–MS with solid-phase extraction; 100 ng/l, GC with nitrogen–phosphorus detection
	Metabolites: 5 ng/l, capillary GC with nitrogen thermionic specific detection and HPLC with photodiode array absorption detection following extraction with styrene-divinylbenzene sorbents and elution with acetone
Treatment performance	0.1 µg/l can be achieved using GAC or powdered activated carbon (PAC); bankside filtration and nanofiltration are also effective
Guideline value derivation	
• allocation to water	20% of upper limit of ADI
• body weight	60 kg adult
• consumption	2 litres/day
Additional comments	JMPR considered that the NOAEL for atrazine is protective for the consequences of neuroendocrine and other adverse effects caused by prolonged exposure to atrazine and its chloro-*s*-triazine metabolites.
	JMPR was not able to assess the source allocation of atrazine to drinking-water. As such, the default 20% allocation was chosen, as it will be very conservative in most countries; in addition, it is expected that exposure of the public will be primarily through drinking-water.
Assessment date	2011
Principal references	FAO/WHO (2009) *Pesticide residues in food—2007 evaluations* WHO (2011) *Atrazine and its metabolites in drinking-water*

JMPR agreed that it is unlikely that atrazine is genotoxic and concluded that atrazine is not likely to pose a carcinogenic risk to humans, as the mode of carcinogenic action in certain susceptible rat strains is not relevant for human risk assessment. The weight of evidence from the epidemiological studies also did not support a causal association between exposure to atrazine and the occurrence of cancer in humans.

In special studies of reproductive toxicity, exposure of rats during early pregnancy (i.e. the luteinizing hormone–dependent period) caused increased pre-implantation or post-implantation losses, including full-litter resorptions. Attenuation of the luteinizing hormone surge and subsequent disruption of the estrous cycle (characterized by an increase in days in estrus) were observed at and above 3.65 mg/kg body weight per day, with a NOAEL of 1.8 mg/kg body weight per day. The effects on the luteinizing hormone surge and disruption of the estrous cycle were further supported by a number of short-term mechanistic studies. Additional experiments suggested that the effects of atrazine on luteinizing hormone and prolactin secretion are mediated via a hypothalamic site of action. JMPR concluded that atrazine was not teratogenic.

Studies using a variety of test systems in vitro and in vivo indicated that modulation of the immune system occurs after exposure to atrazine. However, effects suggestive of impaired function of the immune system were observed only at doses greater than those shown to affect neuroendocrine function, leading to disruption of the estrous cycle or developmental effects.

The toxicity profiles and mode of action of the chloro-*s*-triazine metabolites are similar to those of atrazine; the potency of these metabolites with regard to their neuroendocrine-disrupting properties appeared to be similar to that of the parent compound.

The metabolite hydroxyatrazine does not have the same mode of action or toxicity profile as atrazine and its chloro-*s*-triazine metabolites. The main effect of hydroxyatrazine was kidney toxicity (owing to its low solubility in water, resulting in crystal formation and a subsequent inflammatory response), and there was no evidence that hydroxyatrazine has neuroendocrine-disrupting properties. There was no evidence of carcinogenicity, and hydroxyatrazine did not show genotoxicity in an adequate range of tests in vitro and in vivo.

Barium

Barium is present as a trace element in both igneous and sedimentary rocks, and barium compounds are used in a variety of industrial applications; however, barium in water comes primarily from natural sources. Food is the primary source of intake for the non-occupationally exposed population. However, where barium levels in water are high, drinking-water may contribute significantly to total intake.

Guideline value	0.7 mg/l (700 µg/l)
Occurrence	Concentrations in drinking-water generally below 100 µg/l, although concentrations above 1 mg/l have been measured in drinking-water derived from groundwater

NOAEL in humans	7.3 mg/l in the most sensitive epidemiological study conducted to date, in which there were no significant differences in blood pressure or in the prevalence of cardiovascular disease between a population drinking water containing barium at a mean concentration of 7.3 mg/l and one whose water contained barium at a concentration of 0.1 mg/l
Basis of guideline value derivation	Uncertainty factor of 10 for intraspecies variation applied to NOAEL in humans
Limit of detection	0.1 µg/l by ICP-MS; 2 µg/l by AAS; 3 µg/l by ICP–optical emission spectroscopy
Treatment performance	0.1 mg/l should be achievable using either ion exchange or precipitation softening; other conventional processes are ineffective
Additional comments	The guideline value for barium is based on an epidemiological study in which no adverse effects were observed, although the study population was relatively small and the power of the study was limited. As a consequence, an uncertainty factor of 10 was applied to the level of barium in the drinking-water of the study population. However, the level at which effects would be seen may be significantly greater than this concentration, so the guideline value for barium may be highly conservative, and the margin of safety is likely to be high.
Assessment date	2003
Principal references	IPCS (2001) *Barium and barium compounds* WHO (2003) *Barium in drinking-water*

There is no evidence that barium is carcinogenic or mutagenic. Barium has been shown to cause nephropathy in laboratory animals, but the toxicological end-point of greatest concern to humans appears to be its potential to cause hypertension.

Bentazone

Bentazone (CAS No. 25057-89-0) is a broad-spectrum herbicide used for a variety of crops. Photodegradation occurs in soil and water; however, bentazone is very mobile in soil and moderately persistent in the environment. Bentazone has been reported to occur in surface water, groundwater and drinking-water at concentrations of a few micrograms per litre or less. Although it has been found in groundwater and has a high affinity for the water compartment, it does not seem to accumulate in the environment. Exposure from food is unlikely to be high.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (1999) *Pesticide residues in food—1998 evaluations* WHO (2003) *Bentazone in drinking-water*

Long-term studies conducted in rats and mice have not indicated a carcinogenic potential, and a variety of in vitro and in vivo assays have indicated that bentazone is not genotoxic. A health-based value of 300 µg/l can be calculated on the basis of

an ADI of 0–0.1 mg/kg body weight established by JMPR, based on haematological effects observed in a 2-year dietary study in rats. However, because bentazone occurs at concentrations well below those of health concern, it is not considered necessary to derive a health-based guideline value.

Benzene

Benzene is used principally in the production of other organic chemicals. It is present in petrol, and vehicular emissions constitute the main source of benzene in the environment. Benzene may be introduced into water by industrial effluents and atmospheric pollution.

Guideline value	0.01 mg/l (10 µg/l)
Occurrence	Concentrations in drinking-water, when present, generally much less than 5 µg/l
Basis of guideline value derivation	Robust linear extrapolation model (because of statistical lack of fit of some of the data with the linearized multistage model) applied to leukaemia and lymphomas in female mice and oral cavity squamous cell carcinomas in male rats in a 2-year gavage study
Limit of detection	0.2 µg/l by GC with photoionization detection and confirmation by MS
Treatment performance	0.01 mg/l should be achievable using GAC or air stripping
Additional comments	Lower end of estimated range of concentrations in drinking-water corresponding to an upper-bound excess lifetime cancer risk of 10^{-5} (10–80 µg/l) corresponds to the estimate derived from data on leukaemia from epidemiological studies involving inhalation exposure, which formed the basis for the previous guideline value. The previous guideline value is therefore retained.
Assessment date	1993
Principal reference	WHO (2003) *Benzene in drinking-water*

Acute exposure of humans to high concentrations of benzene primarily affects the central nervous system. At lower concentrations, benzene is toxic to the haematopoietic system, causing a continuum of haematological changes, including leukaemia. Because benzene is carcinogenic to humans, IARC has classified it in Group 1. Haematological abnormalities similar to those observed in humans have been observed in experimental animal species exposed to benzene. In animal studies, benzene was shown to be carcinogenic following both inhalation and ingestion. It induced several types of tumours in both rats and mice in a 2-year carcinogenesis bioassay by gavage in corn oil. Benzene has not been found to be mutagenic in bacterial assays, but it has been shown to cause chromosomal aberrations in vivo in a number of species, including humans, and to be positive in the mouse micronucleus test.

Beryllium

The primary source of beryllium compounds in water appears to be release from coal burning and other industries using beryllium. Other sources of beryllium in surface water include deposition of atmospheric beryllium and weathering of rocks and soils

containing beryllium. Beryllium is not likely to be found in natural water above trace levels as a result of the insolubility of beryllium oxides and hydroxides in the normal pH range.

Reason for not establishing a guideline value	Rarely found in drinking-water at concentrations of health concern
Assessment date	2009
Principal references	IPCS (2001) *Beryllium and beryllium compounds* WHO (2009) *Beryllium in drinking-water*

As beryllium is rarely, if ever, found in drinking-water at concentrations of concern, it is not considered necessary to set a formal guideline value.

A health-based value for beryllium in drinking-water of 12 µg/l can be calculated based on an allocation of 20% of the TDI of 2 µg/kg body weight, derived from a long-term study in which dogs exhibited lesions of the small intestine, to drinking-water and assuming a 60 kg adult drinking 2 litres of water per day. This allocation is probably conservative, as the limited data on food indicate that exposure from this source is likely to be well below the TDI.

Although beryllium appears to be found in drinking-water sources and drinking-water at low concentrations, the database on occurrence is limited, and there may be specific circumstances in which concentrations can be elevated due to natural sources where the pH is either below 5 or above 8 or there is high turbidity.

Boron

Boron compounds are used in the manufacture of glass, soaps and detergents and as flame retardants. Naturally occurring boron is present in groundwater primarily as a result of leaching from rocks and soils containing borates and borosilicates. The borate content of surface water can be increased as a result of wastewater discharges, but this use has decreased significantly, and levels of boron in wastewater discharges continue to fall.

Guideline value	2.4 mg/l (2400 µg/l)
Occurrence	Concentrations vary widely and depend on the surrounding geology and wastewater discharges; for most of the world, the concentration of boron in drinking-water is judged to be below 0.5 mg/l
TDI	0.17 mg/kg body weight, based on a $BMDL_{05}$ of 10.3 mg/kg body weight per day for developmental toxicity (decreased fetal body weight in rats) and an uncertainty factor of 60 (10 for interspecies variation and 6 for intraspecies variation)
Limit of detection	0.15 µg/l by ICP-MS; 6–10 µg/l by ICP–atomic emission spectrometry (AES)
Treatment performance	Conventional water treatment (coagulation, sedimentation, filtration) does not significantly remove boron, and special methods need to be used in order to remove boron from waters with high boron concentrations. Ion exchange and reverse osmosis processes may enable substantial reduction but are likely to be prohibitively expensive. Blending with low-boron supplies may be the only economical method to reduce boron concentrations in waters where these concentrations are high.

Guideline value derivation	
• allocation to water	40% of TDI (because intake from other sources is low)
• body weight	60 kg adult
• consumption	2 litres/day
Additional comments	Because it will be difficult to achieve the guideline value of 2.4 mg/l in some desalinated supplies and in areas with high natural boron levels, local regulatory and health authorities should consider a value in excess of 2.4 mg/l by assessing exposure from other sources.
Assessment date	2009
Principal reference	WHO (2009) *Boron in drinking-water*

Short- and long-term oral exposures to boric acid or borax in laboratory animals have demonstrated that the male reproductive tract is a consistent target of toxicity. Testicular lesions have been observed in rats, mice and dogs given boric acid or borax in food or drinking-water. Developmental toxicity has been demonstrated experimentally in rats, mice and rabbits. Negative results in a large number of mutagenicity assays indicate that boric acid and borax are not genotoxic. In long-term studies in mice and rats, boric acid and borax caused no increase in tumour incidence.

Bromate

Sodium and potassium bromate are powerful oxidizers used mainly in permanent wave neutralizing solutions and the dyeing of textiles using sulfur dyes. Potassium bromate has also been used as an oxidizer to mature flour during milling, in treating barley in beer making and in fish paste products, although JECFA has concluded that the use of potassium bromate in food processing is not appropriate. Bromate is not normally found in water, but can occur as a result of pollution from industrial sources, sometimes as a consequence of its presence in contaminated soil. However, the main source in drinking-water is its formation during ozonation when the bromide ion is present in water. Bromate may also be formed in hypochlorite solutions produced by electrolysis of bromide-containing salt.

Provisional guideline value	0.01 mg/l (10 µg/l)
	The guideline value is provisional because of limitations in available analytical and treatment methods.
Occurrence	Has been reported in drinking-water with a variety of source water characteristics after ozonation at concentrations ranging from less than 2 to 293 µg/l, depending on bromide ion concentration, ozone dosage, pH, alkalinity and dissolved organic carbon; can also be formed in the electrolytic generation of chlorine and hypochlorite from brine with a high level of bromide contamination
Basis of guideline value derivation	Upper-bound estimate of cancer potency for bromate is 0.19 per mg/kg body weight per day, based on low-dose linear extrapolation (a one-stage Weibull time-to-tumour model was applied to the incidence of mesotheliomas, renal tubule tumours and thyroid follicular tumours in male rats given potassium bromate in drinking-water, using the 12-, 26-, 52- and 77-week interim kill data). A health-based value of 2 µg/l is associated with the upper-bound excess cancer risk of 10^{-5}. A similar conclusion may be reached through several other methods of extrapolation, leading to values in the range 2–6 µg/l.

Limit of detection	0.2 µg/l by ion chromatography with UV/visible absorbance detection; 0.3 µg/l by ion chromatography with detection by ICP-MS; 1.5 µg/l by ion chromatography with suppressed conductivity detection
Treatment performance	Bromate is difficult to remove once formed. By appropriate control of disinfection conditions, it is possible to achieve bromate concentrations below 0.01 mg/l.
Assessment date	2003
Principal reference	WHO (2003) *Bromate in drinking-water*

IARC has concluded that although there is inadequate evidence of carcinogenicity in humans, there is sufficient evidence for the carcinogenicity of bromate from high-dose studies in experimental animals; IARC has classified bromate in Group 2B (possibly carcinogenic to humans). Bromate is mutagenic both in vitro and in vivo. At this time, there is not sufficient evidence to conclude as to the mode of carcinogenic action for bromate. Observation of tumours at a relatively early time and the positive response of bromate in a variety of genotoxicity assays suggest that the predominant mode of action at low doses is due to oxidative deoxyribonucleic acid (DNA) damage. Although there is evidence to suggest that the DNA reactivity in kidney tumours may have a non-linear dose–response relationship, there is no evidence to suggest that this same dose–response relationship operates in the development of mesotheliomas or thyroid tumours. Oxidative stress may play a role in the formation of kidney tumours, but the evidence is insufficient to establish lipid peroxidation and free radical production as key events responsible for the induction of kidney tumours. However, emerging evidence points to rapid decomposition of bromate in the gastrointestinal tract, blood and liver, which supports a non-linear dose–response relationship at low doses.

Bromide

Bromide is commonly found in nature along with sodium chloride, owing to their similar physical and chemical properties, but in smaller quantities. Bromide concentrations in seawater range from 65 mg/l to well over 80 mg/l, in fresh water from trace amounts to about 0.5 mg/l and in desalinated waters up to 1 mg/l.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2009
Principal reference	WHO (2009) *Bromide in drinking-water*

Inorganic bromide was evaluated in 1966 by JMPR, which recommended an ADI of 0–1 mg/kg body weight, based on a minimum pharmacologically effective dosage in humans of about 900 mg of potassium bromide, equivalent to 600 mg of bromide ion. The JMPR ADI was reaffirmed with new data in 1988.

The results of human studies suggest a conservative no-observed-effect level (NOEL) (for marginal effect within normal limits of electroencephalograms in

females) of 4 mg/kg body weight per day, giving an ADI of 0–0.4 mg/kg body weight, including a safety factor of 10 for population diversity.

The upper limit of the ADI of 0–0.4 mg/kg body weight yields an acceptable total daily intake of 24 mg/person for a 60 kg person. Assuming a relative source contribution of 50%, the drinking-water value for a 60 kg adult consuming 2 litres/day would be up to 6 mg/l; for a 10 kg child consuming 1 litre/day, the value would be up to 2 mg/l. However, the dietary bromide contribution for a 10 kg child would probably be less than that for an adult. These are reasonably conservative values, and they are unlikely to be encountered in drinking-water supplies.

Bromide can be involved in the reaction between chlorine and naturally occurring organic matter in drinking-water, forming brominated and mixed chloro-bromo by-products, such as trihalomethanes (THMs) and halogenated acetic acids (HAAs), or it can react with ozone to form bromate. The levels of bromide that can result in the formation of these substances are well below the health-based values suggested above. This guidance applies specifically to inorganic bromide ion and not to bromate or organohalogen compounds, for which individual health-based guideline values have been developed.

Brominated acetic acids

Brominated acetic acids are formed during disinfection of water that contains bromide ions and organic matter. Bromide ions occur naturally in surface water and groundwater and exhibit seasonal fluctuations in levels. Bromide ion levels can increase as a result of either saltwater intrusion resulting from drought conditions or pollution. Brominated acetates are generally present in surface water and groundwater distribution systems at mean concentrations below 5 μg/l.

Reason for not establishing guideline values	Available data inadequate to permit derivation of health-based guideline values
Assessment date	2003
Principal references	IPCS (2000) *Disinfectants and disinfectant by-products* WHO (2003) *Brominated acetic acids in drinking-water*

The database for dibromoacetic acid is considered inadequate for the derivation of a guideline value. There are no systemic toxicity studies of subchronic duration or longer. The database also lacks suitable toxicokinetic studies, a carcinogenicity study, a developmental study in a second species and a multigeneration reproductive toxicity study. Available mutagenicity data suggest that dibromoacetate is genotoxic.

Data are also limited on the oral toxicity of monobromoacetic acid and bromochloroacetic acid. Limited mutagenicity and genotoxicity data give mixed results for monobromoacetic acid and generally positive results for bromochloroacetic acid. Data gaps include subchronic or chronic toxicity studies, multigeneration reproductive toxicity studies, standard developmental toxicity studies and carcinogenicity studies. The available data are considered inadequate to establish guideline values for these chemicals.

Cadmium

Cadmium metal is used in the steel industry and in plastics. Cadmium compounds are widely used in batteries. Cadmium is released to the environment in wastewater, and diffuse pollution is caused by contamination from fertilizers and local air pollution. Contamination in drinking-water may also be caused by impurities in the zinc of galvanized pipes and solders and some metal fittings. Food is the main source of daily exposure to cadmium. The daily oral intake is 10–35 µg. Smoking is a significant additional source of cadmium exposure.

Guideline value	0.003 mg/l (3 µg/l)
Occurrence	Levels in drinking-water usually less than 1 µg/l
PTMI	25 µg/kg body weight, based on the relationship between β_2-microglobulin excretion in urine and cadmium excretion in urine for individuals who are 50 years of age and older
Limit of detection	0.01 µg/l by ICP-MS; 2 µg/l by flame AAS
Treatment performance	0.002 mg/l should be achievable using coagulation or precipitation softening
Guideline value derivation	
• allocation to water	10% of provisional tolerable monthly intake (PTMI) because of high intake from food
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	Although new information indicates that a proportion of the general population may be at increased risk for tubular dysfunction when exposed at the current PTMI, the risk estimates that can be made at present are imprecise.
	It is recognized that the margin between the PTMI and the actual monthly intake of cadmium by the general population is small and that this margin may be even smaller in smokers.
Assessment date	2011
Principal references	FAO/WHO (2011) *Evaluation of certain food additives and contaminants* WHO (2011) *Cadmium in drinking-water*

Absorption of cadmium compounds is dependent on the solubility of the compounds. Cadmium accumulates primarily in the kidneys and has a long biological half-life in humans of 10–35 years. There is evidence that cadmium is carcinogenic by the inhalation route, and IARC has classified cadmium and cadmium compounds in Group 2A (probably carcinogenic to humans). However, there is no evidence of carcinogenicity by the oral route and no clear evidence for the genotoxicity of cadmium. The kidney is the main target organ for cadmium toxicity.

In its recent evaluation of cadmium, JECFA found that data relating excretion of the biomarker β_2-microglobulin in urine to cadmium excretion in urine for individuals who are 50 years of age and older provided the most reliable basis on which to determine a critical concentration of cadmium in the urine. Urinary excretion of less

than 5.24 µg of cadmium per gram creatinine was not associated with an increased excretion of β_2-microglobulin, and the dietary exposure that would result in a urinary cadmium concentration at the breakpoint of 5.24 µg/g creatinine was estimated to be 0.8 µg/kg body weight per day or about 25 µg/kg body weight per month. Because of cadmium's exceptionally long half-life, the previous PTWI of 7 µg/kg body weight was withdrawn, and a PTMI of 25 µg/kg body weight was established.

Carbaryl

Carbaryl (CAS No. 63-25-2) is a broad-spectrum carbamate insecticide that is used to control insect pests in crops, trees and ornamental plants. It also has some uses in public health and veterinary practice. Carbaryl has not been reported in drinking-water; however, it could occur following overspraying or spillage into surface water. Exposure through drinking-water is therefore considered to be low unless in exceptional circumstances. The major route of carbaryl intake for the general population is food, but residues are considered to be relatively low.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2006
Principal references	FAO/WHO (2002) *Pesticide residues in food—2001 evaluations* WHO (2008) *Carbaryl in drinking-water*

Carbaryl acts through inhibition of brain cholinesterase, and this is also its primary mode of toxicity. However, carbaryl is also considered to be a non-genotoxic carcinogen in mice, in which it causes vascular tumours in males. On this basis, JMPR established an ADI of 0–0.008 mg/kg body weight. This was based on a lowest-observed-adverse-effect level (LOAEL) of 15 mg/kg body weight per day and application of a safety factor of 2000 (10 for interspecies variation, 10 for intraspecies variation and 20 to reflect the occurrence of the rare and malignant tumour for which a no-effect level could not be identified).

A health-based value of 50 µg/l (rounded value) can be determined from the JMPR ADI of 0–0.008 mg/kg body weight, assuming a 60 kg adult drinking 2 litres of water per day and allowing 20% of the upper limit of the ADI from drinking-water. However, carbaryl does not appear to be found in drinking-water at significant concentrations, and so it is not considered necessary to propose a formal guideline value.

Carbofuran

Carbofuran (CAS No. 1563-66-2) is used worldwide as a pesticide for many crops. Residues in treated crops are generally very low or not detectable. The physicochemical properties of carbofuran and the few data on occurrence indicate that drinking-water from both groundwater and surface water sources is potentially the major route of exposure.

Guideline value	0.007 mg/l (7 µg/l)
Occurrence	Has been detected in surface water, groundwater and drinking-water, generally at levels of a few micrograms per litre or lower; highest concentration (30 µg/l) measured in groundwater
ADI	0–0.002 mg/kg body weight based on a NOAEL of 0.22 mg/kg body weight per day for acute (reversible) effects in dogs in a short-term (4-week) study conducted as an adjunct to a 13-week study in which inhibition of erythrocyte acetylcholinesterase activity was observed, and using an uncertainty factor of 100
Limit of detection	0.1 µg/l by GC with a nitrogen–phosphorus detector; 0.9 µg/l by reversed-phase HPLC with a fluorescence detector
Treatment performance	1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of upper limit of ADI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	Use of a 4-week study was considered appropriate because the NOAEL is based on a reversible acute effect; the NOAEL will also be protective for chronic effects.
Assessment date	1998
Principal references	FAO/WHO (1997) *Pesticide residues in food—1996 evaluations* WHO (2003) *Carbofuran in drinking-water*

Carbofuran is highly toxic after acute oral administration. The main systemic effect of carbofuran poisoning in short-term and long-term toxicity studies appears to be cholinesterase inhibition. No evidence of teratogenicity has been found in reproductive toxicity studies. On the basis of available studies, carbofuran does not appear to be carcinogenic or genotoxic.

Carbon tetrachloride

Carbon tetrachloride is used mainly in the production of chlorofluorocarbon refrigerants, foam-blowing agents and solvents. However, since the Montreal Protocol on Substances that Deplete the Ozone Layer (1987) and its amendments (1990 and 1992) established a timetable for the phase-out of the production and consumption of carbon tetrachloride, manufacture and use have dropped and will continue to drop. Carbon tetrachloride is released mostly into the atmosphere but also into industrial wastewater. Although it readily migrates from surface water to the atmosphere, levels in anaerobic groundwater may remain elevated for months or even years. Although available data on concentrations in food are limited, the intake from air is expected to be much greater than that from food or drinking-water.

Guideline value	0.004 mg/l (4 µg/l)
Occurrence	Concentrations in drinking-water generally less than 5 µg/l

TDI	1.4 µg/kg body weight, based on a NOAEL of 1 mg/kg body weight per day for hepatotoxic effects in a 12-week oral gavage study in rats, adjusting for daily dosing and applying an uncertainty factor of 500 (100 for interspecies and intraspecies variation, 10 for the duration of the study and a modifying factor of 0.5 because it was a bolus study)
Limit of detection	0.1–0.3 µg/l by GC-ECD or GC-MS
Treatment performance	0.001 mg/l should be achievable using air stripping
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The guideline value is lower than the range of values associated with upper-bound lifetime excess cancer risks of 10^{-4}, 10^{-5} and 10^{-6} calculated by linear extrapolation.
Assessment date	2003
Principal references	IPCS (1999) *Carbon tetrachloride* WHO (2003) *Carbon tetrachloride in drinking-water*

The primary targets for carbon tetrachloride toxicity are liver and kidney. In experiments with mice and rats, carbon tetrachloride proved to be capable of inducing hepatomas and hepatocellular carcinomas. The doses inducing hepatic tumours were higher than those inducing cell toxicity. It is likely that the carcinogenicity of carbon tetrachloride is secondary to its hepatotoxic effects. On the basis of available data, carbon tetrachloride can be considered to be a non-genotoxic compound. Carbon tetrachloride is classified by IARC as being possibly carcinogenic to humans (Group 2B): there is sufficient evidence that carbon tetrachloride is carcinogenic in laboratory animals, but inadequate evidence in humans.

Chloral hydrate

Chloral hydrate, or trichloroacetaldehyde, can be formed as a by-product of the chlorination of water containing organic precursor material, such as fulvic and humic acids. It has been found in drinking-water at concentrations of up to 100 µg/l, but concentrations are usually below 10 µg/l. Concentrations are generally higher in surface water than in groundwater, and concentrations appear to increase during distribution.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2004
Principal references	IPCS (2000) *Chloral hydrate* IPCS (2000) *Disinfectants and disinfectant by-products* WHO (2005) *Chloral hydrate in drinking-water*

Chloral hydrate is used as an intermediate in the production of insecticides, herbicides and hypnotic drugs. It has also been widely used as a sedative or hypnotic drug in humans at oral doses of up to about 750–1000 mg/day. Although intake from clinical use is considerably higher than intake from drinking-water, clinical exposure is of shorter-term duration.

No epidemiological or carcinogenic studies were found in humans that associated exposure to chloral hydrate with cancer, despite the fact that chloral hydrate has been used for many decades (and still is used) as a sedative and hypnotic drug in adults and children (specifically for dental procedures). IARC classified chloral hydrate as not classifiable as to its carcinogenicity to humans (Group 3), based on inadequate evidence in humans and limited evidence in experimental animals. There is equivocal evidence for the genotoxicity of chloral hydrate.

A health-based value of 0.1 mg/l (rounded figure) can be calculated on the basis of a TDI of 0.0045 mg/kg body weight derived based on an increased incidence of liver histopathology observed in mice in a 2-year drinking-water study, allocating 80% of the TDI to drinking-water (because most exposure to chloral hydrate is from drinking-water) and assuming a 60 kg adult consuming 2 litres of water per day. However, because chloral hydrate usually occurs in drinking-water at concentrations well below those of health concern, it is not considered necessary to derive a guideline value.

Chloral hydrate levels in drinking-water can be controlled by changes to disinfection practice (e.g. enhanced coagulation and softening to remove organic precursor compounds, moving the point of disinfection to reduce the reaction between chlorine and precursor compounds and using chloramines for residual disinfection instead of chlorine) and by GAC treatment.

Chloramines (monochloramine, dichloramine, trichloramine)

Monochloramine, dichloramine and trichloramine are considered by-products of drinking-water chlorination, being formed when chlorine and ammonia are added to water. Monochloramine may also be added to maintain residual disinfection activity in potable water distribution systems. Because higher chloramines are formed only occasionally and cause taste and odour problems at concentrations lower than those at which monochloramine causes taste and odour problems, only monochloramine has been considered for development of a health-based guideline value. Chloramine is rapidly decomposed in the stomach by gastric juice. The use of chloramines for disinfection instead of chlorine reduces the formation of THMs in drinking-water supplies. However, formation of other by-products, such as haloketones, chloropicrin, cyanogen chloride, HAAs, haloacetonitriles, aldehydes and chlorophenols, has been reported. Monochloramine, the most abundant chloramine, is recognized as a less effective disinfectant than chlorine and is used as a secondary disinfectant to maintain a residual in distribution systems.

Guideline value	*Monochloramine:* 3 mg/l (3000 µg/l)
Occurrence	Typical chloramine concentrations of 0.5–2 mg/l are found in drinking-water supplies where chloramine is used as a primary disinfectant or to provide a chlorine residual in the distribution system

TDI	94 µg/kg body weight, based on a NOAEL of 9.4 mg/kg body weight per day, the highest dose administered to male rats in a 2-year United States National Toxicology Program (NTP) drinking-water study (although mean body weights of rats given the highest dose were lower than those of their respective control groups, it is probable that the lower body weights were caused by the unpalatability of the drinking-water)
Limit of detection	10 µg/l by colorimetric methods
Treatment performance	It is possible to reduce the concentration of chloramine effectively to zero (< 0.1 mg/l) by reduction; however, it is normal practice to supply water with a chloramine residual of a few tenths of a milligram per litre to act as a preservative during distribution.
Guideline value derivation	
• allocation to water	100% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	An additional uncertainty factor for possible carcinogenicity was not applied because equivocal cancer effects reported in the NTP study in only one species and in only one sex were within the range observed in historical controls.
	Most individuals are able to taste chloramines at concentrations below 5 mg/l, and some at levels as low as 0.3 mg/l.
Assessment date	2003
Principal references	IPCS (2000) *Disinfectants and disinfectant by-products* WHO (2003) *Monochloramine in drinking-water*

Reason for not establishing guideline values	Available data inadequate to permit derivation of health-based guideline values for *dichloramine* and *trichloramine*
Assessment date	1993
Principal references	IPCS (2000) *Disinfectants and disinfectant by-products*

Monochloramine

Although monochloramine has been shown to be mutagenic in some in vitro studies, it has not been found to be genotoxic in vivo. IARC has classified chloramine in Group 3 (not classifiable as to its carcinogenicity to humans). In the NTP bioassay in two species, the incidence of mononuclear cell leukaemias in female rats was increased, but no other increases in tumour incidence were observed. IPCS did not consider the increase in mononuclear cell leukaemia to be treatment related.

Dichloramine and trichloramine

Dichloramine and trichloramine have not been extensively studied, and available data are inadequate to permit derivation of health-based guideline values for either of these chemicals. However, these substances can cause taste and odour problems (see chapter 10) if formation of monochloramine is not controlled adequately.

Chlordane

Chlordane (CAS No. 57-47-9) is a broad-spectrum insecticide that has been used since 1947. Its use has recently been increasingly restricted in many countries, and it is now used mainly to destroy termites by subsurface injection into soil. Chlordane may be a low-level source of contamination of groundwater when applied by subsurface injection. Technical chlordane is a mixture of compounds, with the *cis* and *trans* forms of chlordane predominating. It is very resistant to degradation, highly immobile in soil and unlikely to migrate to groundwater, where it has only rarely been found. It is readily lost to the atmosphere. Although levels of chlordane in food have been decreasing, it is highly persistent and has a high bioaccumulation potential.

Guideline value	0.0002 mg/l (0.2 µg/l)
Occurrence	Has been detected in both drinking-water and groundwater, usually at levels below 0.1 µg/l
PTDI	0.5 µg/kg body weight based on a NOAEL of 50 µg/kg body weight per day for increased liver weights, serum bilirubin levels and incidence of hepatocellular swelling, derived from a long-term dietary study in rats, and using an uncertainty factor of 100 (10 each for interspecies and intraspecies variation)
Limit of detection	0.014 µg/l by GC with ECD
Treatment performance	0.1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	1% of PTDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	Chlordane is listed under the Stockholm Convention on Persistent Organic Pollutants. Hence, monitoring may occur in addition to that required by drinking-water guidelines.
Assessment date	2003
Principal references	FAO/WHO (1995) *Pesticide residues in food—1994 evaluations* WHO (2003) *Chlordane in drinking-water*

In experimental animals, prolonged exposure in the diet causes liver damage. Chlordane produces liver tumours in mice, but the weight of evidence indicates that it is not genotoxic. Chlordane can interfere with cell communication in vitro, a characteristic of many tumour promoters. IARC re-evaluated chlordane in 1991 and concluded that there is inadequate evidence for its carcinogenicity in humans and sufficient evidence for its carcinogenicity in animals, classifying it in Group 2B.

Chloride

Chloride in drinking-water originates from natural sources, sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion.

The main source of human exposure to chloride is the addition of salt to food, and the intake from this source is usually greatly in excess of that from drinking-water.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	1993
Principal reference	WHO (2003) *Chloride in drinking-water*

Excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. This can lead to increased concentrations of metals in the supply.

No health-based guideline value is proposed for chloride in drinking-water. However, chloride concentrations in excess of about 250 mg/l can give rise to detectable taste in water (see chapter 10).

Chlorine

Chlorine is produced in large amounts and widely used both industrially and domestically as an important disinfectant and bleach. In particular, it is widely used in the disinfection of swimming pools and is the most commonly used disinfectant and oxidant in drinking-water treatment. In water, chlorine reacts to form hypochlorous acid and hypochlorites. Concentrations of chlorate and some perchlorates increase in hypochlorite solutions upon storage at high ambient temperatures or when new hypochlorite is added to old hypochlorite.

Guideline value	5 mg/l (5000 µg/l)
Occurrence	Present in most disinfected drinking-water at concentrations of 0.2–1 mg/l
TDI	150 µg/kg body weight, derived from a NOAEL for the absence of toxicity in rodents ingesting chlorine in drinking-water for 2 years
Limit of detection	0.01 µg/l following pre-column derivatization to 4-bromoacetanilide by HPLC; 10 µg/l as free chlorine by colorimetry; 200 µg/l by ion chromatography
Treatment performance	It is possible to reduce the concentration of chlorine effectively to zero (< 0.1 mg/l) by reduction. However, it is normal practice to supply water with a chlorine residual of a few tenths of a milligram per litre to act as a preservative during distribution.
Guideline value derivation	
• allocation to water	100% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The guideline value is conservative, as no adverse effect level was identified in the critical study.
	Most individuals are able to taste chlorine at the guideline value.

Assessment date	1993
Principal reference	WHO (2003) *Chlorine in drinking-water*

In humans and experimental animals exposed to chlorine in drinking-water, no specific adverse treatment-related effects have been observed. IARC has classified hypochlorite in Group 3 (not classifiable as to its carcinogenicity to humans).

Chlorite and chlorate

Chlorite and chlorate are disinfection by-products resulting from the use of chlorine dioxide as a disinfectant and for odour and taste control in water. Chlorine dioxide is also used as a bleaching agent for cellulose, paper pulp, flour and oils. Sodium chlorite and sodium chlorate are both used in the production of chlorine dioxide as well as for other commercial purposes. Chlorine dioxide rapidly decomposes into chlorite, chlorate and chloride ions in treated water, chlorite being the predominant species; this reaction is favoured by alkaline conditions. The major route of environmental exposure to chlorine dioxide, sodium chlorite and sodium chlorate is through drinking-water. Chlorate is also formed in sodium hypochlorite solution that is stored for long periods, particularly at high ambient temperatures.

Provisional guideline values	*Chlorite:* 0.7 mg/l (700 µg/l)
	Chlorate: 0.7 mg/l (700 µg/l)
	The guideline values for chlorite and chlorate are designated as provisional because use of chlorine dioxide as a disinfectant may result in the chlorite and chlorate guideline values being exceeded, and difficulties in meeting the guideline value must never be a reason for compromising adequate disinfection.
Occurrence	Levels of chlorite in water reported in one study ranged from 3.2 to 7.0 mg/l; however, the combined levels will not exceed the dose of chlorine dioxide applied. Chlorate can also form in hypochlorite solutions on storage.
TDIs	*Chlorite:* 30 µg/kg body weight based on a NOAEL of 2.9 mg/kg body weight per day identified in a two-generation study in rats, based on lower startle amplitude, decreased absolute brain weights in two generations and altered liver weights in two generations, using an uncertainty factor of 100 (10 each for interspecies and intraspecies variation)
	Chlorate: 30 µg/kg body weight based on a NOAEL of 30 mg/kg body weight per day in a well-conducted 90-day study in rats, based on thyroid gland colloid depletion at the next higher dose, and using an uncertainty factor of 1000 (10 each for interspecies and intraspecies variation and 10 for the short duration of the study)
Limit of detection	5 µg/l by ion chromatography with suppressed conductivity detection for chlorate

Treatment performance	It is possible to reduce the concentration of chlorine dioxide effectively to zero (< 0.1 mg/l) by reduction; however, it is normal practice to supply water with a chlorine dioxide residual of a few tenths of a milligram per litre to act as a preservative during distribution. Chlorate concentrations arising from the use of sodium hypochlorite are generally around 0.1 mg/l, although concentrations above 1 mg/l have been reported. With chlorine dioxide disinfection, the concentration of chlorate depends heavily on process conditions (in both the chlorine dioxide generator and the water treatment plant) and applied dose of chlorine dioxide. As there is no viable option for reducing chlorate concentrations, control of chlorate concentration must rely on preventing its addition (from sodium hypochlorite) or formation (from chlorine dioxide). Chlorite ion is an inevitable by-product arising from the use of chlorine dioxide. When chlorine dioxide is used as the final disinfectant at typical doses, the resulting chlorite concentration should be less than 0.2 mg/l. If chlorine dioxide is used as a pre-oxidant, the resulting chlorite concentration may need to be reduced using ferrous iron or activated carbon.
Guideline value derivation	
• allocation to water	80% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	2003
Principal references	IPCS (2000) *Disinfectants and disinfectant by-products* WHO (2005) *Chlorite and chlorate in drinking-water*

Chlorine dioxide

Chlorine dioxide has been shown to impair neurobehavioural and neurological development in rats exposed perinatally. Significant depression of thyroid hormones has also been observed in rats and monkeys exposed to it in drinking-water studies. A guideline value has not been established for chlorine dioxide because of its rapid hydrolysis to chlorite and because the provisional guideline value for chlorite is adequately protective for potential toxicity from chlorine dioxide. The taste and odour threshold for this compound is 0.4 mg/l.

Chlorite

IARC has concluded that chlorite is not classifiable as to its carcinogenicity to humans. The primary and most consistent finding arising from exposure to chlorite is oxidative stress resulting in changes in the red blood cells. This end-point is seen in laboratory animals and, by analogy with chlorate, in humans exposed to high doses in poisoning incidents. Studies with human volunteers for up to 12 weeks did not identify any effect on blood parameters at the highest dose tested, 36 μg/kg body weight per day.

Chlorate

Like chlorite, the primary concern with chlorate is oxidative damage to red blood cells. Also like chlorite, a chlorate dose of 36 μg/kg body weight per day for 12 weeks did not result in any adverse effects in human volunteers. Although the database for chlorate is less extensive than that for chlorite, a well-conducted 90-day study in rats is available. High doses of chlorate can also interfere with thyroid function.

Chloroacetones

1,1-Dichloroacetone is formed from the reaction between chlorine and organic precursors and has been detected in chlorinated drinking-water. Concentrations are estimated to be less than 10 µg/l and usually less than 1 µg/l.

Reason for not establishing guideline values	Available data inadequate to permit derivation of health-based guideline values for any of the chloroacetones
Assessment date	1993
Principal reference	WHO (2003) *Chloroacetones in drinking-water*

The toxicological data on 1,1-dichloroacetone are very limited, although studies with single doses indicate that it affects the liver.

There are insufficient data at present to permit the setting of guideline values for 1,1-dichloroacetone or any of the other chloroacetones.

Chlorophenols (2-chlorophenol, 2,4-dichlorophenol, 2,4,6-trichlorophenol)

Chlorophenols are present in drinking-water as a result of the chlorination of phenols, as by-products of the reaction of hypochlorite with phenolic acids, as biocides or as degradation products of phenoxy herbicides. Those most likely to occur in drinking-water as by-products of chlorination are 2-chlorophenol, 2,4-dichlorophenol and 2,4,6-trichlorophenol. The taste thresholds for chlorophenols in drinking-water are low.

Guideline value	*2,4,6-Trichlorophenol:* 0.2 mg/l (200 µg/l)
Occurrence	Concentrations of chlorophenols in drinking-water usually less than 1 µg/l
Basis of guideline value derivation	Applying the linearized multistage model to leukaemias in male rats observed in a 2-year feeding study (hepatic tumours found in this study were not used for risk estimation because of the possible role of contaminants in their induction)
Limit of detection	0.5–5 µg/l by formation of pentafluorobenzyl ether derivatives; 0.01 µg/l using GC with ECD
Treatment performance	2,4,6-Trichlorophenol concentrations can be reduced using GAC
Additional comments	The guideline value for 2,4,6-trichlorophenol exceeds its lowest reported taste threshold.
Assessment date	1993
Principal reference	WHO (2003) *Chlorophenols in drinking-water*

Reason for not establishing guideline values	Available data inadequate to permit derivation of health-based guideline values for *2-chlorophenol* and *2,4-dichlorophenol*
Assessment date	1993
Principal reference	WHO (2003) *Chlorophenols in drinking-water*

2-Chlorophenol

Data on the toxicity of 2-chlorophenol are limited. Therefore, no health-based guideline value has been derived.

2,4-Dichlorophenol

Data on the toxicity of 2,4-dichlorophenol are limited. Therefore, no health-based guideline value has been derived.

2,4,6-Trichlorophenol

2,4,6-Trichlorophenol has been reported to induce lymphomas and leukaemias in male rats and hepatic tumours in male and female mice. The compound has not been shown to be mutagenic in the Ames test but has shown weak mutagenic activity in other in vitro and in vivo studies. IARC has classified 2,4,6-trichlorophenol in Group 2B (possibly carcinogenic to humans).

Chloropicrin

Chloropicrin, or trichloronitromethane, is formed by the reaction of chlorine with humic and amino acids and with nitrophenols. Its formation is increased in the presence of nitrates. Limited data from the USA indicate that concentrations in drinking-water are usually less than 5 µg/l.

Reason for not establishing a guideline value	Available data inadequate to permit derivation of health-based guideline value
Assessment date	1993
Principal reference	WHO (2003) *Chloropicrin in drinking-water*

Decreased survival and body weights have been reported following long-term oral exposure in laboratory animals. Chloropicrin has been shown to be mutagenic in bacterial tests and in in vitro assays in lymphocytes. Because of the high mortality in a carcinogenesis bioassay and the limited number of end-points examined in the 78-week toxicity study, the available data were considered inadequate to permit the establishment of a guideline value for chloropicrin.

Chlorotoluron

Chlorotoluron (CAS No. 15545-48-9) is a pre-emergence or early post-emergence herbicide that is slowly biodegradable and mobile in soil. There is only very limited exposure to this compound from food.

Guideline value	0.03 mg/l (30 µg/l)
Occurrence	Detected in drinking-water at concentrations of less than 1 µg/l
TDI	11.3 µg/kg body weight, derived from a NOAEL of 11.3 mg/kg body weight per day for systemic effects in a 2-year feeding study in mice using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for evidence of carcinogenicity)

Limit of detection	0.1 µg/l by separation by reversed-phase HPLC followed by UV and electrochemical detection
Treatment performance	0.1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Chlorotoluron in drinking-water*

Chlorotoluron is of low toxicity following single, short-term and long-term exposures in experimental animals, but it has been shown to cause an increase in adenomas and carcinomas of the kidneys of male mice given high doses for 2 years. As no carcinogenic effects were reported in a 2-year study in rats, it has been suggested that chlorotoluron has a carcinogenic potential that is both species and sex specific. Chlorotoluron and its metabolites have shown no evidence of genotoxicity.

Chlorpyrifos

Chlorpyrifos (CAS No. 2921-88-2) is a broad-spectrum organophosphorus insecticide used for the control of mosquitoes, flies, various crop pests in soil and on foliage, household pests and aquatic larvae. Although it is not recommended for addition to water for public health purposes by the WHO Pesticide Evaluation Scheme (WHOPES), it may be used in some countries as an aquatic larvicide for the control of mosquito larvae. Chlorpyrifos is strongly absorbed by soil and does not readily leach from it, degrading slowly by microbial action. It has a low solubility in water and great tendency to partition from aqueous phases into organic phases in the environment.

Guideline value	0.03 mg/l (30 µg/l)
Occurrence	Detected in surface waters in the USA, usually at concentrations below 0.1 µg/l; also detected in groundwater in less than 1% of the wells tested, usually at concentrations below 0.01 µg/l
ADI	0–0.01 mg/kg body weight on the basis of a NOAEL of 1 mg/kg body weight per day for inhibition of brain acetylcholinesterase activity in studies in mice, rats and dogs, using a 100-fold uncertainty factor, and on the basis of a NOAEL of 0.1 mg/kg body weight per day for inhibition of erythrocyte acetylcholinesterase activity in a study of human subjects exposed for 9 days, using a 10-fold uncertainty factor
Limit of detection	1 µg/l by GC using ECD or flame photometric detection
Treatment performance	No data available; should be amenable to treatment by coagulation (10–20% removal), activated carbon adsorption and ozonation
Guideline value derivation	
• allocation to water	10% of upper limit of ADI
• weight	60 kg adult
• consumption	2 litres/day

Assessment date	2003
Principal references	FAO/WHO (2000) *Pesticide residues in food—1999 evaluations* WHO (2003) *Chlorpyrifos in drinking-water*

JMPR concluded that chlorpyrifos is unlikely to pose a carcinogenic risk to humans. Chlorpyrifos was not genotoxic in an adequate range of studies in vitro and in vivo. In long-term studies, inhibition of cholinesterase activity was the main toxicological finding in all species.

Chromium

Chromium is widely distributed in Earth's crust. It can exist in valences of +2 to +6. In general, food appears to be the major source of intake. Chromium(III) is an essential nutrient.

Provisional guideline value	*Total chromium:* 0.05 mg/l (50 µg/l)
	The guideline value is designated as provisional because of uncertainties in the toxicological database.
Occurrence	Total chromium concentrations in drinking-water usually less than 2 µg/l, although concentrations as high as 120 µg/l have been reported
Basis of guideline value derivation	There are no adequate toxicity studies available to provide a basis for a NOAEL. The guideline value was first proposed in 1958 for hexavalent chromium, based on health concerns, but was later changed to a guideline for total chromium because of difficulties in analysing for the hexavalent form only.
Limit of detection	0.05–0.2 µg/l for total chromium by AAS
Treatment performance	0.015 mg/l should be achievable using coagulation
Assessment date	1993
Principal reference	WHO (2003) *Chromium in drinking-water*

In a long-term carcinogenicity study in rats given chromium(III) by the oral route, no increase in tumour incidence was observed. In rats, chromium(VI) is a carcinogen via the inhalation route, although an NTP study has shown evidence for carcinogenicity via the oral route at high doses. However, there is evidence that the dose–response relationship at low doses is non-linear, because chromium(VI) is reduced to chromium(III) in the stomach and gastrointestinal tract. In epidemiological studies, an association has been found between exposure to chromium(VI) by the inhalation route and lung cancer. IARC has classified chromium(VI) in Group 1 (human carcinogen) and chromium(III) in Group 3 (not classifiable as to its carcinogenicity to humans). Chromium(VI) compounds are active in a wide range of in vitro and in vivo genotoxicity tests, whereas chromium(III) compounds are not.

Copper

Copper is both an essential nutrient and a drinking-water contaminant. It is used to make pipes, valves and fittings and is present in alloys and coatings. Copper sulfate

pentahydrate is sometimes added to surface water for the control of algae. Copper concentrations in drinking-water vary widely, with the primary source most often being the corrosion of interior copper plumbing. Levels in running or fully flushed water tend to be low, whereas those in standing or partially flushed water samples are more variable and can be substantially higher (frequently above 1 mg/l). Copper concentrations in treated water often increase during distribution, especially in systems with an acid pH or high-carbonate waters with an alkaline pH. Food and water are the primary sources of copper exposure in developed countries. Consumption of standing or partially flushed water from a distribution system that includes copper pipes or fittings can considerably increase total daily copper exposure, especially for infants fed formula reconstituted with tap water.

Guideline value	2 mg/l (2000 µg/l)
Occurrence	Concentrations in drinking-water range from ≤ 0.005 to > 30 mg/l, primarily as a result of the corrosion of interior copper plumbing
Basis of guideline value derivation	To be protective against acute gastrointestinal effects of copper and provide an adequate margin of safety in populations with normal copper homeostasis
Limit of detection	0.02–0.1 µg/l by ICP-MS; 0.3 µg/l by ICP–optical emission spectroscopy; 0.5 µg/l by flame AAS
Treatment performance	Copper is not removed by conventional treatment processes. However, copper is not normally a raw water contaminant.
Additional comments	For adults with normal copper homeostasis, the guideline value should permit consumption of 2 or 3 litres of water per day, use of a nutritional supplement and copper from foods without exceeding the tolerable upper intake level of 10 mg/day or eliciting an adverse gastrointestinal response.
	Staining of laundry and sanitary ware occurs at copper concentrations above 1 mg/l. At levels above 2.5 mg/l, copper imparts an undesirable bitter taste to water; at higher levels, the colour of water is also impacted.
	In most instances where copper tubing is used as a plumbing material, concentrations of copper will be below the guideline value. However, there are some conditions, such as highly acidic or aggressive waters, that will give rise to much higher copper concentrations, and the use of copper tubing may not be appropriate in such circumstances.
Assessment date	2003
Principal references	IPCS (1998) *Copper* WHO (2003) *Copper in drinking-water*

IPCS concluded that the upper limit of the acceptable range of oral intake in adults is uncertain but is most likely in the range of several (more than 2 or 3 mg/day), but not many, milligrams per day in adults. This evaluation was based solely on studies of gastrointestinal effects of copper-contaminated drinking-water. The available data on toxicity in experimental animals were not considered helpful in establishing the upper limit of the acceptable range of oral intake owing to uncertainty about an appropriate model for humans, but they help to establish a mode of action for the

response. The data on the gastrointestinal effects of copper must be used with caution, as the effects observed are influenced by the concentration of ingested copper to a greater extent than the total mass or dose ingested in a 24-hour period. Recent studies have delineated the threshold for the effects of copper in drinking-water on the gastrointestinal tract, but there is still some uncertainty regarding the long-term effects of copper on sensitive populations, such as carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis.

Cyanazine

Cyanazine (CAS No. 21725-46-2) is a member of the triazine family of herbicides. It is used as a pre-emergence and post-emergence herbicide for the control of annual grasses and broadleaf weeds. It can be degraded in soil and water by microorganisms and by hydrolysis.

Guideline value	0.0006 mg/l (0.6 µg/l)
Occurrence	Has been detected in surface water and groundwater, usually at concentrations of a few micrograms per litre, although levels as high as 1.3 and 3.5 mg/l have been measured in surface water and groundwater, respectively
TDI	0.198 µg/kg body weight based on a NOAEL of 0.198 mg/kg body weight for hyperactivity in male rats in a 2-year toxicity/carcinogenicity study, using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for limited evidence of carcinogenicity)
Limit of detection	0.01 µg/l by GC-MS
Treatment performance	0.1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1998
Principal reference	WHO (2003) *Cyanazine in drinking-water*

On the basis of the available mutagenicity data on cyanazine, evidence for genotoxicity is equivocal. Cyanazine causes mammary gland tumours in rats but not in mice. The mechanism of mammary gland tumour development in rats is currently under investigation and may prove to be hormonal. Cyanazine is also teratogenic in rats at dose levels of 25 mg/kg body weight per day and higher.

Cyanide

Cyanides can be found in some foods, particularly in some developing countries, and they are occasionally found in drinking-water, but usually only at very low concentrations. However, there are occasions on which large spills of cyanide, associated with industry, occur, and these can give rise to very high concentrations in drinking-water source waters, particularly surface waters.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern, except in emergency situations following a spill to a water source
Assessment date	2009
Principal references	IPCS (2004) *Hydrogen cyanide and cyanides* WHO (2009) *Cyanide in drinking-water*

Cyanide is highly acutely toxic. It is detoxified in the liver by first-pass metabolism following oral exposure. As a consequence, exposure to a dose spread over a longer period, through a day, for example, will result in lower toxicity, or higher tolerance, than the same dose given in a single bolus dose. Exposure to high doses can give rise to thyroid toxicity as a secondary effect of exposure due to the inhibition of iodine uptake from the thiocyanate generated through the detoxifying action of rhodanese. It is difficult to interpret human data in view of the difficulty in assessing the actual absorbed dose in humans following acute fatal intoxication and the lack of well-conducted studies on sublethal toxicity.

There is a need for guidance regarding concentrations that would not be of concern for public health following short-term exposure to cyanide. However, because cyanide is unlikely to occur in drinking-water at concentrations of health concern, it is considered unnecessary to derive a formal guideline value for short-term exposure to cyanide.

The data on acute exposure to cyanide are unsuitable for use in deriving a health-based value for short-term exposure because of the high uncertainty surrounding the data. Using the NOAEL for effects on the reproductive organs of male rats in a 13-week study and an uncertainty factor of 100, a TDI of 0.045 mg/kg body weight can be derived. Because this health-based value is intended for short-term use and exposure would not exceed 5 days, it is considered to be acceptable to allocate 40% of the TDI to drinking-water to allow for exposure to cyanogenic glycosides in food. Therefore, assuming a 60 kg adult drinking 2 litres of water per day with an allocation of 40% of the TDI to drinking-water, a health-based value of 0.5 mg/l (rounded value) for short-term exposure can be calculated.

This health-based value is well below the level that is normally considered to be of health concern for humans. Cyanide is rapidly detoxified, and exposure spread throughout the day will further reduce the potential for effects. This health-based value would be suitable for use for a limited period of up to 5 days, which is the longest period likely to be required under the circumstances of such an emergency. However, it is probable that, in most circumstances, this value will be highly conservative for short-term exposure.

It should be noted that the lowest reported odour threshold for cyanide in drinking-water is 0.17 mg/l, which is below the short-term health-based value. It is therefore possible that a small number of individuals will detect cyanide by odour at concentrations below the health-based value.

The health-based value relates to total cyanide concentration at the tap, including cyanide from cyanogen chloride in drinking-water as a by-product of disinfection with chlorine. Cyanogen chloride rapidly breaks down to cyanide in the distribution system or when ingested. As the low levels of cyanide normally found in drinking-water

are mostly a consequence of the presence of cyanogen chloride, it is not considered necessary to develop a guideline value for long-term exposure to cyanide.

Cyanobacterial toxins: Microcystin-LR

Among the cyanobacterial toxins, microcystins are the best-researched group and probably occur most frequently in fresh waters. Many practical considerations for the abatement of microcystins apply similarly to the other cyanotoxins (i.e. cylindrospermopsins, saxitoxins, anatoxin-a and anatoxin-a(s)), with one key difference that is relevant to the efficacy of their removal in drinking-water treatment: microcystins are usually cell-bound, and substantial amounts are released to the surrounding water only in situations of cell rupture (i.e. lysis), whereas the other cyanotoxins may occur to a larger extent dissolved in water.

Although microcystins may occur in fish, molluscs and shellfish from water bodies with cyanobacterial proliferation, human exposure to microcystins is largely through drinking-water or recreational use of water bodies with cyanobacterial blooms.

Among the more than 80 microcystins identified to date, only a few occur frequently and in high concentrations. Microcystin-LR is among the most frequently occurring and most toxic microcystin congeners. It is the only one for which enough toxicological data are available with which to derive a provisional guideline value. Frequently occurring cyanobacterial genera that may contain microcystins are *Microcystis*, *Planktothrix* and *Anabaena* (see also section 11.5).

Provisional guideline value	*Total microcystin-LR (free plus cell-bound):* 0.001 mg/l (1 µg/l)
	The guideline value is provisional, as it covers only microcystin-LR, the database is limited and new data for the toxicity of cyanobacterial toxins are being generated.
TDI	0.04 µg/kg body weight, based on liver pathology observed in a 13-week study in mice and applying an uncertainty factor of 1000, taking into consideration limitations in the database, in particular lack of data on chronic toxicity and carcinogenicity
Limit of detection	0.1–1 µg/l by HPLC following extraction of cells with 75% aqueous methanol or following concentration of microcystins from liquid samples on C-18; will allow differentiation between variants where standards are available
	0.1–0.5 µg/l by commercially available immunoassay kits (enzyme-linked immunosorbent assay) for microcystins dissolved in water or in aqueous extracts of cells; will detect most microcystins; these are less precise in quantification than HPLC, but useful for screening
	0.5–1.5 µg/l by protein phosphatase assay for microcystins dissolved in water or in aqueous extracts of cells; will detect all microcystins; this assay is less precise in quantification and identification than HPLC, but useful for screening
Monitoring	The preferred approach is visual monitoring (including microscopy for potentially microcystin-containing genera) of source water for evidence of increasing cyanobacterial cell density (blooms) or bloom-forming potential and increased vigilance where such events occur

Prevention and treatment	Actions to decrease the probability of bloom occurrence include catchment and source water management, such as reducing nutrient loading or changing reservoir stratification and mixing. Treatment effective for the removal of cyanobacteria includes filtration to remove intact cells. Treatment effective against free microcystins in water (as well as most other free cyanotoxins) includes oxidation through ozone or chlorine at sufficient concentrations and contact times, as well as GAC and some PAC applications.
Guideline value derivation	
• allocation to water	80% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	2003
Principal references	Chorus & Bartram (1999) *Toxic cyanobacteria in water* WHO (2003) *Cyanobacterial toxins: Microcystin-LR in drinking-water*

Microcystin-LR is a potent inhibitor of eukaryotic protein serine/threonine phosphatases 1 and 2A. The primary target for microcystin toxicity is the liver, as microcystins cross cell membranes chiefly through the bile acid transporter. Guideline value derivation was based on an oral 13-week study with mice, supported by an oral 44-day study with pigs. A large number of poisonings of livestock and wildlife have been recorded. Evidence of tumour promotion has been published. In 2006, IARC classified microcystin-LR as a possible carcinogen (Group 2B).

Practical considerations

Cyanobacteria occur widely in lakes, reservoirs, ponds and slow-flowing rivers. Where their excessive growth leads to high cell numbers, sometimes termed "bloom" events, their toxins can reach concentrations in raw water that are potentially hazardous to human health. Blooms occur if concentrations of nutrients (phosphorus and nitrogen) are elevated, particularly in stagnant or very slowly flowing water bodies. Blooms tend to recur in the same water bodies. Cells of some cyanobacterial species may accumulate at the surface as scums or at the thermocline of thermally stratified reservoirs. Such accumulations may develop rapidly, and they may be of very variable duration (hours to weeks). In many circumstances, blooms and accumulations are seasonal.

A variety of resource protection and source management actions are available to decrease the probability of bloom occurrence. Among these, the most sustainable and effective measure is to reduce nutrient (particularly phosphorus) concentrations in the water body to levels sufficiently low to substantially limit the amount of cyanobacterial biomass that can grow. This is achieved by controlling nutrient loads from sewage effluents and from land areas. The latter involves controlling erosion as well as the amount of manure and fertilizers spread in the catchment. Further, hydrological management actions such as water body mixing and flushing can render hydrophysical conditions less suitable for cyanobacteria and thus shift plankton species from cyanobacteria to others (i.e. planktonic algae such as diatoms) that are less relevant to human health.

As microcystins almost always occur largely cell-bound, any drinking-water treatment that removes particles—i.e. soil or riverbank filtration, flocculation and filtration or dissolved air filtration—controls them effectively if the process is optimized to target their removal. This also applies to the cell-bound fraction of other cyanotoxins. Process operation should avoid cell rupture and toxin release. Hazardously high concentrations of dissolved cyanotoxins appear to occur less frequently. They are well removed by most types of activated carbon. Chlorination and ozonation are effective for the removal of many cyanotoxins at sufficiently high doses and contact times, but not very effective for saxitoxins. Potassium permanganate is effective for microcystins, whereas limited or no data are available at present for other toxins. Chlorine dioxide and chloramine are ineffective for removing cyanotoxins.

Cyanotoxin monitoring is most effectively based on surveillance of source water for evidence of cyanobacterial blooms or bloom-forming potential (i.e. nutrient levels and phytoplankton species composition), with vigilance increased where such events occur. In contrast, monitoring finished water against target cyanotoxin concentrations is unsatisfactory for determining whether or not it is safe, because of the large variety of toxins (particularly of microcystins), the lack of guideline values for all but one (i.e. microcystin-LR) against which to monitor and the lack of analytical standards for many. Analysis of cyanotoxins is particularly useful for validating and optimizing the efficacy of control measures such as riverbank filtration or treatment. A caveat in cyanotoxin analysis is the need for extraction of the cell-bound fraction from the cells; although this is easy to do, particularly for microcystins, neglecting extraction from cells will lead to dramatic underestimation of concentrations.

Cyanogen chloride

Cyanogen chloride may be formed as a by-product of chloramination or chlorination of water. It is also formed by the chlorination of cyanide ion present in raw water.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2009
Principal references	IPCS (2004) *Hydrogen cyanide and cyanides* WHO (2009) *Cyanogen chloride in drinking-water*

Cyanogen chloride is rapidly metabolized to cyanide in the body. There are few data available on the oral toxicity of cyanogen chloride.

As cyanogen chloride is unlikely to be found in drinking-water at concentrations that are of health concern, it is considered unnecessary to develop a formal guideline value for cyanogen chloride. Instead, for guidance purposes, a health-based value is derived based on cyanide.

Using a NOAEL for cyanide of 4.5 mg/kg body weight per day for minor changes in the testis in a subchronic study in which rats were exposed through their drinking-water and an uncertainty factor of 100, a TDI for cyanide of 0.045 mg/kg body weight (corresponding to a cyanogen chloride dose of 0.11 mg/kg body weight) can be

derived. In view of the minor nature of the changes observed and the NOAEL in a previous chronic study, it is not considered necessary to include an additional uncertainty factor to allow for the length of the study. Further, it appears that a dose that may be toxic in acute poisoning would certainly be tolerated under chronic conditions, owing to efficient detoxification. Assuming a 60 kg adult drinking 2 litres of water per day and allowing 20% of the TDI to come from water because of the potential for exposure to cyanogenic glycosides in food, the health-based value for long-term exposure is 0.3 mg/l for cyanide or 0.6 mg/l for cyanogen chloride (rounded values).

Although low concentrations of cyanide in raw waters will be converted to cyanogen chloride by chlorination, cyanogen chloride may also be formed during the production of chloramines in situ as a residual disinfectant to maintain the hygienic condition of the distribution system. It is important that treatment be optimized to minimize the formation of cyanogen chloride while maintaining adequate chloramine residuals where chloramination is practised.

2,4-D

The term 2,4-D is used here to refer to the free acid, 2,4-dichlorophenoxyacetic acid (CAS No. 94-75-7). Commercial 2,4-D products are marketed as the free acid, alkali and amine salts and ester formulations. 2,4-D itself is chemically stable, but its esters are rapidly hydrolysed to the free acid. 2,4-D is a systemic herbicide used for control of broad-leaved weeds, including aquatic weeds. 2,4-D is rapidly biodegraded in the environment. Residues of 2,4-D in food rarely exceed a few tens of micrograms per kilogram.

Guideline value	0.03 mg/l (30 µg/l)
Occurrence	Levels in water usually below 0.5 µg/l, although concentrations as high as 30 µg/l have been measured
ADI	0–0.01 mg/kg body weight for the sum of 2,4-D and its salts and esters, expressed as 2,4-D, on the basis of a NOAEL of 1 mg/kg body weight per day in a 1-year study of toxicity in dogs (for a variety of effects, including histopathological lesions in kidneys and liver) and a 2-year study of toxicity and carcinogenicity in rats (for renal lesions)
Limit of detection	0.1 µg/l by gas–liquid chromatography with electrolytic conductivity detection
Treatment performance	1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of upper limit of ADI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The guideline value applies to 2,4-D, as salts and esters of 2,4-D are rapidly hydrolysed to the free acid in water.
Assessment date	1998
Principal references	FAO/WHO (1997) *Pesticide residues in food—1996 evaluations* WHO (2003) *2,4-D in drinking-water*

Epidemiological studies have suggested an association between exposure to chlorophenoxy herbicides, including 2,4-D, and two forms of cancer in humans: soft tissue sarcomas and non-Hodgkin lymphoma. The results of these studies, however, are inconsistent; the associations found are weak, and conflicting conclusions have been reached by the investigators. Most of the studies did not provide information on exposure specifically to 2,4-D, and the risk was related to the general category of chlorophenoxy herbicides, a group that includes 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), which was potentially contaminated with dioxins. JMPR concluded that it was not possible to evaluate the carcinogenic potential of 2,4-D on the basis of the available epidemiological studies. JMPR also concluded that 2,4-D and its salts and esters are not genotoxic. The toxicity of the salts and esters of 2,4-D is comparable to that of the acid.

2,4-DB

The half-lives for degradation of chlorophenoxy herbicides, including 2,4-DB, or 2,4-dichlorophenoxybutyric acid (CAS No. 94-82-6), in the environment are in the order of several days. Chlorophenoxy herbicides are not often found in food.

Guideline value	0.09 mg/l (90 µg/l)
Occurrence	Chlorophenoxy herbicides not frequently found in drinking-water; when detected, concentrations usually no greater than a few micrograms per litre
TDI	30 µg/kg body weight, based on a NOAEL of 3 mg/kg body weight per day for effects on body and organ weights, blood chemistry and haematological parameters in a 2-year study in rats, with an uncertainty factor of 100 (for interspecies and intraspecies variation)
Limit of detection	1 µg/l to 1 mg/l for various methods commonly used for the determination of chlorophenoxy herbicides in water, including solvent extraction, separation by GC, gas–liquid chromatography, thin-layer chromatography or HPLC, with ECD or UV detection
Treatment performance	0.1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The NOAEL used in the guideline value derivation is similar to the NOAEL of 2.5 mg/kg body weight per day obtained in a short-term study in dogs and the NOAEL for hepatocyte hypertrophy of 5 mg/kg body weight per day obtained in a 3-month study in rats.
Assessment date	1993
Principal reference	WHO (2003) *Chlorophenoxy herbicides (excluding 2,4-D and MCPA) in drinking-water*

Chlorophenoxy herbicides, as a group, have been classified in Group 2B (possibly carcinogenic to humans) by IARC. However, the available data from studies in exposed populations and experimental animals do not permit assessment of the carcinogenic potential to humans of any specific chlorophenoxy herbicide. Therefore, drinking-water guidelines for these compounds are based on a threshold approach for other toxic effects.

DDT and metabolites

The structure of dichlorodiphenyltrichloroethane, or DDT (CAS No. 107917-42-0), permits several different isomeric forms; commercial products consist predominantly of *p*,*p*′-DDT. Its use has been restricted or banned in several countries, although DDT is still used in some countries for the control of vectors that transmit yellow fever, sleeping sickness, typhus, malaria and other insect-transmitted diseases. DDT and its metabolites are persistent in the environment and resistant to complete degradation by microorganisms. Food is the major source of intake of DDT and related compounds for the general population, although exposure has significantly decreased as a consequence of the greatly reduced use of DDT for all except specialist applications.

Guideline value	0.001 mg/l (1 µg/l)
Occurrence	Detected in surface water at concentrations below 1 µg/l; also detected in drinking-water at 100-fold lower concentrations
PTDI	0.01 mg/kg body weight based on a NOAEL of 1 mg/kg body weight per day for developmental toxicity in rats, applying an uncertainty factor of 100 (for interspecies and intraspecies variation)
Limit of detection	0.011 µg/l by GC using ECD
Treatment performance	0.1 µg/l should be achievable using coagulation or GAC
Guideline value derivation	
• allocation to water	1% of PTDI
• weight	10 kg child
• consumption	1 litre/day
Additional comments	DDT is listed under the Stockholm Convention on Persistent Organic Pollutants. Hence, monitoring may occur in addition to that required by drinking-water guidelines.
	It should be noted that the level of DDT and its metabolites in food has been falling steadily, and the allocation of 1% of the PTDI may be very conservative.
	The guideline value is derived on the basis of a 10 kg child consuming 1 litre of drinking-water per day, because infants and children may be exposed to greater amounts of chemicals in relation to their body weight and because of concern over the bioaccumulation of DDT.
	It should be emphasized that the benefits of DDT use in malaria and other vector control programmes outweigh any health risk from the presence of DDT in drinking-water.

Assessment date	2003
Principal references	FAO/WHO (2001) *Pesticide residues in food—2000 evaluations* WHO (2003) *DDT and its derivatives in drinking-water*

A working group convened by IARC classified the DDT complex (the mixture of the various isomers of DDT and associated compounds) as a non-genotoxic carcinogen in rodents and a potent promoter of liver tumours. IARC has concluded that there is insufficient evidence in humans and sufficient evidence in experimental animals for the carcinogenicity of DDT (Group 2B) based upon liver tumours observed in rats and mice. The results of epidemiological studies of pancreatic cancer, multiple myeloma, non-Hodgkin lymphoma and uterine cancer did not support the hypothesis of an association with environmental exposure to the DDT complex. Conflicting data were obtained with regard to some genotoxic end-points. In most studies, DDT did not induce genotoxic effects in rodent or human cell systems, nor was it mutagenic to fungi or bacteria. The United States Agency for Toxic Substances and Disease Registry concluded that the DDT complex could impair reproduction and development in several species. Hepatic effects of DDT in rats include increased liver weights, hypertrophy, hyperplasia, induction of microsomal enzymes, including cytochrome P450, cell necrosis, increased activity of serum liver enzymes and mitogenic effects, which might be related to a regenerative liver response to high doses of DDT.

Dialkyltins

The group of chemicals known as the organotins is composed of a large number of compounds with differing properties and applications. The most widely used organotins are the disubstituted compounds, which are employed as stabilizers in plastics, including polyvinyl chloride (PVC) water pipes, and the trisubstituted compounds, which are widely used as biocides.

Reason for not establishing a guideline value	Available data inadequate to permit derivation of health-based guideline values for any of the dialkyltins
Assessment date	2003
Principal reference	WHO (2003) *Dialkyltins in drinking-water*

The disubstituted compounds that may leach from PVC water pipes at low concentrations for a short time after installation are primarily immunotoxins, although they appear to be of low general toxicity. The data available are insufficient to permit the proposal of guideline values for individual dialkyltins.

1,2-Dibromo-3-chloropropane

1,2-Dibromo-3-chloropropane (CAS No. 96-12-8), or DBCP, is a soil fumigant that is highly soluble in water. It has a taste and odour threshold in water of 10 μg/l. DBCP was detected in vegetables grown in treated soils, and low levels have been detected in air.

Guideline value	0.001 mg/l (1 µg/l)
Occurrence	Limited survey found levels of up to a few micrograms per litre in drinking-water
Basis of guideline value derivation	Linearized multistage model was applied to the data on the incidence of stomach, kidney and liver tumours in the male rat in a 104-week dietary study
Limit of detection	0.02 µg/l by GC with ECD
Treatment performance	1 µg/l should be achievable using air stripping followed by GAC
Additional comments	The guideline value of 1 µg/l should be protective for the reproductive toxicity of DBCP.
Assessment date	1993
Principal reference	WHO (2003) *1,2-Dibromo-3-chloropropane in drinking-water*

On the basis of data from different strains of rats and mice, DBCP was determined to be carcinogenic in both sexes by the oral, inhalation and dermal routes. DBCP was also determined to be a reproductive toxicant in humans and several species of laboratory animals. DBCP was found to be genotoxic in a majority of in vitro and in vivo assays. IARC has classified DBCP in Group 2B based upon sufficient evidence of carcinogenicity in animals. Recent epidemiological evidence suggests an increase in cancer mortality in individuals exposed to high levels of DBCP.

1,2-Dibromoethane

1,2-Dibromoethane (CAS No. 106-93-4), or ethylene dibromide, is used as a lead scavenger in tetraalkyl lead petrol and antiknock preparations and as a fumigant for soils, grains and fruits. However, with the phasing out of leaded petrol and of the use of 1,2-dibromoethane in agricultural applications in many countries, use of this substance has declined significantly. In addition to its continued use as a petrol additive in some countries, 1,2-dibromoethane is currently used principally as a solvent and as an intermediate in the chemical industry.

Provisional guideline value	0.0004 mg/l (0.4 µg/l)
	The guideline value is provisional owing to serious limitations of the critical studies.
Occurrence	Detected in groundwater following its use as a soil fumigant at concentrations as high as 100 µg/l
Basis of guideline value derivation	Lower end of the range (and thus more conservative estimate) of lifetime low-dose cancer risks calculated by linearized multistage modelling of the incidences of haemangiosarcomas and tumours in the stomach, liver, lung and adrenal cortex (adjusted for the observed high early mortality, where appropriate, and corrected for the expected rate of increase in tumour formation in rodents in a standard bioassay of 104 weeks) of rats and mice exposed by gavage
Limit of detection	0.01 µg/l by microextraction GC-MS; 0.03 µg/l by purge-and-trap GC with halogen-specific detector; 0.8 µg/l by purge-and-trap capillary column GC with photoionization and electrolytic conductivity detectors in series

Treatment performance	0.1 µg/l should be achievable using GAC
Assessment date	2003
Principal references	IPCS (1995) *Report of the 1994 meeting of the Core Assessment Group* IPCS (1996) *1,2-Dibromoethane* WHO (2003) *1,2-Dibromoethane in drinking-water*

1,2-Dibromoethane has induced an increased incidence of tumours at several sites in all carcinogenicity bioassays identified in which rats or mice were exposed to the compound by gavage, ingestion in drinking-water, dermal application and inhalation. However, many of these studies were characterized by high early mortality, limited histopathological examination, small group sizes or use of only one exposure level. The substance acted as an initiator of liver foci in an initiation/promotion assay but did not initiate skin tumour development. 1,2-Dibromoethane was consistently genotoxic in in vitro assays, although results of in vivo assays were mixed. Biotransformation to active metabolites, which have been demonstrated to bind to DNA, is probably involved in the induction of tumours. Available data do not support the existence of a non-genotoxic mechanism of tumour induction. The available data thus indicate that 1,2-dibromoethane is a genotoxic carcinogen in rodents. Data on the potential carcinogenicity in humans are inadequate; however, it is likely that 1,2-dibromoethane is metabolized similarly in rodent species and in humans (although there may be varying potential for the production of active metabolites in humans, owing to genetic polymorphism). IARC classified 1,2-dibromoethane in Group 2A (probably carcinogenic to humans).

Dichloroacetic acid

Chlorinated acetic acids, including dichloroacetic acid (DCA), are formed from organic material during water chlorination. DCA has been used as a therapeutic agent to treat lactic acidosis, diabetes and familial hyperlipidaemia in humans.

Provisional guideline value	0.05 mg/l (50 µg/l)
	The guideline value is designated as provisional on the basis of technical achievability.
Occurrence	Found in groundwater and surface water distribution systems at concentrations up to about 100 µg/l, with mean concentrations below 20 µg/l
Basis of guideline value derivation	Linear multistage model applied to combined data for carcinomas and adenomas in male mice exposed to doses up to 429 mg/kg body weight per day for up to 2 years
Limit of detection	< 0.1–0.4 µg/l by GC with ECD; practical quantification limit 1 µg/l
Treatment performance	Concentrations may be reduced by installing or optimizing coagulation to remove precursors or by controlling the pH during chlorination.
Additional comments	The concentration associated with a 10^{-5} upper-bound excess lifetime cancer risk is 40 µg/l. In some circumstances, however, it may not be possible to adequately disinfect potable water and maintain DCA levels below 40 µg/l, so the provisional guideline value of 50 µg/l is retained.

Assessment date	2004
Principal reference	WHO (2005) *Dichloroacetic acid in drinking-water*

IARC reclassified DCA as Group 2B (possibly carcinogenic to humans) in 2002, based on the absence of data on human carcinogenicity and sufficient evidence of its carcinogenicity in experimental animals. This classification was based primarily on findings of liver tumours in rats and mice. Genotoxicity data are considered to be inconclusive, particularly at lower doses. Glycogen deposition, peroxisome proliferation, changes in signal transduction pathways and DNA hypomethylation have all been observed following DCA exposure and have been hypothesized to be involved in its carcinogenicity. However, the available data are not sufficient to establish a cancer mode of action with reasonable certainty, especially at the very low exposure levels expected to apply to humans ingesting chlorinated drinking-water. Recent data suggest that there may be more than one mechanism leading to tumours, as altered hepatic foci from treated mice were found to have three different types of cellular characteristics.

Dichlorobenzenes (1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene)

The dichlorobenzenes (DCBs) are widely used in industry and in domestic products such as odour-masking agents, chemical dyestuffs and pesticides. Sources of human exposure are predominantly air and food.

Guideline values	*1,2-Dichlorobenzene:* 1 mg/l (1000 µg/l)
	1,4-Dichlorobenzene: 0.3 mg/l (300 µg/l)
Occurrence	Have been found in raw water sources at levels as high as 10 µg/l and in drinking-water at concentrations up to 3 µg/l; much higher concentrations (up to 7 mg/l) present in contaminated groundwater
TDIs	*1,2-Dichlorobenzene:* 429 µg/kg body weight, based on a NOAEL of 60 mg/kg body weight per day for tubular degeneration of the kidney identified in a 2-year mouse gavage study, adjusting for daily dosing and using an uncertainty factor of 100 (for interspecies and intraspecies variation)
	1,4-Dichlorobenzene: 107 µg/kg body weight, based on a LOAEL of 150 mg/kg body weight per day for kidney effects identified in a 2-year rat study, adjusting for daily dosing and using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for the use of a LOAEL instead of a NOAEL and the carcinogenicity end-point)
Limit of detection	0.01–0.25 µg/l by gas–liquid chromatography with ECD; 3.5 µg/l by GC using a photoionization detector
Treatment performance	0.01 mg/l should be achievable using air stripping
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day

Additional comments	Guideline values for both 1,2- and 1,4-DCB far exceed their lowest reported taste thresholds in water of 1 and 6 µg/l, respectively.
Assessment date	1993
Principal reference	WHO (2003) *Dichlorobenzenes in drinking-water*

Reason for not establishing a guideline value	Available data inadequate to permit derivation of health-based guideline value for *1,3-dichlorobenzene*
Assessment date	1993
Principal reference	WHO (2003) *Dichlorobenzenes in drinking-water*

1,2-Dichlorobenzene

1,2-DCB is of low acute toxicity by the oral route of exposure. Oral exposure to high doses of 1,2-DCB affects mainly the liver and kidneys. The balance of evidence suggests that 1,2-DCB is not genotoxic, and there is no evidence for its carcinogenicity in rodents.

1,3-Dichlorobenzene

There are insufficient toxicological data on this compound to permit a guideline value to be proposed, but it should be noted that it is rarely found in drinking-water.

1,4-Dichlorobenzene

1,4-DCB is of low acute toxicity, but there is evidence that it increases the incidence of renal tumours in rats and of hepatocellular adenomas and carcinomas in mice after long-term exposure. IARC has placed 1,4-DCB in Group 2B (possibly carcinogenic to humans). 1,4-DCB is not considered to be genotoxic, and the relevance for humans of the tumours observed in experimental animals is doubtful.

1,1-Dichloroethane

1,1-Dichloroethane is used as a chemical intermediate and solvent. There are limited data showing that it can be present at concentrations of up to 10 µg/l in drinking-water. It is primarily of concern for groundwater.

Reason for not establishing a guideline value	Available data inadequate to permit derivation of health-based guideline value
Assessment date	1993
Principal reference	WHO (2003) *1,1-Dichloroethane in drinking-water*

1,1-Dichloroethane is rapidly metabolized by mammals to acetic acid and a variety of chlorinated compounds. It is of relatively low acute toxicity, and limited data are available on its toxicity from short-term and long-term studies. There is limited in vitro evidence of genotoxicity. One carcinogenicity study by gavage in mice and rats provided no conclusive evidence of carcinogenicity, although there was some evidence of an increased incidence of haemangiosarcomas in treated animals.

In view of the very limited database on toxicity and carcinogenicity, it was concluded that no guideline value should be proposed.

1,2-Dichloroethane

1,2-Dichloroethane is used mainly as an intermediate in the production of vinyl chloride and other chemicals and to a lesser extent as a solvent. It was used as a scavenger for tetraethyl lead in gasoline. It may enter surface waters via effluents from industries that manufacture or use the substance. It may also enter groundwater, where it may persist for long periods, following disposal in waste sites. It is found in urban air.

Guideline value	0.03 mg/l (30 µg/l)
Occurrence	Has been found in drinking-water at levels of up to a few micrograms per litre
Basis of guideline value derivation	Applying the linearized multistage model to haemangiosarcomas observed in male rats in a 78-week gavage study
Limit of detection	0.03 µg/l by GC with photoionization detection; 0.03–0.2 µg/l by GC with electrolytic conductivity detector; 0.06–2.8 µg/l by GC-MS; 5 µg/l by GC with flame ionization detection (FID)
Treatment performance	0.0001 mg/l should be achievable using GAC
Additional comments	The guideline value of 0.03 mg/l is consistent with the value derived from IPCS (1998), based on a 10^{-5} risk level.
Assessment date	2003
Principal references	IPCS (1995) *1,2-Dichloroethane*, 2nd ed. IPCS (1998) *1,2-Dichloroethane* WHO (2003) *1,2-Dichloroethane in drinking-water*

IARC has classified 1,2-dichloroethane in Group 2B (possible human carcinogen). It has been shown to produce statistically significant increases in a number of tumour types in laboratory animals, including the relatively rare haemangiosarcoma, and the balance of evidence indicates that it is potentially genotoxic. Targets of 1,2-dichloroethane toxicity in orally exposed animals included the immune system, central nervous system, liver and kidney. Data indicate that 1,2-dichloroethane is less potent when inhaled.

1,1-Dichloroethene

1,1-Dichloroethene, or vinylidene chloride, is used mainly as a monomer in the production of polyvinylidene chloride co-polymers and as an intermediate in the synthesis of other organic chemicals. It is an occasional contaminant of drinking-water, usually being found together with other chlorinated hydrocarbons. There are no data on levels in food, but levels in air are generally less than 40 ng/m^3 except at some manufacturing sites. 1,1-Dichloroethene is detected in finished drinking-water taken from groundwater sources at median concentrations of 0.28–1.2 µg/l and in public drinking-water supplies at concentrations up to 0.5 µg/l.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2004
Principal references	IPCS (2003) *1,1-Dichloroethene (vinylidene chloride)* WHO (2005) *1,1-Dichloroethene in drinking-water*

1,1-Dichloroethene is a central nervous system depressant and may cause liver and kidney toxicity in occupationally exposed humans. It causes liver and kidney damage in laboratory animals. IARC has placed 1,1-dichloroethene in Group 3 (not classifiable as to its carcinogenicity to humans). It was found to be genotoxic in a number of test systems in vitro but was not active in the dominant lethal and micronucleus assays in vivo. It induced kidney tumours in mice in one inhalation study but was reported not to be carcinogenic in a number of other studies, including several in which it was given in drinking-water.

A health-based value of 140 µg/l (rounded value) can be calculated on the basis of a TDI of 0.046 mg/kg body weight, derived using the benchmark dose (BMD) approach from a study in which the critical effect was minimal hepatocellular midzonal fatty change in female rats. However, this value is significantly higher than the concentrations of 1,1-dichloroethene normally found in drinking-water. It is therefore considered unnecessary to set a formal guideline value for 1,1-dichloroethene in drinking-water.

1,2-Dichloroethene

1,2-Dichloroethene exists in a *cis* and a *trans* form. The *cis* form is more frequently found as a water contaminant. The presence of these two isomers, which are metabolites of other unsaturated halogenated hydrocarbons in wastewater and anaerobic groundwater, may indicate the simultaneous presence of other organochlorine chemicals, such as vinyl chloride. Accordingly, their presence indicates that more intensive monitoring should be conducted. There are no data on exposure from food. Concentrations in air are low, with higher concentrations, in the microgram per cubic metre range, near production sites. The *cis* isomer was previously used as an anaesthetic.

Guideline value	0.05 mg/l (50 µg/l)
Occurrence	Has been found in drinking-water supplies derived from groundwater at levels up to 120 µg/l
TDI	17 µg/kg body weight, based on a NOAEL (for increases in serum alkaline phosphatase levels and increased thymus weight) of 17 mg/kg body weight from a 90-day study in mice administered *trans*-1,2-dichloroethene in drinking-water, using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for the short duration of the study)
Limit of detection	0.17 µg/l by GC-MS

Treatment performance	0.01 mg/l should be achievable using GAC or air stripping
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	Data on the *trans* isomer were used to calculate a joint guideline value for both isomers because toxicity for the *trans* isomer occurred at a lower dose than for the *cis* isomer and because data suggest that the mouse is a more sensitive species than the rat.
Assessment date	1993
Principal reference	WHO (2003) *1,2-Dichloroethene in drinking-water*

There is little information on the absorption, distribution or excretion of 1,2-dichloroethene. However, by analogy with 1,1-dichloroethene, 1,2-dichloroethene would be expected to be readily absorbed, distributed mainly to the liver, kidneys and lungs and rapidly excreted. The *cis* isomer is more rapidly metabolized than the *trans* isomer in in vitro systems. Both isomers have been reported to cause increased serum alkaline phosphatase levels in rodents. In a 3-month study in mice given the *trans* isomer in drinking-water, there was a reported increase in serum alkaline phosphatase and reduced thymus and lung weights. Transient immunological effects were also reported, the toxicological significance of which is unclear. *Trans*-1,2-dichloroethene also caused reduced kidney weights in rats, but at higher doses. Only one rat toxicity study is available for the *cis* isomer, which produced toxic effects in rats similar in magnitude to those induced by the *trans* isomer in mice, but at higher doses. There are limited data to suggest that both isomers may possess some genotoxic activity. There is no information on carcinogenicity.

Dichloromethane

Dichloromethane, or methylene chloride, is widely used as a solvent for many purposes, including coffee decaffeination and paint stripping. Exposure from drinking-water is likely to be insignificant compared with that from other sources.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Has been found in surface water samples at concentrations ranging from 0.1 to 743 µg/l; levels usually higher in groundwater because volatilization is restricted, with concentrations as high as 3600 µg/l reported; mean concentrations in drinking-water less than 1 µg/l
TDI	6 µg/kg body weight, derived from a NOAEL of 6 mg/kg body weight per day for hepatotoxic effects in a 2-year drinking-water study in rats, using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for concern about carcinogenic potential)
Limit of detection	0.3 µg/l by purge-and-trap GC with MS detection (note that dichloromethane vapour readily penetrates tubing during the procedure)

Treatment performance	20 µg/l should be achievable using air stripping
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Dichloromethane in drinking-water*

Dichloromethane is of low acute toxicity. An inhalation study in mice provided conclusive evidence of carcinogenicity, whereas drinking-water studies in rats and mice provided only suggestive evidence. IARC has placed dichloromethane in Group 2B (possible human carcinogen); however, the balance of evidence suggests that it is not a genotoxic carcinogen and that genotoxic metabolites are not formed in relevant amounts in vivo.

1,2-Dichloropropane

1,2-Dichloropropane (CAS No. 78-87-5), or 1,2-DCP, is used as an insecticide fumigant on grain and soil and to control peach tree borers. It is also used as an intermediate in the production of tetrachloroethene and other chlorinated products and as a solvent. 1,2-DCP is relatively resistant to hydrolysis, is poorly adsorbed onto soil and can migrate into groundwater.

Provisional guideline value	0.04 mg/l (40 µg/l)
	The guideline value is provisional owing to limitations of the toxicological database.
Occurrence	Detected in groundwater and drinking-water, usually at concentrations below 20 µg/l, although levels as high as 440 µg/l have been measured in well water
TDI	14 µg/kg body weight based on a LOAEL of 71.4 mg/kg body weight per day (100 mg/kg body weight per day adjusted for daily dosing) for changes in haematological parameters in a 13-week study in male rats, with an uncertainty factor of 5000 (100 for interspecies and intraspecies variation, 10 for use of a LOAEL and 5 to reflect limitations of the database, including the limited data on in vivo genotoxicity and use of a subchronic study)
Limit of detection	0.02 µg/l by purge-and-trap GC with an electrolytic conductivity detector or GC-MS
Treatment performance	1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1998

Principal reference	WHO (2003) *1,2-Dichloropropane (1,2-DCP) in drinking-water*

1,2-DCP was evaluated by IARC in 1986 and 1987. The substance was classified in Group 3 (not classifiable as to its carcinogenicity to humans) on the basis of limited evidence for its carcinogenicity in experimental animals and insufficient data with which to evaluate its carcinogenicity in humans. Results from in vitro assays for mutagenicity were mixed. The in vivo studies, which were limited in number and design, were negative. In accordance with the IARC evaluation, the evidence from the long-term carcinogenicity studies in mice and rats was considered limited, and it was concluded that the use of a threshold approach for the toxicological evaluation of 1,2-DCP was appropriate.

1,3-Dichloropropane

1,3-Dichloropropane (CAS No. 142-28-9) has several industrial uses and may be found as a contaminant of soil fumigants containing 1,3-dichloropropene. It is rarely found in water.

Reason for not establishing a guideline value	Available data inadequate to permit derivation of health-based guideline value
Assessment date	1993
Principal reference	WHO (2003) *1,3-Dichloropropane in drinking-water*

1,3-Dichloropropane is of low acute toxicity. There is some indication that it may be genotoxic in bacterial systems. No short-term, long-term, reproductive or developmental toxicity data pertinent to exposure via drinking-water could be located in the literature. The available data are considered insufficient to permit recommendation of a guideline value.

1,3-Dichloropropene

1,3-Dichloropropene (CAS Nos 542-75-6 isomer mixture; 10061-01-5 *cis* isomer; 10061-02-6 *trans* isomer) is a soil fumigant, the commercial product being a mixture of *cis* and *trans* isomers. It is used to control a wide variety of soil pests, particularly nematodes in sandy soils. Notwithstanding its high vapour pressure, it is soluble in water at the gram per litre level and can be considered a potential water contaminant.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Has been found in surface water and groundwater at concentrations of a few micrograms per litre
Basis of guideline value derivation	Calculated by applying the linearized multistage model to the observation of lung and bladder tumours in female mice in a 2-year gavage study
Limit of detection	0.34 and 0.20 µg/l by purge-and-trap packed column GC using an electrolytic conductivity detector or microcoulometric detector for the *cis* and *trans* isomers, respectively

Treatment performance	No information found on removal from water
Assessment date	1993
Principal reference	WHO (2003) *1,3-Dichloropropene in drinking-water*

1,3-Dichloropropene is a direct-acting mutagen that has been shown to produce forestomach tumours following long-term oral gavage exposure in rats and mice. Tumours have also been found in the bladder and lungs of female mice and the liver of male rats. Long-term inhalation studies in the rat have proved negative, whereas some benign lung tumours have been reported in inhalation studies in mice. IARC has classified 1,3-dichloropropene in Group 2B (possible human carcinogen).

Dichlorprop

The half-lives for degradation of chlorophenoxy herbicides, including dichlorprop (CAS No. 120-36-5), or 2,4-DP, in the environment are in the order of several days. Chlorophenoxy herbicides are not often found in food.

Guideline value	0.1 mg/l (100 µg/l)
Occurrence	Chlorophenoxy herbicides not frequently found in drinking-water; when detected, concentrations usually no greater than a few micrograms per litre
TDI	36.4 µg/kg body weight, based on a NOAEL of 3.64 mg/kg body weight per day for renal toxicity in a 2-year dietary study in rats, applying an uncertainty factor of 100 (for intraspecies and interspecies variation)
Limit of detection	1 µg/l to 1 mg/l for various methods commonly used for the determination of chlorophenoxy herbicides in water, including solvent extraction, separation by GC, gas–liquid chromatography, thin-layer chromatography or HPLC, with ECD or UV detection
Treatment performance	No information found on removal from water
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Chlorophenoxy herbicides (excluding 2,4-D and MCPA) in drinking-water*

Chlorophenoxy herbicides, as a group, have been classified in Group 2B (possible human carcinogen) by IARC. However, the available data from studies in exposed populations and experimental animals do not permit assessment of the carcinogenic potential to humans of any specific chlorophenoxy herbicide. Therefore, drinking-water guidelines for these compounds are based on a threshold approach for other toxic effects. In dietary studies in rats, slight liver hypertrophy was observed in a

3-month study, and effects in a 2-year study included hepatocellular swelling, mild anaemia, increased incidence of brown pigment in the kidneys (possibly indicative of slight degeneration of the tubular epithelium) and decreased urinary specific gravity and protein.

Di(2-ethylhexyl)adipate

Di(2-ethylhexyl)adipate (DEHA) is used mainly as a plasticizer for synthetic resins such as PVC. Reports of the presence of DEHA in surface water and drinking-water are scarce, but DEHA has occasionally been identified in drinking-water at levels of a few micrograms per litre. As a consequence of its use in PVC films, food is the most important source of human exposure (up to 20 mg/day).

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal reference	WHO (2003) *Di(2-ethylhexyl)adipate in drinking-water*

DEHA is of low short-term toxicity; however, dietary levels above 6000 mg/kg of feed induce peroxisomal proliferation in the liver of rodents. This effect is often associated with the development of liver tumours. DEHA induced liver carcinomas in female mice at very high doses, but not in male mice or rats. It is not genotoxic. IARC has placed DEHA in Group 3 (not classifiable as to its carcinogenicity to humans).

A health-based value of 80 µg/l can be calculated for DEHA on the basis of a TDI of 280 µg/kg body weight, based on fetotoxicity in rats, and allocating 1% of the TDI to drinking-water. However, because DEHA occurs at concentrations well below those of health concern, it is not considered necessary to derive a formal guideline value.

Di(2-ethylhexyl)phthalate

Di(2-ethylhexyl)phthalate (DEHP) is used primarily as a plasticizer. Exposure among individuals may vary considerably because of the broad nature of products into which DEHP is incorporated. In general, food will be the main exposure route.

Guideline value	0.008 mg/l (8 µg/l)
Occurrence	Found in surface water, groundwater and drinking-water in concentrations of a few micrograms per litre; in polluted surface water and groundwater, concentrations of hundreds of micrograms per litre have been reported
TDI	25 µg/kg body weight, based on a NOAEL of 2.5 mg/kg body weight per day for peroxisomal proliferation in the liver in rats, using an uncertainty factor of 100 for interspecies and intraspecies variation
Limit of detection	0.1 µg/l by GC-MS

Treatment performance	No information found on removal from water
Guideline value derivation	
• allocation to water	1% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The reliability of some data on environmental water samples is questionable because of secondary contamination during sampling and working-up procedures. Concentrations that exceed the solubility more than 10-fold have been reported.
Assessment date	1993
Principal reference	WHO (2003) *Di(2-ethylhexyl)phthalate in drinking-water*

In rats, DEHP is readily absorbed from the gastrointestinal tract. In primates (including humans), absorption after ingestion is lower. Species differences are also observed in the metabolic profile. Most species excrete primarily the conjugated mono-ester in urine. Rats, however, predominantly excrete terminal oxidation products. DEHP is widely distributed in the body, with highest levels in liver and adipose tissue, without showing significant accumulation. The acute oral toxicity is low. The most striking effect in short-term toxicity studies is the proliferation of hepatic peroxisomes, indicated by increased peroxisomal enzyme activity and histopathological changes. The available information suggests that primates, including humans, are far less sensitive to this effect than rodents. In long-term oral carcinogenicity studies, hepatocellular carcinomas were found in rats and mice. IARC has concluded that DEHP is possibly carcinogenic to humans (Group 2B). In 1988, JECFA evaluated DEHP and recommended that human exposure to this compound in food be reduced to the lowest level attainable. JECFA considered that this might be achieved by using alternative plasticizers or alternatives to plastic material containing DEHP. In a variety of in vitro and in vivo studies, DEHP and its metabolites have shown no evidence of genotoxicity, with the exception of induction of aneuploidy and cell transformation.

Dimethoate

Dimethoate (CAS No. 60-51-5) is an organophosphorus insecticide used to control a broad range of insects in agriculture, as well as the housefly. It has a half-life of 18 hours to 8 weeks and is not expected to persist in water, although it is relatively stable at pH 2–7. A total daily intake from food of 0.001 µg/kg body weight has been estimated.

Guideline value	0.006 mg/l (6 µg/l)
Occurrence	Detected at trace levels in a private well in Canada, but not detected in a Canadian survey of surface water or drinking-water supplies
ADI	0–0.002 mg/kg body weight based on an apparent NOAEL of 1.2 mg/kg body weight per day for reproductive performance in a study of reproductive toxicity in rats, applying an uncertainty factor of 500 (100 for interspecies and intraspecies variation, 5 to take into consideration concern regarding whether the NOAEL could be a LOAEL)

Assessment date	2003
Principal references	FAO/WHO (1997) *Pesticide residues in food—1996 evaluations* WHO (2003) *Dimethoate in drinking-water*

In studies with human volunteers, dimethoate has been shown to be a cholinesterase inhibitor and a skin irritant. Dimethoate is not carcinogenic to rodents. JMPR concluded that although in vitro studies indicate that dimethoate has mutagenic potential, this potential does not appear to be expressed in vivo. In a multigeneration study of reproductive toxicity in rats, the NOAEL appeared to be 1.2 mg/kg body weight per day, but there was some indication that reproductive performance may have been affected at lower doses. No data were available to assess whether the effects on reproductive performance were secondary to inhibition of cholinesterase. JMPR concluded that it was not appropriate to base the ADI on the results of the studies of volunteers, as the crucial end-point (reproductive performance) has not been assessed in humans. It was suggested that there may be a need to re-evaluate the toxicity of dimethoate after the periodic review of the residue and analytical aspects of dimethoate has been completed if it is determined that omethoate is a major residue.

1,4-Dioxane

1,4-Dioxane is used as a stabilizer in chlorinated solvents and as a solvent for resins, oils and waxes, for agricultural and biochemical intermediates and for adhesives, sealants, cosmetics, pharmaceuticals, rubber chemicals and surface coatings.

Guideline value	0.05 mg/l (50 µg/l)
Occurrence	Has been measured in surface water at concentrations up to 40 µg/l and in groundwater at concentrations up to 80 µg/l
TDI	16 µg/kg body weight, based on a NOAEL of 16 mg/kg body weight per day for hepatocellular tumours observed in a long-term drinking-water study in rats, using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for non-genotoxic carcinogenicity)
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Basis of guideline value derivation based on carcinogenicity	Linear multistage model applied to data for hepatic tumours from drinking-water studies in rats
Limit of detection	0.1–50 µg/l by GC-MS
Treatment performance	Not removed using conventional water treatment processes; effectively removed by biological activated carbon treatment

Additional comments	Similar guideline values were derived using the TDI approach (assuming 1,4-dioxane is not genotoxic in humans at low doses) and linear multistage modelling (because the compound clearly induces multiple tumours in various organs).
Assessment date	2004
Principal reference	WHO (2005) *1,4-Dioxane in drinking-water*

1,4-Dioxane caused hepatic and nasal cavity tumours in rodents in most long-term oral studies conducted. Tumours in peritoneum, skin and mammary gland were also observed in rats given a high dose. Lung tumours were specifically detected after intraperitoneal injection. Although cohort studies of workers did not reveal any elevation in the incidence of death by cancer, a significant increase in the incidence of liver cancer was found in a comparative mortality study. However, the evidence is inadequate for human carcinogenicity assessment because of small samples or lack of exposure data. A possibly weak genotoxic potential of 1,4-dioxane has been suggested. IARC has classified 1,4-dioxane in Group 2B (possibly carcinogenic to humans).

Diquat

Diquat (CAS No. 2764-72-9) is a non-selective contact herbicide and crop desiccant. Diquat may also be used (at or below 1 mg/l) as an aquatic herbicide for the control of free-floating and submerged aquatic weeds in ponds, lakes and irrigation ditches. Because of its rapid degradation in water and strong adsorption onto sediments, diquat has rarely been found in drinking-water.

Reason for not establishing a guideline value	May be used as an aquatic herbicide for the control of free-floating and submerged aquatic weeds in ponds, lakes and irrigation ditches, but rarely found in drinking-water
Assessment date	2003
Principal references	FAO/WHO (1994) *Pesticide residues in food—1993 evaluations* WHO (2003) *Diquat in drinking-water*

Diquat does not appear to be carcinogenic or genotoxic. The main toxicological finding in experimental animals is cataract formation. A health-based value of 6 μg/l for diquat ion can be calculated on the basis of an ADI of 0–0.002 mg of diquat ion per kilogram of body weight, based on cataract formation at the next higher dose in a 2-year study in rats. However, because diquat has rarely been found in drinking-water, it is not considered necessary to derive a formal guideline value. It should also be noted that the limit of detection of diquat in water is 1 μg/l, and its practical quantification limit is about 10 μg/l.

Edetic acid

Human exposure to edetic acid, also known as ethylenediaminetetraacetic acid or EDTA, arises directly from its use in food additives, medicines and personal care and

hygiene products. Exposure to EDTA from drinking-water will be mostly very low in comparison with that from other sources. Once EDTA is present in the aquatic environment, its speciation will depend on the water quality and the presence of trace metals with which it will combine. The removal of EDTA from communal wastewater by biodegradation in sewage purification plants is very limited.

Guideline value	*EDTA (as the free acid):* 0.6 mg/l (600 µg/l)
Occurrence	Present in surface waters generally at concentrations below 70 µg/l, although higher concentrations (900 µg/l) have been measured; detected in drinking-water prepared from surface waters at concentrations of 10–30 µg/l
ADI	0–1.9 mg/kg body weight as the free acid (ADI of 0–2.5 mg/kg body weight proposed by JECFA for calcium disodium edetate as a food additive)
Limit of detection	1 µg/l by potentiometric stripping analyis
Treatment performance	0.01 mg/l using GAC plus ozonation
Guideline value derivation	
• allocation to water	1% of upper limit of ADI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	Concern has been expressed over the ability of EDTA to complex and therefore reduce the availability of zinc. However, this is of significance only at elevated doses substantially in excess of those encountered in the environment.
Assessment date	1998
Principal reference	WHO (2003) *Edetic acid (EDTA) in drinking-water*

Calcium disodium edetate is poorly absorbed from the gut. The long-term toxicity of EDTA is complicated by its ability to chelate essential and toxic metals. Those toxicological studies that are available indicate that the apparent toxicological effects of EDTA have in fact been due to zinc deficiency as a consequence of complexation. EDTA does not appear to be teratogenic or carcinogenic in experimental animals. The vast clinical experience of the use of EDTA in the treatment of metal poisoning has demonstrated its safety in humans.

Endosulfan

Endosulfan (CAS No. 115-29-7) is an insecticide used in countries throughout the world to control pests on fruit, vegetables and tea and on non-food crops such as tobacco and cotton. In addition to its agricultural use, it is used in the control of the tsetse fly, as a wood preservative and for the control of home garden pests. Endosulfan contamination does not appear to be widespread in the aquatic environment, but the chemical has been found in agricultural runoff and rivers in industrialized areas

where it is manufactured or formulated, as well as in surface water and groundwater samples collected from hazardous waste sites in the USA. Surface water samples in the USA generally contain less than 1 µg/l. The main source of exposure of the general population is food, but residues have generally been found to be well below the FAO/WHO maximum residue limits. Another important route of exposure to endosulfan for the general population is the use of tobacco products.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (1999) *Pesticide residues in food—1998 evaluations* WHO (2003) *Endosulfan in drinking-water*

JMPR concluded that endosulfan is not genotoxic, and no carcinogenic effects were noted in long-term studies using mice and rats. The kidney is the target organ for toxicity. Several recent studies have shown that endosulfan, alone or in combination with other pesticides, may bind to estrogen receptors and perturb the endocrine system. A health-based value of 20 µg/l can be calculated for endosulfan on the basis of an ADI of 0–0.006 mg/kg body weight, based on results from a 2-year dietary study of toxicity in rats and supported by a 78-week study in mice, a 1-year study in dogs and a developmental toxicity study in rats. However, because endosulfan occurs at concentrations well below those of health concern, it is not considered necessary to derive a formal guideline value.

Endrin

Endrin (CAS No. 72-20-8) is a broad-spectrum foliar insecticide that acts against a wide range of agricultural pests. It is also used as a rodenticide. There is now very little use of endrin. Small amounts of endrin are present in some foods, but the total intake from food has decreased significantly.

Guideline value	0.0006 mg/l (0.6 µg/l)
Occurrence	Traces of endrin found in the drinking-water supplies of several countries
PTDI	0.2 µg/kg body weight, based on a NOAEL of 0.025 mg/kg body weight per day in a 2-year study in dogs and applying an uncertainty factor of 100 for interspecies and intraspecies variation
Limit of detection	0.002 µg/l by GC with ECD
Treatment performance	0.2 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of PTDI
• weight	60 kg adult
• consumption	2 litres/day

Additional comments	Endrin is listed under the Stockholm Convention on Persistent Organic Pollutants. Hence, monitoring may occur in addition to that required by drinking-water guidelines.
Assessment date	2003
Principal references	FAO/WHO (1995) *Pesticide residues in food—1994 evaluations* IPCS (1992) *Endrin* WHO (2003) *Endrin in drinking-water*

Toxicological data are insufficient to indicate whether endrin is a carcinogenic hazard to humans. The primary site of action of endrin is the central nervous system.

Epichlorohydrin

Epichlorohydrin is used for the manufacture of glycerol, unmodified epoxy resins and water treatment coagulant polymers and some ion exchange resins. No quantitative data are available on its occurrence in food or drinking-water. Epichlorohydrin is slowly hydrolysed in aqueous media.

Provisional guideline value	0.0004 mg/l (0.4 µg/l)
	The guideline value is considered to be provisional because of the uncertainties surrounding the toxicity of epichlorohydrin and the use of a large uncertainty factor in deriving the guideline value.
Occurrence	No quantitative data available
TDI	0.14 µg/kg body weight, on the basis of a LOAEL of 2 mg/kg body weight per day for forestomach hyperplasia observed in a 2-year gavage study in rats, adjusting for daily dosing and using an uncertainty factor of 10 000 to take into consideration interspecies and intraspecies variation (100), the use of a LOAEL instead of a NOAEL (10) and carcinogenicity (10)
Limit of detection	0.01 µg/l by GC with ECD; 0.1 and 0.5 µg/l by GC-MS; 10 µg/l by GC with FID
Treatment performance	Conventional treatment processes do not remove epichlorohydrin. Epichlorohydrin concentrations in drinking-water are controlled by limiting either the epichlorohydrin content of polyamine flocculants or the dose used, or both.
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	Although epichlorohydrin is a genotoxic carcinogen, the use of the linearized multistage model for estimating cancer risk was considered inappropriate because tumours are seen only at the site of administration, where epichlorohydrin is highly irritating.
Assessment date	2003
Principal reference	WHO (2003) *Epichlorohydrin in drinking-water*

Epichlorohydrin is rapidly and extensively absorbed following oral, inhalation or dermal exposure. It binds easily to cellular components. Major toxic effects are local irritation and damage to the central nervous system. It induces squamous cell carcinomas in the nasal cavity by inhalation and forestomach tumours by the oral route. It has been shown to be genotoxic in vitro and in vivo. IARC has placed epichlorohydrin in Group 2A (probably carcinogenic to humans).

Ethylbenzene

The primary sources of ethylbenzene in the environment are the petroleum industry and the use of petroleum products. Because of its physicochemical properties, more than 96% of ethylbenzene in the environment can be expected to be present in air. Values of up to 26 μg/m^3 in air have been reported. Ethylbenzene is found in trace amounts in surface water, groundwater, drinking-water and food.

Guideline value	0.3 mg/l (300 μg/l)
Occurrence	Concentrations in drinking-water generally below 1 μg/l; levels up to 300 μg/l have been reported in groundwater contaminated by point emissions
TDI	97.1 μg/kg body weight, based on a NOAEL of 136 mg/kg body weight per day for hepatotoxicity and nephrotoxicity observed in a limited 6-month study in rats, adjusting for daily dosing and using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for the limited database and short duration of the study)
Limit of detection	0.002–0.005 μg/l by GC with photoionization detector; 0.03–0.06 μg/l by GC-MS
Treatment performance	0.001 mg/l should be achievable using air stripping
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The guideline value exceeds the lowest reported odour threshold for ethylbenzene in drinking-water (0.002 mg/l).
Assessment date	1993
Principal reference	WHO (2003) *Ethylbenzene in drinking-water*

Ethylbenzene is readily absorbed by the oral, inhalation or dermal route. In humans, storage in fat has been reported. Ethylbenzene is almost completely converted to soluble metabolites, which are excreted rapidly in urine. The acute oral toxicity is low. No definite conclusions can be drawn from limited teratogenicity data. No data on reproduction, long-term toxicity or carcinogenicity are available. Ethylbenzene has shown no evidence of genotoxicity in in vitro or in vivo systems.

Fenitrothion

Fenitrothion (CAS No. 122-14-5) is mainly used in agriculture for controlling insects on rice, cereals, fruits, vegetables, stored grains and cotton and in forest areas. It is also

used for the control of flies, mosquitoes and cockroaches in public health programmes and indoor use. Fenitrothion is stable in water only in the absence of sunlight or microbial contamination. In soil, biodegradation is the primary route of degradation, although photolysis may also play a role. Fenitrothion residues detected in water were low (maximum 1.30 µg/l) during the spruce budworm spray programme. Following the spraying of forests to control spruce budworm, water samples did not contain detectable amounts of fenitrothion; post-spray samples contained less than 0.01 µg/l. Levels of fenitrothion residues in fruits, vegetables and cereal grains decline rapidly after treatment, with a half-life of 1–2 days. Intake of fenitrothion appears to be primarily (95%) from food.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (2001) *Pesticide residues in food—2000 evaluations* WHO (2003) *Fenitrothion in drinking-water*

On the basis of testing in an adequate range of studies in vitro and in vivo, JMPR concluded that fenitrothion is unlikely to be genotoxic. It also concluded that fenitrothion is unlikely to pose a carcinogenic risk to humans. In long-term studies of toxicity, inhibition of cholinesterase activity was the main toxicological finding in all species. A health-based value of 8 µg/l can be calculated for fenitrothion on the basis of an ADI of 0–0.005 mg/kg body weight, based on a NOAEL of 0.5 mg/kg body weight per day for inhibition of brain and erythrocyte cholinesterase activity in a 2-year study of toxicity in rats and supported by a NOAEL of 0.57 mg/kg body weight per day for inhibition of brain and erythrocyte cholinesterase activity in a 3-month study of ocular toxicity in rats and a NOAEL of 0.65 mg/kg body weight per day for reduced food consumption and body weight gain in a study of reproductive toxicity in rats, and allocating 5% of the upper limit of the ADI to drinking-water. However, because fenitrothion occurs at concentrations well below those of health concern, it is not considered necessary to derive a formal guideline value.

Fenoprop

The half-lives for degradation of chlorophenoxy herbicides, including fenoprop (CAS No. 93-72-1), also known as 2,4,5-trichlorophenoxy propionic acid or 2,4,5-TP, in the environment are in the order of several days. Chlorophenoxy herbicides are not often found in food.

Guideline value	0.009 mg/l (9 µg/l)
Occurrence	Chlorophenoxy herbicides not frequently found in drinking-water; when detected, concentrations usually no greater than a few micrograms per litre
TDI	3 µg/kg body weight, based on a NOAEL of 0.9 mg/kg body weight for adverse effects on the liver in a study in which dogs were administered fenoprop in the diet for 2 years, with an uncertainty factor of 300 (100 for interspecies and intraspecies variation and 3 for limitations of the database)

Limit of detection	0.2 µg/l by either packed or capillary column GC with ECD
Treatment performance	0.001 mg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Chlorophenoxy herbicides (excluding 2,4-D and MCPA) in drinking-water*

Chlorophenoxy herbicides, as a group, have been classified in Group 2B (possibly carcinogenic to humans) by IARC. However, the available data from studies in exposed populations and experimental animals do not permit assessment of the carcinogenic potential to humans of any specific chlorophenoxy herbicide. Therefore, drinking-water guidelines for these compounds are based on a threshold approach for other toxic effects. Effects observed in long-term studies with dogs given fenoprop in the diet include mild degeneration and necrosis of hepatocytes and fibroblastic proliferation in one study and severe liver pathology in another study. In rats, increased kidney weight was observed in two long-term dietary studies.

Fluoride[1]

Fluorine is a common element that is widely distributed in Earth's crust and exists in the form of fluorides in a number of minerals, such as fluorspar, cryolite and fluorapatite. Traces of fluorides are present in many waters, with higher concentrations often associated with groundwaters. In some areas rich in fluoride-containing minerals, well water may contain up to about 10 mg of fluoride per litre, although much higher concentrations can be found. High fluoride concentrations can be found in many parts of the world, particularly in parts of India, China, Central Africa and South America, but high concentrations can be encountered locally in most parts of the world. Virtually all foodstuffs contain at least traces of fluorine. All vegetation contains some fluoride, which is absorbed from soil and water. Tea in particular can contain high fluoride concentrations, and levels in dry tea are on average 100 mg/kg.

Fluoride is widely used in dental preparations to combat dental caries, particularly in areas of high sugar intake. These can be in the form of tablets, mouthwashes, toothpaste, varnishes or gels for local application. In some countries, fluoride may also be added to table salt or drinking-water in order to provide protection against dental caries. The amounts added to drinking-water are such that final concentrations are usually between 0.5 and 1 mg/l. The fluoride in final water is always present as fluoride ions, whether from natural sources or from artificial fluoridation.

[1] As fluoride is one of the chemicals of greatest health concern in some natural waters, its chemical fact sheet has been expanded.

Total daily fluoride exposure can vary markedly from one region to another. This will depend on the concentration of fluoride in drinking-water and the amount drunk, levels in foodstuffs and the use of fluoridated dental preparations. In addition, fluoride exposure in some areas is considerably higher as a consequence of a range of practices, including the consumption of brick tea and the cooking and drying of food with high-fluoride coal.

Guideline value	1.5 mg/l (1500 µg/l)
Occurrence	In groundwater, concentrations vary with the type of rock through which the water flows but do not usually exceed 10 mg/l; highest natural level reported is 2800 mg/l
Basis of guideline value derivation	Epidemiological evidence that concentrations above this value carry an increasing risk of dental fluorosis and that progressively higher concentrations lead to increasing risks of skeletal fluorosis. The value is higher than that recommended for artificial fluoridation of water supplies, which is usually 0.5–1.0 mg/l.
Limit of detection	0.01 mg/l by ion chromatography; 0.1 mg/l by ion-selective electrodes or the sulfo phenyl azo dihydroxy naphthalene disulfonic acid colorimetric method
Treatment performance	1 mg/l should be achievable using activated alumina (not a "conventional" treatment process, but relatively simple to install filters)
Additional comments	A management guidance document on fluoride is available.
	In setting national standards for fluoride or in evaluating the possible health consequences of exposure to fluoride, it is essential to consider the intake of water by the population of interest and the intake of fluoride from other sources (e.g. from food, air and dental preparations). Where the intakes from other sources are likely to approach, or be greater than, 6 mg/day, it would be appropriate to consider setting standards at concentrations lower than the guideline value.
	In areas with high natural fluoride levels in drinking-water, the guideline value may be difficult to achieve, in some circumstances, with the treatment technology available.
Assessment date	2003
Principal references	Fawell et al. (2006) *Fluoride in drinking-water* IPCS (2002) *Fluorides* USNRC (2006) *Fluoride in drinking water* WHO (2003) *Fluoride in drinking-water*

After oral uptake, water-soluble fluorides are rapidly and almost completely absorbed from the gastrointestinal tract, although this may be reduced by complex formation with aluminium, phosphorus, magnesium or calcium. There is no difference in absorption between natural or added fluoride in drinking-water. Fluoride in inhaled particles—from high-fluoride coal, for example—is also absorbed, depending on the particle size and solubility of the fluoride compounds present. Absorbed fluoride is rapidly distributed throughout the body, where it is incorporated into teeth and bones, with virtually no storage in soft tissues. Fluoride in teeth and bone can be

mobilized after external exposure has ceased or been reduced. Fluoride is excreted via urine, faeces and sweat.

Fluoride may be an essential element for humans; however, essentiality has not been demonstrated unequivocally. Meanwhile, there is evidence of fluoride being a beneficial element with regard to the prevention of dental caries.

To produce signs of acute fluoride intoxication, minimum oral doses of about 1 mg of fluoride per kilogram of body weight were required. Many epidemiological studies of possible adverse effects of the long-term ingestion of fluoride via drinking-water have been carried out. These studies clearly establish that high fluoride intakes primarily produce effects on skeletal tissues (bones and teeth). Low concentrations provide protection against dental caries, both in children and in adults. The protective effects of fluoride increase with concentration up to about 2 mg of fluoride per litre of drinking-water; the minimum concentration of fluoride in drinking-water required to produce it is approximately 0.5 mg/l. However, fluoride can also have an adverse effect on tooth enamel and may give rise to mild dental fluorosis (prevalence: 12–33%) at drinking-water concentrations between 0.9 and 1.2 mg/l, depending on drinking-water intake and exposure to fluoride from other sources. Mild dental fluorosis may not be detectable except by specialist examination. The risk of dental fluorosis will depend on the total intake of fluoride from all sources and not just the concentration in drinking-water.

Elevated fluoride intakes can have more serious effects on skeletal tissues. Skeletal fluorosis (with adverse changes in bone structure) may be observed when drinking-water contains 3–6 mg of fluoride per litre, particularly with high water consumption. Crippling skeletal fluorosis usually develops only where drinking-water contains over 10 mg of fluoride per litre. IPCS concluded that there is clear evidence from India and China that skeletal fluorosis and an increased risk of bone fractures occur at a total intake of 14 mg of fluoride per day. This conclusion was supported by a review by the United States National Research Council in 2006. The relationship between exposure and response for adverse effects in bone is frequently difficult to ascertain because of inadequacies in most of the epidemiological studies. IPCS concluded from estimates based on studies from China and India that for a total intake of 14 mg/day, there is a clear excess risk of skeletal adverse effects; and there is suggestive evidence of an increased risk of effects on the skeleton at total fluoride intakes above about 6 mg/day.

Several epidemiological studies are available on the possible association between fluoride in drinking-water and cancer. IPCS evaluated these studies and concluded that, overall, the evidence of carcinogenicity in laboratory animals is inconclusive and that the available evidence does not support the hypothesis that fluoride causes cancer in humans; however, the data on bone cancer are limited. The results of several epidemiological studies on the possible adverse effects of fluoride in drinking-water on pregnancy outcome indicate that there is no relationship between the rates of Down syndrome or congenital malformation and the consumption of fluoridated drinking-water.

There is no evidence to suggest that the guideline value of 1.5 mg/l set in 1984 and reaffirmed in 1993 needs to be revised. Concentrations above this value carry an increasing risk of dental fluorosis, and much higher concentrations lead to skeletal

fluorosis. The value is higher than that recommended for artificial fluoridation of water supplies, which is usually 0.5–1.0 mg/l.

In setting national standards or local guidelines for fluoride or in evaluating the possible health consequences of exposure to fluoride, it is essential to consider the average daily intake of water by the population of interest and the intake of fluoride from other sources (e.g. from food and air). Where the intakes are likely to approach, or be greater than, 6 mg/day, it would be appropriate to consider setting a standard or local guideline at a concentration lower than 1.5 mg/l.

Practical considerations

Fluoride is usually determined by means of an ion-selective electrode, which makes it possible to measure the total amount of free and complex-bound fluoride dissolved in water. The method can detect fluoride concentrations in water well below the guideline value. However, appropriate sample preparation is a critical step in the accurate quantification of fluoride, especially where only the free fluoride ion is measured.

A range of treatment technologies are available for both large and small supplies. Different methods for small supplies are favoured in different countries; these are based on bone charcoal, contact precipitation, activated alumina and clay. However, in some areas with high natural fluoride levels in drinking-water, the guideline value may be difficult to achieve in some circumstances with the treatment technology available. Large supplies tend to rely on activated alumina or advanced treatment processes such as reverse osmosis.

Formaldehyde

Formaldehyde occurs in industrial effluents and is emitted into air from plastic materials and resin glues. Formaldehyde in drinking-water results primarily from the oxidation of natural organic matter during ozonation and chlorination. Concentrations of up to 30 µg/l have been found in ozonated drinking-water. Formaldehyde can also be found in drinking-water as a result of release from polyacetal plastic fittings. Formaldehyde's physicochemical properties suggest that it is unlikely to volatilize from water, so exposure by inhalation during showering is expected to be low.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2004
Principal references	IPCS (2002) *Formaldehyde* WHO (2005) *Formaldehyde in drinking-water*

Rats and mice exposed to formaldehyde by inhalation exhibited an increased incidence of carcinomas of the nasal cavity at doses that caused irritation of the nasal epithelium. Ingestion of formaldehyde in drinking-water for 2 years caused stomach irritation in rats. Papillomas of the stomach associated with severe tissue irritation were observed in one study. IARC has classified formaldehyde in Group 1 (carcinogenic to

humans). The weight of evidence indicates that formaldehyde is not carcinogenic by the oral route.

Owing to formaldehyde's high reactivity, effects in the tissue of first contact following ingestion are more likely to be related to the concentration of the formaldehyde consumed than to its total intake. A tolerable concentration of 2.6 mg/l for ingested formaldehyde has been established based on a NOEL of 260 mg/l for histopathological effects in the oral and gastric mucosa of rats administered formaldehyde in their drinking-water for 2 years, using an uncertainty factor of 100 (for interspecies and intraspecies variation). In view of the significant difference between the expected concentrations of formaldehyde in drinking-water and the tolerable concentration, it is not considered necessary to set a formal guideline value for formaldehyde.

Glyphosate and AMPA

Glyphosate (CAS No. 1071-83-6) is a broad-spectrum herbicide used in both agriculture and forestry and for aquatic weed control. Microbial biodegradation of glyphosate occurs in soil, aquatic sediment and water, the major metabolite being aminomethylphosphonic acid (AMPA) (CAS No. 1066-51-9). Glyphosate is chemically stable in water and is not subject to photochemical degradation. The low mobility of glyphosate in soil indicates minimal potential for the contamination of groundwater. Glyphosate can, however, enter surface and subsurface waters after direct use near aquatic environments or by runoff or leaching from terrestrial applications.

Reason for not establishing guideline values	Occur in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (1998) *Pesticide residues in food—1997 evaluations* IPCS (1994) *Glyphosate* WHO (2003) *Glyphosate and AMPA in drinking-water*

Glyphosate and AMPA have similar toxicological profiles, and both are considered to exhibit low toxicity. A health-based value of 0.9 mg/l can be derived based on the group ADI for AMPA alone or in combination with glyphosate of 0–0.3 mg/kg body weight, based upon a NOAEL of 32 mg/kg body weight per day, the highest dose tested, identified in a 26-month study of toxicity in rats fed technical-grade glyphosate and using an uncertainty factor of 100 (for interspecies and intraspecies variation).

Because of their low toxicity, the health-based value derived for AMPA alone or in combination with glyphosate is orders of magnitude higher than concentrations of glyphosate or AMPA normally found in drinking-water. Under usual conditions, therefore, the presence of glyphosate and AMPA in drinking-water does not represent a hazard to human health. For this reason, the establishment of a formal guideline value for glyphosate and AMPA is not deemed necessary.

Halogenated acetonitriles (dichloroacetonitrile, dibromoacetonitrile, bromochloroacetonitrile, trichloroacetonitrile)

Halogenated acetonitriles are produced during water chlorination or chloramination from naturally occurring substances, including algae, fulvic acid and proteinaceous material. In general, increasing temperature or decreasing pH is associated with increasing concentrations of halogenated acetonitriles. Ambient bromide levels appear to influence, to some degree, the speciation of halogenated acetonitrile compounds. Dichloroacetonitrile is by far the most predominant halogenated acetonitrile species detected in drinking-water.

Provisional guideline value	*Dichloroacetonitrile:* 0.02 mg/l (20 µg/l)
	The guideline value for dichloroacetonitrile is provisional owing to limitations of the toxicological database.
Guideline value	*Dibromoacetonitrile:* 0.07 mg/l (70 µg/l)
Occurrence	Concentrations of individual halogenated acetonitriles can exceed 0.01 mg/l, although levels of 0.002 mg/l or less are more usual
TDIs	*Dichloroacetonitrile:* 2.7 µg/kg body weight based on a LOAEL of 8 mg/kg body weight per day for increased relative liver weight in male and female rats in a 90-day study, using an uncertainty factor of 3000 (taking into consideration intraspecies and interspecies variation, the short duration of the study, the use of a minimal LOAEL and database deficiencies)
	Dibromoacetonitrile: 11 µg/kg body weight, based on a NOAEL of 11.3 mg/kg body weight per day for decreased body weight in male rats in a 90-day drinking-water study and an uncertainty factor of 1000 (accounting for interspecies and intraspecies variation, subchronic to chronic extrapolation and database insufficiencies)
Limit of detection	0.03 µg/l by GC with ECD
Treatment performance	Reduction of organic precursors will reduce the formation of halogenated acetonitriles.
Guideline value derivation	
• allocation to water	20% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	2003
Principal references	IPCS (2000) *Disinfectants and disinfectant by-products* WHO (2003) *Halogenated acetonitriles in drinking-water*

Reason for not establishing guideline values	Available data inadequate to permit derivation of health-based guideline values for *bromochloroacetonitrile* and *trichloroacetonitrile*
Assessment date	2003
Principal references	IPCS (2000) *Disinfectants and disinfectant by-products* WHO (2003) *Halogenated acetonitriles in drinking-water*

IARC has concluded that dichloroacetonitrile, dibromoacetonitrile, bromochloroacetonitrile and trichloroacetonitrile are not classifiable as to their carcinogenicity in humans. Dichloroacetonitrile and bromochloroacetonitrile have been shown to be mutagenic in bacterial assays, whereas results for dibromoacetonitrile and trichloroacetonitrile were negative. All four of these halogenated acetonitriles induced sister chromatid exchange and DNA strand breaks and adducts in mammalian cells in vitro but were negative in the mouse micronucleus test.

The majority of reproductive and developmental toxicity studies of the halogenated acetonitriles were conducted using tricaprylin as a vehicle for gavage administration of the compound under study. As tricaprylin was subsequently demonstrated to be a developmental toxicant that potentiated the effects of trichloroacetonitrile and, presumably, other halogenated acetonitriles, results reported for developmental studies using tricaprylin as the gavage vehicle are likely to overestimate the developmental toxicity of these halogenated acetonitriles.

Dichloroacetonitrile

Dichloroacetonitrile induced decreases in body weight and increases in relative liver weight in short-term studies. Although developmental toxicity has been demonstrated, the studies used tricaprylin as the vehicle for gavage administration.

Dibromoacetonitrile

Dibromoacetonitrile is currently under analysis for chronic toxicity in mice and rats. None of the available reproductive or developmental studies were adequate to use in the quantitative dose–response assessment. The data gap may be particularly relevant because cyanide, a metabolite of dibromoacetonitrile, induces male reproductive system toxicity and because of uncertainty regarding the significance of the testes effects observed in a 14-day NTP rat study.

Bromochloroacetonitrile

Available data are insufficient to serve as a basis for derivation of a guideline value for bromochloroacetonitrile.

Trichloroacetonitrile

Available data are also insufficient to serve as a basis for derivation of a guideline value for trichloroacetonitrile. The previous provisional guideline value of 1 μg/l was based on a developmental toxicity study in which trichloroacetonitrile was administered by gavage in tricaprylin vehicle, and a re-evaluation judged this study to be unreliable in light of the finding in a more recent study that tricaprylin potentiates the developmental and teratogenic effects of halogenated acetonitriles and alters the spectrum of malformations in the fetuses of treated dams.

Hardness

Hardness in water is caused by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium cations. It is usually expressed as milligrams of calcium carbonate per litre. Hardness is the traditional measure of the capacity of

water to react with soap, hard water requiring considerably more soap to produce a lather.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	1993, revised in 2011
Principal reference	WHO (2011) *Hardness in drinking-water*

Natural and treated waters have a wide range of mineral content, from very low levels in rainwater and naturally soft and softened water to higher levels in naturally hard waters. Bottled and packaged waters can be naturally mineralized or naturally soft or demineralized. Thus, the mineral consumption from drinking-water and cooking water will vary widely, depending upon location, treatment and water source.

The degree of hardness of drinking-water is important for aesthetic acceptability by consumers (see chapter 10) and for economic and operational considerations. Many hard waters are softened for those reasons using several applicable technologies. The choice of the most appropriate conditioning technology will depend on local circumstances (e.g. water quality issues, piping materials, corrosion) and will be applied either centrally or in individual homes as a consumer preference.

Consumers should be informed of the mineral composition of their water, whether or not it is modified. The contribution of drinking-water minerals to mineral nutrition should be considered where changes in supply are proposed or where less traditional sources, such as recycled water, seawater or brackish water, are processed and exploited for drinking-water. The treatments used remove most minerals, and stabilization of water is always necessary prior to distribution.

Drinking-water can be a contributor to calcium and magnesium intake and could be important for those who are marginal for calcium and magnesium. Where drinking-water supplies are supplemented with or replaced by demineralized water that requires conditioning, consideration should be given to adding calcium and magnesium salts to achieve concentrations similar to those that the population received from the original supply. Modification of calcium and magnesium concentrations in drinking-water for health reasons should comply with the technical requirements to provide water suitable for distribution.

Although there is evidence from epidemiological studies for a protective effect of magnesium or hardness on cardiovascular mortality, the evidence is being debated and does not prove causality. Further studies are being conducted. There are insufficient data to suggest either minimum or maximum concentrations of minerals at this time, as adequate intake will depend on a range of other factors. Therefore, no guideline values are proposed.

Heptachlor and heptachlor epoxide

Heptachlor (CAS No. 76-44-8) is a broad-spectrum insecticide, the use of which has been banned or restricted in many countries. At present, the major use of heptachlor

is for termite control by subsurface injection into soil. Heptachlor is quite persistent in soil, where it is mainly transformed to its epoxide. Heptachlor epoxide (CAS No. 1024-57-3) is very resistant to further degradation. Heptachlor and heptachlor epoxide bind to soil particles and migrate very slowly. Heptachlor and heptachlor epoxide have been found in drinking-water at nanogram per litre levels. Diet is considered to represent the major source of exposure to heptachlor, although intake is decreasing significantly, as its use has substantially declined.

Reason for not establishing a guideline value	Occur in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (1992) *Pesticide residues in food—1991 evaluations* FAO/WHO (1995) *Pesticide residues in food—1994 evaluations* WHO (2003) *Heptachlor and heptachlor epoxide in drinking-water*

Prolonged exposure to heptachlor has been associated with damage to the liver and central nervous system toxicity. In 1991, IARC reviewed the data on heptachlor and concluded that the evidence for carcinogenicity was sufficient in animals and inadequate in humans, classifying it in Group 2B (possibly carcinogenic to humans). A health-based value of 0.03 µg/l can be calculated for heptachlor and heptachlor epoxide on the basis of a PTDI of 0.1 µg/kg body weight, based on a NOAEL for heptachlor of 0.025 mg/kg body weight per day from two studies in the dog, taking into consideration inadequacies of the database and allocating 1% of the PTDI to drinking-water. However, because heptachlor and heptachlor epoxide occur at concentrations well below those of health concern, it is not considered necessary to derive a formal guideline value. It should also be noted that concentrations below 0.1 µg/l are generally not achievable using conventional treatment technology.

Hexachlorobenzene

The major agricultural application for hexachlorobenzene (CAS No. 118-74-1), or HCB, was as a seed dressing for crops to prevent the growth of fungi, but its use is now uncommon. At present, it appears mainly as a by-product of several chemical processes or an impurity in some pesticides. HCB is distributed throughout the environment because it is mobile and resistant to degradation. It bioaccumulates in organisms because of its physicochemical properties and its slow elimination. HCB is commonly detected at low levels in food, and it is generally present at low concentrations in ambient air. It has been detected only infrequently, and at very low concentrations (below 0.1 µg/l), in drinking-water supplies.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	IPCS (1997) *Hexachlorobenzene* WHO (2003) *Hexachlorobenzene in drinking-water*

IARC has evaluated the evidence for the carcinogenicity of HCB in animals and humans and assigned it to Group 2B (possibly carcinogenic to humans). HCB has been shown to induce tumours in three animal species and at a variety of sites. A health-based value of 1 µg/l can be derived for HCB by applying the linearized multistage low-dose extrapolation model to liver tumours observed in female rats in a 2-year dietary study. Using an alternative (tumorigenic $dose_{05}$, or TD_{05}) approach, a TDI of 0.16 µg/kg body weight can be calculated, which corresponds to a health-based value of approximately 0.05 µg/l, if one assumes a 1% allocation of the TDI to drinking-water. It should be noted that concentrations in food have been falling steadily, and this allocation factor may be considered very conservative.

Because the health-based values derived from both of these approaches are considerably higher than the concentrations at which HCB is detected in drinking-water (i.e. sub-nanograms per litre), when it is detected, it is not considered necessary to establish a formal guideline value for HCB in drinking-water. HCB is listed under the Stockholm Convention on Persistent Organic Pollutants.

Hexachlorobutadiene

Hexachlorobutadiene, or HCBD, is used as a solvent in chlorine gas production, a pesticide, an intermediate in the manufacture of rubber compounds and a lubricant. Concentrations of up to 6 µg/l have been reported in the effluents from chemical manufacturing plants. HCBD is also found in air and food.

Guideline value	0.0006 mg/l (0.6 µg/l)
Occurrence	Has been detected in surface water at concentrations of a few micrograms per litre and in drinking-water at concentrations below 0.5 µg/l
TDI	0.2 µg/kg body weight, based on a NOAEL of 0.2 mg/kg body weight per day for renal toxicity in a 2-year feeding study in rats, using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for limited evidence of carcinogenicity and genotoxicity of some metabolites)
Limit of detection	0.01 µg/l by GC-MS; 0.18 µg/l by GC with ECD
Treatment performance	0.001 mg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The practical quantification limit for HCBD is of the order of 2 µg/l, but concentrations in drinking-water can be controlled by specifying the HCBD content of products coming into contact with it.
Assessment date	2003
Principal references	IPCS (1994) *Hexachlorobutadiene* WHO (2003) *Hexachlorobutadiene in drinking-water*

HCBD is easily absorbed and metabolized via conjugation with glutathione. This conjugate can be further metabolized to a nephrotoxic derivative. Kidney tumours were observed in a long-term oral study in rats. HCBD has not been shown to be carcinogenic by other routes of exposure. IARC has placed HCBD in Group 3 (not classifiable as to its carcinogenicity to humans). Positive and negative results for HCBD have been obtained in bacterial assays for point mutation; however, several metabolites have given positive results.

Hydrogen sulfide

Hydrogen sulfide is a gas with an offensive "rotten eggs" odour that is detectable at very low concentrations, below 0.8 μg/m^3 in air. It is formed when sulfides are hydrolysed in water. However, the level of hydrogen sulfide found in drinking-water will usually be low, because sulfides are readily oxidized in well-aerated or chlorinated water.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	1993
Principal reference	WHO (2003) *Hydrogen sulfide in drinking-water*

The acute toxicity to humans of hydrogen sulfide following inhalation of the gas is high; eye irritation can be observed at concentrations of 15–30 mg/m^3. Although oral toxicity data are lacking, it is unlikely that a person could consume a harmful dose of hydrogen sulfide from drinking-water. Consequently, no guideline value is proposed. However, hydrogen sulfide can be easily detected in drinking-water by taste or odour (see chapter 10).

Inorganic tin

Tin is used principally in the production of coatings used in the food industry. Food, particularly canned food, therefore represents the major route of human exposure to tin. For the general population, drinking-water is not a significant source of tin, and levels in drinking-water greater than 1–2 μg/l are exceptional. However, there is increasing use of tin in solder, which may be used in domestic plumbing, and tin has been proposed for use as a corrosion inhibitor.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal reference	WHO (2003) *Inorganic tin in drinking-water*

Tin and inorganic tin compounds are poorly absorbed from the gastrointestinal tract, do not accumulate in tissues and are rapidly excreted, primarily in faeces.

No increased incidence of tumours was observed in long-term carcinogenicity studies conducted in mice and rats fed tin(II) chloride. Tin has not been shown to be teratogenic or fetotoxic in mice, rats or hamsters. In rats, the NOAEL in a long-term feeding study was 20 mg/kg body weight per day.

The main adverse effect on humans of excessive levels of tin in canned beverages (above 150 mg/kg) or other canned foods (above 250 mg/kg) has been acute gastric irritation. There is no evidence of adverse effects in humans associated with chronic exposure to tin.

In 1989, JECFA established a PTWI of 14 mg/kg body weight from a TDI of 2 mg/kg body weight on the basis that the problem with tin is associated with acute gastrointestinal irritancy, the threshold for which is about 200 mg/kg in food. This was reaffirmed by JECFA in 2000. In view of its low toxicity, the presence of tin in drinking-water does not, therefore, represent a hazard to human health. For this reason, the establishment of a guideline value for inorganic tin is not deemed necessary.

Iodine

Iodine occurs naturally in water in the form of iodide. Traces of iodine are produced by oxidation of iodide during water treatment. Iodine is occasionally used for water disinfection in the field or in emergency situations.

Reason for not establishing a guideline value	Available data inadequate to permit derivation of health-based guideline value, and lifetime exposure to iodine through water disinfection is unlikely
Assessment date	1993
Principal reference	WHO (2003) *Iodine in drinking-water*

Iodine is an essential element for the synthesis of thyroid hormones. Estimates of the dietary requirement for adult humans range from 80 to 150 μg/day; in many parts of the world, there are dietary deficiencies in iodine, resulting in severe adverse effects on neurological development. In 1988, JECFA set a provisional maximum tolerable daily intake (PMTDI) for iodine of 1 mg/day (17 μg/kg body weight per day) from all sources, based primarily on data on the effects of iodide. However, recent data from studies in rats indicate that the effects of iodine in drinking-water on thyroid hormone concentrations in the blood differ from those of iodide.

Available data therefore suggest that derivation of a guideline value for iodine on the basis of information on the effects of iodide is inappropriate, and there are few relevant data on the effects of iodine. Because iodine is not recommended for long-term disinfection, lifetime exposure to iodine concentrations such as might occur from water disinfection is unlikely. For these reasons, a guideline value for iodine has not been established at this time. There is, however, a need for guidance concerning the use of iodine as a disinfectant in emergency situations and for travellers.

Iron

Iron is one of the most abundant metals in Earth's crust. It is found in natural fresh waters at levels ranging from 0.5 to 50 mg/l. Iron may also be present in drinking-water

as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	1993
Principal reference	WHO (2003) *Iron in drinking-water*

Iron is an essential element in human nutrition, particularly in the iron(II) oxidation state. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50 mg/day.

As a precaution against storage in the body of excessive iron, in 1983, JECFA established a PMTDI of 0.8 mg/kg body weight, which applies to iron from all sources except for iron oxides used as colouring agents and iron supplements taken during pregnancy and lactation or for specific clinical requirements. An allocation of 10% of this PMTDI to drinking-water gives a value of about 2 mg/l, which does not present a hazard to health. The taste and appearance of drinking-water will usually be affected below this level (see chapter 10).

No guideline value for iron in drinking-water is proposed.

Isoproturon

Isoproturon (CAS No. 34123-59-6) is a selective, systemic herbicide used in the control of annual grasses and broad-leaved weeds in cereals. It can be photodegraded, hydrolysed and biodegraded and persists for periods ranging from days to weeks. It is mobile in soil. There is evidence that exposure to this compound through food is low.

Guideline value	0.009 mg/l (9 µg/l)
Occurrence	Has been detected in surface water and groundwater, usually at concentrations below 0.1 µg/l; levels above 0.1 µg/l have occasionally been detected in drinking-water
TDI	3 µg/kg body weight based on a NOAEL of approximately 3 mg/kg body weight in a 90-day study in dogs and a 2-year feeding study in rats, with an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for evidence of non-genotoxic carcinogenicity in rats)
Limit of detection	10–100 ng/l by reversed-phase HPLC followed by UV or electrochemical detection
Treatment performance	0.1 µg/l should be achievable using ozonation
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day

Assessment date	1993
Principal reference	WHO (2003) *Isoproturon in drinking-water*

Isoproturon is of low acute toxicity and low to moderate toxicity following short-term and long-term exposures. It does not possess significant genotoxic activity, but it causes marked enzyme induction and liver enlargement. Isoproturon caused an increase in hepatocellular tumours in male and female rats, but this was apparent only at doses that also caused liver toxicity. Isoproturon appears to be a tumour promoter rather than a complete carcinogen.

Lead

Lead is used principally in the production of lead-acid batteries, solder and alloys. The organolead compounds tetraethyl and tetramethyl lead have also been used extensively as antiknock and lubricating agents in petrol, although their use for these purposes in many countries has largely been phased out. Owing to the decreasing use of lead-containing additives in petrol and of lead-containing solder in the food processing industry, concentrations in air and food are declining; in most countries, lead levels in blood are also declining unless there are specific sources, such as dust from leaded paint or household recycling of lead-containing materials. Lead is rarely present in tap water as a result of its dissolution from natural sources; rather, its presence is primarily from corrosive water effects on household plumbing systems containing lead in pipes, solder, fittings or the service connections to homes. The amount of lead dissolved from the plumbing system depends on several factors, including pH, temperature, water hardness and standing time of the water, with soft, acidic water being the most plumbosolvent. Free chlorine residuals in drinking-water tend to form more insoluble lead-containing sediments, whereas chloramine residuals may form more soluble sediments in lead pipe.

Provisional guideline value	0.01 mg/l (10 µg/l)
	The guideline value is provisional on the basis of treatment performance and analytical achievability.
Occurrence	Concentrations in drinking-water are generally below 5 µg/l, although much higher concentrations (above 100 µg/l) have been measured where lead fittings are present. The primary source of lead is from service connections and plumbing in buildings; therefore, lead should be measured at the tap. Lead concentrations can also vary according to the period in which the water has been in contact with the lead-containing materials.
Basis of guideline value derivation	The guideline value was previously based on a JECFA PTWI, which has since been withdrawn, and no new PTWI has been established, on the basis that there does not appear to be a threshold for the key effects of lead. However, substantial efforts have been made to reduce lead exposure from a range of sources, including drinking-water. Because it is extremely difficult to achieve a lower concentration by central conditioning, such as phosphate dosing, the guideline value is maintained at 10 µg/l but is designated as provisional on the basis of treatment performance and analytical achievability.

Limit of detection	1 µg/l by AAS; practical quantification limit in the region of 1–10 µg/l
Treatment performance	Not a raw water contaminant; treatment not applicable
Additional comments	Infants and children are considered to be the most sensitive subgroups of the population.
	Lead is exceptional compared with other chemical hazards, in that most lead in drinking-water arises from plumbing in buildings, and the remedy consists principally of removing plumbing and fittings containing lead. This requires much time and money, and it is recognized that not all water will meet the guideline value immediately. Meanwhile, all other practical measures to reduce total exposure to lead, including corrosion control, should be implemented.
Assessment date	2011
Principal reference	FAO/WHO (2011) *Evaluation of certain food additives and contaminants* WHO (2011) *Lead in drinking-water*

Exposure to lead is associated with a wide range of effects, including various neurodevelopmental effects, mortality (mainly due to cardiovascular diseases), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes. Impaired neurodevelopment in children is generally associated with lower blood lead concentrations than the other effects, the weight of evidence is greater for neurodevelopmental effects than for other health effects and the results across studies are more consistent than those for other effects. For adults, the adverse effect associated with lowest blood lead concentrations for which the weight of evidence is greatest and most consistent is a lead-associated increase in systolic blood pressure. JECFA concluded that the effects on neurodevelopment and systolic blood pressure provided the appropriate bases for dose–response analyses.

Based on the dose–response analyses, JECFA estimated that the previously established PTWI of 25 µg/kg body weight is associated with a decrease of at least 3 intelligence quotient (IQ) points in children and an increase in systolic blood pressure of approximately 3 mmHg (0.4 kPa) in adults. These changes are important when viewed as a shift in the distribution of IQ or blood pressure within a population. JECFA therefore concluded that the PTWI could no longer be considered health protective, and it was withdrawn.

Because the dose–response analyses do not provide any indication of a threshold for the key effects of lead, JECFA concluded that it was not possible to establish a new PTWI that would be considered to be health protective. JECFA reaffirmed that because of the neurodevelopmental effects, fetuses, infants and children are the subgroups that are most sensitive to lead.

It needs to be recognized that lead is exceptional compared with other chemical hazards, in that most lead in drinking-water arises from plumbing in buildings, and the remedy consists principally of removing plumbing and fittings containing lead, which requires much time and money. It is therefore emphasized that all other practical measures to reduce total exposure to lead, including corrosion control, should be implemented.

Lindane

Lindane (γ-hexachlorocyclohexane; γ-HCH) (CAS No. 58-89-9) is used as an insecticide on fruit and vegetable crops, for seed treatment and in forestry. It is also used as a therapeutic pesticide in humans and animals. Several countries have restricted the use of lindane. Lindane can be degraded in soil and rarely leaches to groundwater. In surface waters, it can be removed by evaporation. Exposure of humans occurs mainly via food, but this is decreasing. There may also be exposure from its use in public health and as a wood preservative.

Guideline value	0.002 mg/l (2 µg/l)
Occurrence	Has been detected in both surface water and groundwater, usually at concentrations below 0.1 µg/l, although concentrations as high as 12 µg/l have been measured in wastewater-contaminated rivers
ADI	0–0.005 mg/kg body weight on the basis of a NOAEL of 0.47 mg/kg body weight per day in a 2-year toxicity/carcinogenicity study in rats in which an increased incidence of periacinar hepatocellular hypertrophy, increased liver and spleen weights and increased mortality occurred at higher doses, using an uncertainty factor of 100 (for interspecies and intraspecies variation)
Limit of detection	0.01 µg/l using GC
Treatment performance	0.1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	1% of upper limit of ADI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	It should be noted that concentrations in food have been falling steadily, and the 1% allocation factor may be considered very conservative.
Assessment date	2003
Principal references	FAO/WHO (2003) *Pesticide residues in food—2002 evaluations* WHO (2003) *Lindane in drinking-water*

Lindane was toxic to the kidney and liver after administration orally, dermally or by inhalation in short-term and long-term studies of toxicity and reproductive toxicity in rats. The renal toxicity of lindane was specific to male rats and was considered not to be relevant to human risk assessment, as it is a consequence of accumulation of α_{2u}-globulin, a protein that is not found in humans. Hepatocellular hypertrophy was observed in a number of studies in mice, rats and rabbits and was reversed only partially after recovery periods of up to 6 weeks. Lindane did not induce a carcinogenic response in rats or dogs, but it caused an increased incidence of adenomas and carcinomas of the liver in agouti and pseudoagouti mice, but not in black or any other strains of mice, in a study of the role of genetic background in the latency and incidence of tumorigenesis. JMPR concluded that there was no evidence of genotoxicity. In the absence of genotoxicity and on the basis of the weight of the evidence

from the studies of carcinogenicity, JMPR concluded that lindane is not likely to pose a carcinogenic risk to humans. Further, in an epidemiological study designed to assess the potential association between breast cancer and exposure to chlorinated pesticides, no correlation with lindane was found.

Malathion

Malathion (CAS No. 121-75-5) is commonly used to control mosquitoes and a variety of insects that attack fruits, vegetables, landscaping plants and shrubs. It can also be found in other pesticide products used indoors, on pets to control ticks and insects and to control human head and body lice. Under least favourable conditions (i.e. low pH and little organic content), malathion may persist in water with a half-life of months or even years. However, under most conditions, the half-life appears to be roughly 7–14 days. Malathion has been detected in surface water and drinking-water at concentrations below 2 μg/l.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (1998) *Pesticide residues in food—1997 evaluations* WHO (2003) *Malathion in drinking-water*

Malathion inhibits cholinesterase activity in mice, rats and human volunteers. It increased the incidence of liver adenomas in mice when administered in the diet. Most of the evidence indicates that malathion is not genotoxic, although some studies indicate that it can produce chromosomal aberrations and sister chromatid exchange in vitro. JMPR has concluded that malathion is not genotoxic.

A health-based value of 0.9 mg/l can be calculated for malathion based on an allocation of 10% of the upper limit of the JMPR ADI—based on a NOAEL of 29 mg/kg body weight per day in a 2-year study of toxicity and carcinogenicity in rats, using an uncertainty factor of 100 for interspecies and intraspecies variation and supported by a NOAEL of 25 mg/kg body weight per day in a developmental toxicity study in rabbits—to drinking-water. However, intake of malathion from all sources is generally low and well below the upper limit of the ADI. As the chemical occurs in drinking-water at concentrations much lower than the health-based value, the presence of malathion in drinking-water under usual conditions is unlikely to represent a hazard to human health. For this reason, it is considered unnecessary to derive a formal guideline value for malathion in drinking-water.

Manganese

Manganese is one of the most abundant metals in Earth's crust, usually occurring with iron. It is used principally in the manufacture of iron and steel alloys, as an oxidant for cleaning, bleaching and disinfection (as potassium permanganate) and as an ingredient in various products. More recently, it has been used in an organic compound, methylcyclopentadienyl manganese tricarbonyl, or MMT, as an octane

enhancer in petrol in North America. Manganese greensands are used in some locations for potable water treatment. Manganese is naturally occurring in many surface water and groundwater sources, particularly in anaerobic or low oxidation conditions, and this is the most important source for drinking-water. Manganese occurs naturally in many food sources, and the greatest exposure to manganese is usually from food.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	2003, revised 2011
Principal references	IPCS (1999) *Manganese and its compounds* WHO (2011) *Manganese in drinking-water*

Manganese is an essential element for humans and animals. Although there have been epidemiological studies that report adverse neurological effects following extended exposure to very high levels in drinking-water, there are a number of significant potential confounding factors in these studies, and a number of other studies have failed to observe adverse effects following exposure through drinking-water. Experimental animal data, especially rodent data, are not appropriate for human risk assessment because the physiological requirements for manganese vary among different species. Further, rodents are of limited value in assessing neurobehavioural effects, because the neurological effects (e.g. tremor, gait disorders) seen in primates are often preceded or accompanied by psychological symptoms (e.g. irritability, emotional lability), which are not apparent in rodents. The only primate study is of limited use in a quantitative risk assessment because only one dose group was studied in a small number of animals and the manganese content in the basal diet was not provided.

A health-based value of 0.4 mg/l can be derived for manganese based on the upper range value of manganese intake of 11 mg/day, identified using dietary surveys, at which there are no observed adverse effects, using an uncertainty factor of 3 to take into consideration the possible increased bioavailability of manganese from water, allocating 20% of the TDI to drinking-water and assuming the consumption of 2 litres of water per day by a 60 kg adult. However, as this health-based value is well above concentrations of manganese normally found in drinking-water, it is not considered necessary to derive a formal guideline value.

It is also noted that concentrations below the health-based value may give rise to black deposits in water mains over an extended period (see chapter 10).

MCPA

MCPA, or 4-(2-methyl-4-chlorophenoxy)acetic acid (CAS No. 94-74-6), is a chlorophenoxy post-emergence herbicide that is very soluble, is highly mobile and can leach from the soil. It is metabolized by bacteria and can be photochemically degraded. MCPA has only limited persistence in water.

Guideline value	0.002 mg/l (2 µg/l)
Occurrence	Not frequently detected in drinking-water; has been measured in surface water and groundwater at concentrations below 0.54 and 5.5 µg/l, respectively
TDI	0.5 µg/kg body weight, based on a NOAEL of 0.15 mg/kg body weight for renal and liver toxicity observed at higher dose levels in a 1-year feeding study in dogs, with an uncertainty factor of 300 (100 for interspecies and intraspecies variation and 3 for inadequacies of the database)
Limit of detection	0.01 µg/l by GC-MS and GC with ECD
Treatment performance	0.1 µg/l should be achievable using GAC or ozonation
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *MCPA in drinking-water*

There are only limited and inconclusive data on the genotoxicity of MCPA. IARC evaluated MCPA in 1983 and concluded that the available data on humans and experimental animals were inadequate for an evaluation of carcinogenicity. Further evaluations by IARC on chlorophenoxy herbicides in 1986 and 1987 concluded that evidence for their carcinogenicity was limited in humans and inadequate in animals (Group 2B). Recent carcinogenicity studies on rats and mice did not indicate that MCPA was carcinogenic. No adequate epidemiological data on exposure to MCPA alone are available.

Mecoprop

The half-lives for degradation of chlorophenoxy herbicides, including mecoprop (CAS No. 93-65-2; 7085-19-0 racemic mixture), also known as 2(2-methyl-chlorophenoxy)propionic acid or MCPP, in the environment are in the order of several days. Chlorophenoxy herbicides are not often found in food.

Guideline value	0.01 mg/l (10 µg/l)
Occurrence	Chlorophenoxy herbicides not frequently found in drinking-water; when detected, concentrations usually no greater than a few micrograms per litre
TDI	3.33 µg/kg body weight, based on a NOAEL of 1 mg/kg body weight for effects on kidney weight in 1- and 2-year studies in rats, with an uncertainty factor of 300 (100 for interspecies and intraspecies variation and 3 for limitations of the database)
Limit of detection	0.01 µg/l by GC-MS; 0.01–0.02 µg/l by GC with ECD
Treatment performance	0.1 µg/l should be achievable using GAC or ozonation

Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Chlorophenoxy herbicides (excluding 2,4-D and MCPA) in drinking-water*

Chlorophenoxy herbicides, as a group, have been classified in Group 2B (possibly carcinogenic to humans) by IARC. However, the available data from studies in exposed populations and experimental animals do not permit assessment of the carcinogenic potential to humans of any specific chlorophenoxy herbicide. Therefore, drinking-water guidelines for these compounds are based on a threshold approach for other toxic effects. Effects of dietary administration of mecoprop in short-term and long-term studies include decreased relative kidney weight (rats and dogs), increased relative liver weight (rats), effects on blood parameters (rats and dogs) and depressed body weight gain (dogs).

Mercury

Mercury is used in the electrolytic production of chlorine, in electrical appliances, in dental amalgams and as a raw material for various mercury compounds. Methylation of inorganic mercury has been shown to occur in fresh water and in seawater, although almost all mercury in uncontaminated drinking-water is thought to be in the form of Hg^{2+}. Thus, it is unlikely that there is any direct risk of the intake of organic mercury compounds, especially of alkylmercurials, as a result of the ingestion of drinking-water. However, there is a possibility that methylmercury will be converted into inorganic mercury. Food is the main source of mercury in non-occupationally exposed populations; the mean dietary intake of mercury in various countries ranges from 2 to 20 µg/day per person.

Guideline value	0.006 mg/l (6 µg/l) for inorganic mercury
Occurrence	Mercury is present in the inorganic form in surface water and groundwater at concentrations usually below 0.5 µg/l, although local mineral deposits may produce higher levels in groundwater
TDI	2 µg/kg body weight for inorganic mercury based on a NOAEL of 0.23 mg/kg body weight per day for kidney effects in a 26-week study in rats and applying an uncertainty factor of 100 (for interspecies and intraspecies variation) after adjusting for daily dosing
Limit of detection	0.05 µg/l by cold vapour AAS; 0.6 µg/l by ICP; 5 µg/l by flame AAS
Treatment performance	It should be possible to achieve a concentration below 1 µg/l by treatment of raw waters that are not grossly contaminated with mercury using methods that include coagulation/sedimentation/filtration, PAC and ion exchange.

Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	A similar TDI may be obtained by applying an uncertainty factor of 1000 (an additional uncertainty factor of 10 for adjustment from a LOAEL to a NOAEL) to the LOAEL for renal effects of 1.9 mg/kg body weight per day in a 2-year NTP study in rats.
	The current guideline value applies to inorganic mercury, which is the form found in drinking-water, whereas the previous guideline value applied to total (inorganic and organic) mercury.
Assessment date	2004
Principal references	IPCS (2003) *Elemental mercury and inorganic mercury compounds* WHO (2005) *Mercury in drinking-water*

The toxic effects of inorganic mercury compounds are seen mainly in the kidney in both humans and laboratory animals following short-term and long-term exposure. In rats, effects include increased absolute and relative kidney weights, tubular necrosis, proteinuria and hypoalbuminaemia. In humans, acute oral poisoning results primarily in haemorrhagic gastritis and colitis; the ultimate damage is to the kidney. The overall weight of evidence is that mercury(II) chloride has the potential to increase the incidence of some benign tumours at sites where tissue damage is apparent and that it possesses weak genotoxic activity but does not cause point mutations.

Methoxychlor

Methoxychlor (CAS No. 72-43-5) is an insecticide used on vegetables, fruit, trees, fodder and farm animals. It is poorly soluble in water and highly immobile in most agricultural soils. Under normal conditions of use, methoxychlor does not seem to be of environmental concern. Daily intake from food and air is expected to be below 1 µg per person. Environmental metabolites are formed preferentially under anaerobic rather than aerobic conditions and include mainly the dechlorinated and demethylated products. There is some potential for the accumulation of the parent compound and its metabolites in surface water sediments.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Detected occasionally in drinking-water, at concentrations as high as 300 µg/l in rural areas
TDI	5 µg/kg body weight, based on a systemic NOAEL of 5 mg/kg body weight in a teratology study in rabbits, with an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 reflecting concern for threshold carcinogenicity and the limited database)
Limit of detection	0.001–0.01 µg/l by GC
Treatment performance	0.1 µg/l should be achievable using GAC

Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Methoxychlor in drinking-water*

The genotoxic potential of methoxychlor appears to be negligible. In 1979, IARC assigned methoxychlor to Group 3. Subsequent data suggest a carcinogenic potential of methoxychlor for liver and testes in mice. This may be due to the hormonal activity of proestrogenic mammalian metabolites of methoxychlor and may therefore have a threshold. The study, however, was inadequate, because only one dose was used and because this dose may have been above the maximum tolerated dose. The database for studies on long-term, short-term and reproductive toxicity is inadequate. A teratology study in rabbits reported a systemic NOAEL of 5 mg/kg body weight per day, which is lower than the LOAELs and NOAELs from other studies. This NOAEL was therefore selected for use in the derivation of a TDI.

Methyl parathion

Methyl parathion (CAS No. 298-00-0) is a non-systemic insecticide and acaricide that is produced throughout the world and has been registered for use on many crops, in particular cotton. It partitions mainly to air and soil in the environment. There is virtually no movement through soil, and neither the parent compound nor its breakdown products will reach groundwater. By far the most important route for the environmental degradation of methyl parathion is microbial degradation. Half-lives of methyl parathion in water are in the order of weeks to months. Concentrations of methyl parathion in natural waters of agricultural areas in the USA ranged up to 0.46 μg/l, with highest levels in summer. The general population can come into contact with methyl parathion via air, water or food.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (1996) *Pesticide residues in food—1995 evaluations.* IPCS (1992) *Methyl parathion* WHO (2003) *Methyl parathion in drinking-water*

A NOAEL of 0.3 mg/kg body weight per day was derived from the combined results of several studies conducted in humans, based on the depression of erythrocyte and plasma cholinesterase activities. Methyl parathion decreased cholinesterase activities in long-term studies in mice and rats, but did not induce carcinogenic effects. Methyl parathion was mutagenic in bacteria, but there was no evidence of genotoxicity in a limited range of studies in mammalian systems.

A health-based value of 9 µg/l can be calculated for methyl parathion on the basis of an ADI of 0–0.003 mg/kg body weight, based on a NOAEL of 0.25 mg/kg body weight per day in a 2-year study in rats for retinal degeneration, sciatic nerve demyelination, reduced body weight, anaemia and decreased brain acetylcholinesterase activity, using an uncertainty factor of 100 for interspecies and intraspecies variation. As the toxicological end-points seen in experimental animals were other than acetylcholinesterase inhibition, it was considered more appropriate to use these data rather than the NOAEL derived for cholinesterase inhibition in humans.

Intake of methyl parathion from all sources is generally low and well below the upper limit of the ADI. As the health-based value is much higher than concentrations of methyl parathion likely to be found in drinking-water, the presence of methyl parathion in drinking-water under usual conditions is unlikely to represent a hazard to human health. For this reason, the establishment of a formal guideline value for methyl parathion is not deemed necessary.

Methyl tertiary-butyl ether

The major use of methyl *tert*-butyl ether, or MTBE, is as a gasoline additive. Surface water can be contaminated by gasoline spills; however, owing to the high volatility of MTBE, most is lost to evaporation. Spills and leaking storage tanks can cause more serious problems in groundwater, where MTBE is more persistent. MTBE has been detected in groundwater and drinking-water at concentrations in the nanogram to microgram per litre range.

Reason for not establishing a guideline value	Any guideline that would be derived would be significantly higher than concentrations at which MTBE would be detected by odour
Assessment date	2004
Principal references	IPCS (1998) *Methyl tertiary-butyl ether* WHO (2005) *Methyl tertiary-butyl ether (MTBE) in drinking-water*

No human cancer studies have been published for either the general population or occupationally exposed cohorts. There have been a number of human studies of neurological and clinical effects of exposure to MTBE by inhalation, with mixed results. In general, no objective changes could be seen at levels of MTBE normally found, even in such microenvironments as gasoline filling stations.

The weight of evidence suggests that MTBE is not genotoxic. A large number of studies using in vitro and in vivo mammalian and non-mammalian systems have been conducted to assess the mutagenicity of MTBE, almost all of which have produced negative results. These results suggest that the mechanism of action of MTBE is more likely to be non-genotoxic than genotoxic, although no one mechanism appears to explain all of the observed effects.

It has been concluded that MTBE should be considered a rodent carcinogen but that it is not genotoxic, and the carcinogenic response is evident only at high levels of exposure that also induce other adverse effects. The available data are therefore considered inconclusive and prohibit their use for human carcinogenic risk assessment.

A health-based guideline value has not been derived for MTBE, owing to the fact that any guideline value that would be derived would be significantly higher than the concentration at which it would be detected by odour (15 µg/l is the lowest level eliciting a response in a study using taste- and odour-sensitive participants).

Metolachlor

Metolachlor (CAS No. 51218-45-2) is a selective pre-emergence herbicide used on a number of crops. It can be lost from the soil through biodegradation, photodegradation and volatilization. It is fairly mobile and under certain conditions can contaminate groundwater, but it is mostly found in surface water.

Guideline value	0.01 mg/l (10 µg/l)
Occurrence	Detected in surface water and groundwater at concentrations that can exceed 10 µg/l
TDI	3.5 µg/kg body weight, based on a NOAEL of 3.5 mg/kg body weight for an apparent decrease in kidney weight at the two highest dose levels in a 1-year dog study, with an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 reflecting some concern regarding carcinogenicity)
Limit of detection	0.75–0.01 µg/l by GC with nitrogen–phosphorus detection
Treatment performance	0.1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Metolachlor in drinking-water*

In a 1-year study in dogs, administration of metolachlor resulted in decreased kidney weight at the two highest dose levels. In 2-year studies with rodents fed metolachlor in the diet, the only toxicological effects observed in mice were decreased body weight gain and decreased survival in females at the highest dose level, whereas rats showed decreased body weight gain and food consumption at the highest dose level. There is no evidence from available studies that metolachlor is carcinogenic in mice. In rats, an increase in liver tumours in females as well as a few nasal tumours in males have been observed. Metolachlor is not genotoxic.

Molinate

Molinate (CAS No. 2212-67-1) is a herbicide used to control broad-leaved and grassy weeds in rice. The available data suggest that groundwater pollution by molinate is restricted to some rice-growing regions. Data on the occurrence of molinate in the environment are limited. Molinate is of low persistence in water and soil, with a half-life of about 5 days.

Guideline value	0.006 mg/l (6 µg/l)
Occurrence	Concentrations in water rarely exceed 1 µg/l
TDI	2 µg/kg body weight, based on a NOAEL for reproductive toxicity in the rat of 0.2 mg/kg body weight, with an uncertainty factor of 100 (for interspecies and intraspecies variation)
Limit of detection	0.01 µg/l by GC-MS
Treatment performance	0.001 mg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Molinate in drinking-water*

On the basis of the limited information available, molinate does not seem to be carcinogenic or mutagenic in experimental animals. Evidence suggests that impairment of the reproductive performance of the male rat represents the most sensitive indicator of molinate exposure. However, epidemiological data based on the examination of workers involved in molinate production do not indicate any effect on human fertility.

Molybdenum

Molybdenum is found naturally in soil and is used in the manufacture of special steels and in the production of tungsten and pigments, and molybdenum compounds are used as lubricant additives and in agriculture to prevent molybdenum deficiency in crops. Concentrations in drinking-water are usually less than 0.01 mg/l, although concentrations as high as 200 µg/l have been reported in areas near mining sites.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	1993, revised in 2011
Principal references	WHO (2011) *Molybdenum in drinking-water*

Molybdenum is considered to be an essential element, with an estimated daily requirement of 0.1–0.3 mg for adults.

As molybdenum occurs at very low concentrations in drinking-water, it is not considered necessary to set a formal guideline value. For guidance purposes, a health-based value can be derived.

In a 2-year study of humans exposed via drinking-water, the NOAEL was found to be 0.2 mg/l, but there are some concerns about the quality of this study. As molybdenum is an essential element, a factor of 3 is considered to be adequate to reflect intraspecies variation. This gives a health-based value of 0.07 mg/l (rounded figure), which is in the same range as that derived on the basis of the results of toxicological studies in experimental animals and is consistent with the essential daily requirement for molybdenum.

Monochloroacetic acid

Chlorinated acetic acids are formed from organic material during water chlorination.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Present in surface water–derived drinking-water at concentrations up to 82 µg/l (mean 2.1 µg/l)
TDI	3.5 µg/kg body weight, based on a LOAEL of 3.5 mg/kg body weight per day from a study in which increased absolute and relative spleen weights were observed in male rats exposed to monochloroacetic acid in drinking-water for 2 years, using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for use of a minimal LOAEL instead of a NOAEL and database deficiencies, including the lack of a multigeneration reproductive toxicity study)
Limit of detection	2 µg/l by GC with ECD; 5 µg/l by GC-MS
Treatment performance	No information available
Guideline value derivation	
• allocation to water	20% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	2003
Principal reference	WHO (2003) *Monochloroacetic acid in drinking-water*

No evidence of carcinogenicity of monochloroacetate was found in 2-year gavage bioassays with rats and mice. Monochloroacetate has given mixed results in a limited number of mutagenicity assays and has been negative for clastogenicity in genotoxicity studies. IARC has not classified the carcinogenicity of monochloroacetic acid.

Monochlorobenzene

Releases of monochlorobenzene (MCB) to the environment are thought to be mainly due to volatilization losses associated with its use as a solvent in pesticide formulations, as a degreasing agent and from other industrial applications. MCB has been detected in surface water, groundwater and drinking-water; mean concentrations were less than 1 µg/l in some potable water sources (maximum 5 µg/l) in Canada. The major source of human exposure is probably air.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern, and health-based value would far exceed lowest reported taste and odour threshold
Assessment date	2003
Principal reference	WHO (2003) *Monochlorobenzene in drinking-water*

MCB is of low acute toxicity. Oral exposure to high doses of MCB results in effects mainly on the liver, kidneys and haematopoietic system. There is limited evidence of

carcinogenicity in male rats, with high doses increasing the occurrence of neoplastic nodules in the liver. The majority of evidence suggests that MCB is not mutagenic; although it binds to DNA in vivo, the level of binding is low.

A health-based value of 300 µg/l can be calculated for MCB on the basis of a TDI of 85.7 µg/kg body weight, based on neoplastic nodules identified in a 2-year rat study with dosing by gavage, and taking into consideration the limited evidence of carcinogenicity. However, because MCB occurs at concentrations well below those of health concern, it is not considered necessary to derive a formal guideline value. It should also be noted that the health-based value far exceeds the lowest reported taste and odour threshold for MCB in water.

MX

MX, which is the common name for 3-chloro-4-dichloromethyl-5-hydroxy-2-(5H)-furanone, is formed by the reaction of chlorine with complex organic matter in drinking-water. It has been identified in chlorinated humic acid solutions and drinking-water in Finland, the United Kingdom and the USA and was found to be present in 37 water sources at levels of 2–67 ng/l. Five drinking-water samples from different Japanese cities contained MX at concentrations ranging from less than 3 to 9 ng/l.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	IPCS (2000) *Disinfectants and disinfectant by-products* WHO (2003) *MX in drinking-water*

MX is a potent mutagen in bacteria and in cells in vitro and has undergone a lifetime study in rats in which some tumorigenic responses were observed. These data indicate that MX induces thyroid and bile duct tumours. IARC has classified MX in Group 2B (possibly carcinogenic to humans) on the basis of rat tumorigenicity and its strong mutagenicity.

A health-based value of 1.8 µg/l can be calculated for MX on the basis of the increase in cholangiomas and cholangiocarcinomas in female rats using the linearized multistage model (without a body surface area correction). However, this is significantly above the concentrations that would be found in drinking-water, and, in view of the analytical difficulties in measuring this compound at such low concentrations, it is considered unnecessary to propose a formal guideline value for MX in drinking-water.

Nickel

Nickel is used mainly in the production of stainless steel and nickel alloys. Food is the dominant source of nickel exposure in the non-smoking, non-occupationally exposed population; water is generally a minor contributor to the total daily oral intake. However, where there is heavy pollution, where there are areas in which nickel that occurs naturally in groundwater is mobilized or where there is use of certain types of kettles,

of non-resistant material in wells or of water that has come into contact with nickel- or chromium-plated taps, the nickel contribution from water may be significant.

Guideline value	0.07 mg/l (70 µg/l)
Occurrence	Concentration in drinking-water normally less than 0.02 mg/l, although nickel released from taps and fittings may contribute up to 1 mg/l; in special cases of release from natural or industrial nickel deposits in the ground, concentrations in drinking-water may be higher
TDI	12 µg/kg body weight, derived from a LOAEL established after oral provocation of fasted patients with an empty stomach
Limit of detection	0.1 µg/l by ICP-MS; 0.5 µg/l by flame AAS; 10 µg/l by ICP-AES
Treatment performance	20 µg/l should be achievable by conventional treatment (e.g. coagulation). Where naturally occurring nickel is mobilized in groundwater, removal is by ion exchange or adsorption. Where nickel leaches from alloys in contact with drinking-water or from chromium- or nickel-plated taps, control is by appropriate control of materials in contact with the drinking-water and flushing taps before using the water.
Guideline value derivation	
• allocation to water	20% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	Although the guideline value is close to the acute LOAEL, the LOAEL is based on total exposure from drinking-water, and absorption from drinking-water on an empty stomach is 10- to 40-fold higher than absorption from food. Basing the total acceptable intake for oral challenge from studies using drinking-water on an empty stomach in fasted patients can therefore be considered a worst-case scenario.
	A general toxicity value of 130 µg/l could be determined from a well-conducted two-generation study in rats. However, this general toxicity value may not be sufficiently protective of individuals sensitized to nickel, for whom a sufficiently high oral challenge has been shown to elicit an eczematous reaction.
Assessment date	2004
Principal reference	WHO (2005) *Nickel in drinking-water*

IARC concluded that inhaled nickel compounds are carcinogenic to humans (Group 1) and that metallic nickel is possibly carcinogenic (Group 2B). However, there is a lack of evidence of a carcinogenic risk from oral exposure to nickel. In a well-conducted two-generation reproductive study in rats administered nickel by gavage, a clear NOEL was observed for adult rats and their offspring for all the end-points studied, including integrity and performance of male and female reproductive systems, growth and development of offspring and post-implantation/perinatal lethality. Allergic contact dermatitis is the most prevalent effect of nickel in the general population.

Nitrate and nitrite[1]

Nitrate (NO_3^-) is found naturally in the environment and is an important plant nutrient. It is present at varying concentrations in all plants and is a part of the nitrogen cycle. Nitrite (NO_2^-) is not usually present in significant concentrations except in a reducing environment, as nitrate is the more stable oxidation state. It can be formed by the microbial reduction of nitrate and in vivo by reduction from ingested nitrate. Nitrite can also be formed chemically in distribution pipes by *Nitrosomonas* bacteria during stagnation of nitrate-containing and oxygen-poor drinking-water in galvanized steel pipes or if chloramination is used to provide a residual disinfectant.

Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater disposal and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. Surface water nitrate concentrations can change rapidly owing to surface runoff of fertilizer, uptake by phytoplankton and denitrification by bacteria, but groundwater concentrations generally show relatively slow changes. Some groundwaters may also have nitrate contamination as a consequence of leaching from natural vegetation.

In general, the most important source of human exposure to nitrate and nitrite is through vegetables (nitrite and nitrate) and through meat in the diet (nitrite is used as a preservative in many cured meats). In some circumstances, however, drinking-water can make a significant contribution to nitrate and, occasionally, nitrite intake. In the case of bottle-fed infants, drinking-water can be the major external source of exposure to nitrate and nitrite.

Guideline values	*Nitrate:* 50 mg/l as nitrate ion (or 11 mg/l as nitrate-nitrogen) to protect against methaemoglobinaemia in bottle-fed infants (short-term exposure)
	Nitrite: 3 mg/l as nitrite ion (or 0.9 mg/l as nitrite-nitrogen) to protect against methaemoglobinaemia in bottle-fed infants (short-term exposure)
	Combined nitrate plus nitrite: The sum of the ratios of the concentrations as reported or detected in the sample of each to its guideline value should not exceed 1.
Occurrence	In most countries, nitrate levels in drinking-water derived from surface water do not exceed 10 mg/l, although nitrate levels in well water often exceed 50 mg/l; nitrite levels are normally lower, less than a few milligrams per litre
Basis of guideline value derivation	*Nitrate (bottle-fed infants):* In epidemiological studies, methaemoglobinaemia was not reported in infants in areas where drinking-water consistently contained less than 50 mg of nitrate per litre
	Nitrite (bottle-fed infants): Application of body weight of 5 kg for an infant and drinking-water consumption of 0.75 litre to lowest level of the dose range associated with methaemoglobinaemia, 0.4 mg/kg body weight. This is supported by accepting a relative potency for nitrite and nitrate with respect to methaemoglobin formation of 10:1 (on a molar basis).

[1] As nitrate and nitrite are chemicals of significant concern in some natural waters, the chemical fact sheet on nitrate and nitrite has been expanded.

Limit of detection	0.005–0.01 mg/l (nitrite) by a molecular absorption spectrometric method; 0.01–1 mg/l (nitrate) by spectrometric techniques; 0.022 mg/l (nitrate) and 0.035 mg/l (nitrite) by ion chromatography; 0.1 mg/l (nitrate) and 0.05 mg/l (nitrite) by LC
Treatment performance	*Nitrate:* 5 mg/l or lower should be achievable using biological denitrification (surface waters) or ion exchange (groundwaters)
	Nitrite: 0.1 mg/l should be achievable using chlorination (to form nitrate)
Additional comments	Nitrite can occur in the distribution system at higher concentrations when chloramination is used, but the occurrence is almost invariably sporadic. Methaemoglobinaemia is therefore the most important consideration, and the guideline derived for protection against methaemoglobinaemia would be the most appropriate under these circumstances, allowing for any nitrate that may also be present.
	Methaemoglobinaemia in infants appears to be associated with simultaneous diarrhoeal disease. Authorities should therefore be **all the more vigilant** that water to be used for bottle-fed infants is microbiologically safe when nitrate is present at concentrations near the guideline value or in the presence of endemic infantile diarrhoea. Water should not be used for bottle-fed infants if the concentration of nitrate is above 100 mg/l but can be used if the concentration is between 50 and 100 mg/l if the water is microbiologically safe and there is increased vigilance by medical authorities.
	All water systems that practise chloramination should closely and regularly monitor their systems to verify disinfectant levels, microbiological quality and nitrite levels. If nitrification is detected (e.g. reduced disinfectant residuals and increased nitrite levels), steps can be taken to modify the treatment train or water chemistry in order to minimize nitrite formation. Efficient disinfection must never be compromised.
	The occurrence of nitrite in the distribution system as a consequence of chloramine use will be intermittent, and average exposures over time should not exceed about 0.2 mg/l.
Assessment date	1998, revised in 2007 and 2010
Principal references	FAO/WHO (2002) *Evaluation of certain food additives* FAO/WHO (2003) Nitrite (and potential endogenous formation of *N*-nitroso compounds) Schmoll et al. (2006) *Protecting groundwater for health* WHO (2011) *Nitrate and nitrite in drinking-water*

Absorption of nitrate ingested from vegetables, meat or water is rapid and in excess of 90%, and final excretion is in the urine. In humans, about 25% of ingested nitrate is recirculated in saliva, of which about 20% is converted to nitrite by the action of bacteria in the mouth. There is also endogenous formation of nitrate from nitric oxide and protein breakdown as part of normal metabolism. In normal healthy adults, this endogenous synthesis leads to the excretion of about 62 mg of nitrate ion per day in the urine. Endogenous formation of nitrate or nitrite can be significantly increased in the presence of infections, particularly gastrointestinal infections. When nitrate intake is low, endogenous formation may be the major source of nitrate in

the body. Nitrate metabolism is different in humans and rats, as rats may not actively secrete nitrate in their saliva.

Nitrate probably has a role in protecting the gastrointestinal tract against a variety of gastrointestinal pathogens, as nitrous oxide and acidified nitrite have antibacterial properties. It may have other beneficial physiological roles. There may therefore be a benefit from exogenous nitrate uptake, and there remains a need to balance the potential risks with the potential benefits.

Significant bacterial reduction of nitrate to nitrite does not normally take place in the stomach, except in individuals with low gastric acidity or with gastrointestinal infections. These may include individuals using antacids, particularly those that block acid secretion.

In humans, methaemoglobinaemia is a consequence of the reaction of nitrite with haemoglobin in the red blood cells to form methaemoglobin, which binds oxygen tightly and does not release it, thus blocking oxygen transport. Although most absorbed nitrite is oxidized to nitrate in the blood, residual nitrite can react with haemoglobin. High levels of methaemoglobin (greater than 10%) formation in infants can give rise to cyanosis, referred to as blue-baby syndrome. Although clinically significant methaemoglobinaemia can occur as a result of extremely high nitrate intake in adults and children, the most familiar situation is its occurrence in bottle-fed infants. This was considered to be primarily a consequence of high levels of nitrate in water, although there have been cases of methaemoglobinaemia in weaned infants associated with high nitrate intake from vegetables. Bottle-fed infants are considered to be at greater risk because the intake of water in relation to body weight is high and, in infants, the development of repair enzymes is limited. In clinical epidemiological studies of methaemoglobinaemia and subclinical increases in methaemoglobin levels associated with drinking-water nitrate, 97% of cases occurred at concentrations in excess of 44.3 mg/l, with clinical symptoms associated with the higher concentrations. The affected individuals were almost exclusively under 3 months of age.

Although drinking-water nitrate may be an important risk factor for methaemoglobinaemia in bottle-fed infants, there is compelling evidence that the risk of methaemoglobinaemia is primarily increased in the presence of simultaneous gastrointestinal infections, which increase endogenous nitrite formation, may increase nitrate reduction to nitrite and may also increase the intake of water in combatting dehydration. Cases have been described in which gastrointestinal infection seems to have been the primary cause of methaemoglobinaemia. Most cases of methaemoglobinaemia reported in the literature are associated with contaminated private wells that also have a high probability of microbial contamination and predominantly when the drinking-water is anaerobic, which should not occur if it is properly disinfected.

Nitrite can react with nitrosatable compounds, primarily secondary amines, in the body to form *N*-nitroso compounds. A number of these are considered to be carcinogenic to humans, whereas others, such as *N*-nitrosoproline, are not. Several studies have been carried out on the formation of *N*-nitroso compounds in relation to nitrate intake in humans, but there is large variation in the intake of nitrosatable

compounds and in gastric physiology. Higher mean levels of *N*-nitroso compounds, along with high nitrate levels, have been found in the gastric juice of individuals who are achlorhydric (very low levels of hydrochloric acid in the stomach). However, other studies have been largely inconclusive, and there appears to be no clear relationship with drinking-water nitrate compared with overall nitrate intake. Moderate consumption of a number of dietary antioxidant components, such as ascorbic acid and green tea, appears to reduce endogenous *N*-nitrosamine formation.

A significant number of epidemiological studies have been carried out on the association of nitrate intake with primarily gastric cancers. Although the epidemiological data are considered to be inadequate to allow definitive conclusions to be drawn regarding all cancers, there is no convincing evidence of a causal association with any cancer site. The weight of evidence indicates that there is unlikely to be a causal association between gastric cancer and nitrate in drinking-water.

There have been suggestions that nitrate in drinking-water could be associated with congenital malformations, but the overall weight of evidence does not support this.

Nitrate appears to competitively inhibit iodine uptake, with the potential for an adverse effect on the thyroid; however, this would be an issue only under circumstances of high nitrate intake and simultaneous iodine deficiency, although the nitrate intakes at which this becomes significant are uncertain.

There have been suggestions of an association between nitrate in drinking-water and the incidence of childhood diabetes mellitus. However, subsequent studies have not found a significant relationship, and no mechanism has been identified.

In some studies on rats treated with high doses of nitrite, a dose-related hypertrophy of the zona glomerulosa of the adrenal was seen; one strain of rats appeared to be more sensitive than others. However, this minimal hyperplasia was considered to be due to physiological adaptation to small fluctuations in blood pressure in response to high nitrite doses.

Nitrate is not carcinogenic in laboratory animals. Nitrite has been frequently studied, and there have been suggestions of carcinogenic activity, but only at very high doses. The most recent long-term studies have shown only equivocal evidence of carcinogenicity in the forestomach of female mice, but not in rats or male mice. In view of the lack of evidence for genotoxicity, this led to the conclusion that sodium nitrite was not carcinogenic in mice and rats. In addition, as humans do not possess a forestomach and the doses were high, the significance of these data for humans is very doubtful.

The guideline value for nitrate of 50 mg/l as nitrate (or 11 mg/l if reported as nitrate-nitrogen) is based on epidemiological evidence for methaemoglobinaemia in infants, which results from short-term exposure, and is protective for bottle-fed infants and, consequently, other parts of the population. This outcome is complicated by the presence of microbial contamination and subsequent gastrointestinal infection, which can increase the risk for this group significantly. Authorities should therefore be all the more vigilant that water to be used for bottle-fed infants is microbiologically safe when nitrate is present at concentrations near the guideline value.

The guideline value for nitrite of 3 mg/l as nitrite (or 0.9 mg/l if reported as nitrite-nitrogen) is based on human data showing that doses of nitrite that cause methaemoglobinaemia in infants range from 0.4 mg/kg body weight to more than 200 mg/kg body weight. By applying the lowest level of the range (0.4 mg/kg body weight), a body weight of 5 kg for an infant and a drinking-water consumption of 0.75 litre, a guideline value of 3 mg/l (rounded figure) can be derived.

Because of the possibility of the simultaneous occurrence of nitrate and nitrite in drinking-water, the sum of the ratios of the concentration (C) of each to its guideline value (GV) should not exceed 1:

$$\frac{C_{nitrate}}{GV_{nitrate}} + \frac{C_{nitrite}}{GV_{nitrite}} \leq 1$$

For chronic exposure, JECFA proposed an ADI of 0–3.7 mg/kg body weight for nitrate and an ADI of 0–0.07 mg/kg body weight for nitrite, expressed as nitrite ion. The value for nitrate is based on a NOEL of 370 mg/kg body weight per day in laboratory animal studies; in view of the known interspecies variation in nitrate/nitrite metabolism, however, it was not considered appropriate at this time to use this in the risk assessment for humans. The JECFA ADI for nitrite was based on effects on heart and lung in a 2-year study in rats using a safety factor of 100. However, owing to the uncertainty surrounding the susceptibility of humans compared with experimental animals, this value was considered provisional and has now been suspended and is being subjected to review in light of evidence on the differences in nitrite metabolism between laboratory rodents and humans.

Practical considerations

The most appropriate means of controlling nitrate concentrations, particularly in groundwater, is the prevention of contamination. This may take the form of appropriate management of agricultural practices, the careful siting of pit latrines and septic tanks, sewer leakage control, as well as management of fertilizer and manure application and storage of animal manures. It may also take the form of denitrification of wastewater effluents.

Methaemoglobinaemia has most frequently been associated with private wells. It is particularly important to ensure that septic tanks and pit latrines are not sited near a well or where a well is to be dug and to ensure that animal manure is kept at a sufficient distance to ensure that runoff cannot enter the well or the ground near the well. It is particularly important that the household use of manures and fertilizers on small plots near wells should be managed with care to avoid potential contamination. The well should be sufficiently protected to prevent runoff from entering the well. Where there are elevated concentrations of nitrate or where inspection of the well indicated that there are sources of nitrate close by that could be causing contamination, particularly where there are indications that microbiological quality might also be poor, a number of actions can be taken. Water should be boiled or disinfected by an appropriate means before consumption. Where alternative supplies are available for bottle-fed

infants, these can be used, taking care to ensure that they are microbiologically safe. Steps should then be taken to protect the well and ensure that sources of both nitrate and microbial contamination are removed from the vicinity of the well.

In areas where household wells are common, health authorities may wish to take a number of steps to ensure that nitrate contamination is not or does not become a problem. Such steps could include targeting mothers, particularly expectant mothers, with appropriate information about water safety, assisting with visual inspection of wells to determine whether a problem may exist, providing testing facilities where a problem is suspected, providing guidance on disinfecting water or where nitrate levels are particularly high, providing bottled water from safe sources or providing advice as to where such water can be obtained.

With regard to piped supplies, where nitrate is present, the first potential approach to treatment of drinking-water supplies, if source substitution is not feasible, is to dilute the contaminated water with a low-nitrate source. Where blending is not feasible, a number of treatment techniques are available for drinking-water. The first is disinfection, which may serve to oxidize nitrite to the less toxic nitrate as well as minimize the pathogenic and non-pathogenic reducing bacterial population in the water. Nitrate removal methods include ion exchange (normally for groundwaters) and biological denitrification (normally for surface waters). However, there are disadvantages associated with both approaches, including the need for regeneration and disposal of spent regenerant with ion exchange, the complexities of operation and the potential for microbial and carbon feed contamination of the final water with biological denitrification.

Care should be taken with the use of chloramination for providing a residual disinfectant in the distribution system. It is important to manage this to minimize nitrite formation, either in the main distribution system or in the distribution systems of buildings where chloramines are used to control *Legionella*.

Nitrilotriacetic acid

Nitrilotriacetic acid, or NTA, is used primarily in laundry detergents as a replacement for phosphates and in the treatment of boiler water to prevent accumulation of mineral scale.

Guideline value	0.2 mg/l (200 µg/l)
Occurrence	Concentrations in drinking-water usually do not exceed a few micrograms per litre, although concentrations as high as 35 µg/l have been measured
TDI	10 µg/kg body weight, based on nephritis and nephrosis in a 2-year study in rats and using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for carcinogenic potential at high doses)
Limit of detection	0.2 µg/l using GC with a nitrogen-specific detector
Treatment performance	No information found on removal from water
Guideline value derivation	
• allocation to water	50% of TDI
• weight	60 kg adult
• consumption	2 litres/day

Assessment date	1993
Principal reference	WHO (2003) *Nitrilotriacetic acid in drinking-water*

NTA is not metabolized in experimental animals and is rapidly eliminated, although some may be briefly retained in bone. It is of low acute toxicity to experimental animals, but it has been shown to produce kidney tumours in rodents following long-term exposure to doses higher than those required to produce nephrotoxicity. IARC has placed NTA in Group 2B (possibly carcinogenic to humans). It is not genotoxic, and the reported induction of tumours is believed to be due to cytotoxicity resulting from the chelation of divalent cations such as zinc and calcium in the urinary tract, leading to the development of hyperplasia and subsequently neoplasia.

Nitrobenzene

Nitrobenzene is used primarily in the production of aniline, but it is also used as a solvent, as an ingredient of metal polishes and soaps and in the synthesis of other organic compounds, including acetaminophen. Nitrobenzene can be released to water during these production processes.

Concentrations of nitrobenzene in environmental samples, such as surface water, groundwater and air, are generally low, except in areas with industrial pollution. Based on limited data, it appears that the potential for contamination is greater for groundwater than for surface water.

The general population can be exposed to variable concentrations of nitrobenzene in air and possibly drinking-water. Only populations in the vicinity of manufacturing activities and petroleum refining plants are likely to have any significant exposure to nitrobenzene; however, people living in and around abandoned hazardous waste sites may also have potential for higher exposure, due to possible groundwater and soil contamination and uptake of nitrobenzene by plants.

Reason for not establishing a guideline value	Rarely found in drinking-water at concentrations of health concern
Assessment date	2009
Principal reference	WHO (2009) *Nitrobenzene in drinking-water*

Nitrobenzene is toxic to humans by the inhalation, dermal and oral routes of exposure. The main systemic effect associated with human exposure to nitrobenzene is methaemoglobinaemia. Although some recent studies have reported positive results in mutagenicity tests, it cannot be excluded that nitrobenzene is a non-genotoxic chemical. No long-term oral administration studies are available. Based on inhalation studies, IARC concluded that there was inadequate evidence in humans but sufficient evidence in experimental animals for the carcinogenicity of nitrobenzene and classified nitrobenzene in Group 2B (possibly carcinogenic to humans).

Because nitrobenzene occurrence in drinking-water at concentrations above trace levels is infrequent, it is not considered necessary to derive a formal guideline value. However, health-based values can be calculated to provide guidance in the event

of spills and where there are higher concentrations in industrial areas. Two health-based values are derived based on the limited available information: one for short-term exposure (30 µg/l) and the other for long-term exposure (8–63 µg/l, depending on end-point and approach used). It should be emphasized that the derivation of the long-term health-based values includes large uncertainties because of the dose metric conversion from inhalation studies and the possibility of increased metabolism to aniline in the gastrointestinal tract.

It should be emphasized that nitrobenzene is a potent methaemoglobinaemic agent in humans, which is of particular concern for bottle-fed infants. Currently, data are not adequate to determine a separate health-based value for this end-point.

It should also be noted that the reported odour threshold for nitrobenzene in water is 30–110 µg/l.

N-Nitrosodimethylamine

N-Nitrosodimethylamine, or NDMA, can occur in drinking-water through the degradation of dimethylhydrazine (a component of rocket fuel) as well as from several other industrial processes. It is also a contaminant of certain pesticides. NDMA has recently been identified as a disinfection by-product of chloramination (by the reaction of monochloramine with dimethylamine, a ubiquitous component of waters affected by wastewater discharges) and, to some extent, chlorination. NDMA can also be formed as a by-product of anion exchange treatment of water.

Guideline value	0.0001 mg/l (0.1 µg/l)
Occurrence	Where chloramination is used, distribution system samples can have much higher levels of NDMA than the finished water at the treatment plant; levels as high as 0.16 µg/l have been measured in the distribution system, but concentrations in water at the treatment plant are generally less than 0.01 µg/l
Basis of guideline value derivation	Hepatic biliary cystadenomas in female rats, the most sensitive carcinogenic end-point, observed in a drinking-water study, using a multistage model
Limit of detection	0.028 ng/l by capillary column GC and chemical ionization tandem MS; 0.4 ng/l by capillary column GC and high-resolution MS; 0.7–1.6 ng/l by GC-MS and ammonia positive chemical ionization detection
Treatment performance	The most common process for NDMA removal is UV irradiation. A concentration below 0.005 µg/l should be achievable by UV irradiation provided that the water is not grossly contaminated. NDMA is not removable by air stripping, activated carbon adsorption, reverse osmosis or biodegradation.
Additional comments	Potential methods for reducing the formation of NDMA during disinfection include avoiding the use of chloramination, use of breakpoint chlorination and removal of ammonia prior to chlorination.
Assessment date	2006
Principal references	IPCS (2002) *N-Nitrosodimethylamine* WHO (2008) *N-Nitrosodimethylamine in drinking-water*

There is conclusive evidence that NDMA is a potent carcinogen in experimental animals by several routes of exposure, including through ingestion of drinking-water. NDMA has been classified by IARC as probably carcinogenic to humans. The mechanism by which NDMA produces cancer is well understood to involve biotransformation by liver microsomal enzymes, generating the methyldiazonium ion. This reactive metabolite forms DNA adducts, with most evidence pointing to O^6-methylguanine as the likely proximal carcinogenic agent. As a consequence of the clear evidence of carcinogenicity, there have been few studies of other possible toxicity end-points.

There is also ample evidence that NDMA is genotoxic both in vivo and in vitro. Activation by liver microsomal S9 fractions is necessary for a positive in vitro result. The recent observation that human S9 fractions are much more active in promoting genotoxicity in the Ames test than rat S9 fractions suggests that humans may be especially sensitive to the carcinogenicity of NDMA.

Although there have been several case–control studies and one cohort study of NDMA in humans, none of them can be used to derive a quantitative risk of cancer. The results are supportive of the assumption that NDMA consumption is positively associated with either gastric or colorectal cancer. However, none of the studies focused on drinking-water as the route of exposure; instead, they used estimations of total dietary intake of NDMA.

Parathion

Parathion (CAS No. 56-38-2) is a non-systemic insecticide that is used in many countries throughout the world. It is used as a fumigant and acaricide and as a pre-harvest soil and foliage treatment on a wide variety of crops, both outdoors and in greenhouses. Parathion released to the environment will adsorb strongly to the top layer of soil and is not likely to leach significantly. Parathion disappears from surface waters in about a week. The general population is not usually exposed to parathion from air or water. Parathion residues in food are the main source of exposure.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (1996) *Pesticide residues in food—1995 evaluations* WHO (2003) *Parathion in drinking-water*

Parathion inhibits cholinesterase activity in all species tested. There has been no evidence of carcinogenicity in 2-year rat studies. JMPR concluded that parathion is not genotoxic.

A health-based value of 10 µg/l can be calculated for parathion on the basis of an ADI of 0–0.004 mg/kg body weight based on a NOAEL of 0.4 mg/kg body weight per day in a 2-year study in rats for retinal atrophy and inhibition of brain acetylcholinesterase at the next higher dose, and using an uncertainty factor of 100 for interspecies and intraspecies variation. Lower NOAELs in experimental animals, based only on inhibition of erythrocyte or brain acetylcholinesterase, were not considered relevant

because of the availability of a NOAEL for erythrocyte acetylcholinesterase inhibition in humans, which was 0.1 mg/kg body weight per day.

Intake of parathion from all sources is generally low and well below the upper limit of the ADI. As the health-based value is much higher than concentrations of parathion likely to be found in drinking-water, the presence of parathion in drinking-water under usual conditions is unlikely to represent a hazard to human health. For this reason, the establishment of a formal guideline value for parathion is not deemed necessary.

Pendimethalin

Pendimethalin (CAS No. 40487-42-1) is a pre-emergence herbicide that is fairly immobile and persistent in soil. It is used in large amounts in Japan (5000 tonnes per year). It is lost through photodegradation, biodegradation and volatilization. The leaching potential of pendimethalin appears to be very low, but little is known about its more polar degradation products.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Rarely found in drinking-water in the limited studies available
TDI	5 µg/kg body weight, based on evidence of slight liver toxicity even at the lowest dose tested (5 mg/kg body weight) in a long-term rat feeding study, with an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for a combination of the use of a LOAEL instead of a NOAEL and limitations of the database)
Limit of detection	0.01 µg/l by GC-MS
Treatment performance	1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Pendimethalin in drinking-water*

In a short-term dietary study in rats, a variety of indications of hepatotoxicity as well as increased kidney weights in males were observed at the highest dose level. In a long-term dietary study, some toxic effects (hyperglycaemia in the mouse and hepatotoxicity in the rat) were present even at the lowest dose level. On the basis of available data, pendimethalin does not appear to have significant mutagenic activity. Long-term studies in mice and rats have not provided evidence of carcinogenicity; however, these studies have some important methodological limitations.

Pentachlorophenol

Pentachlorophenol (CAS No. 87-86-5), or PCP, and other chlorophenols are used primarily for protecting wood from fungal growth. Food is usually the major source of exposure to PCP unless there is a specific local contamination of drinking-water by PCP or exposure from log homes treated with PCP.

Provisional guideline value	0.009 mg/l (9 µg/l)
	The guideline value is considered provisional because of the variations in metabolism between experimental animals and humans.
Occurrence	Concentrations in water samples are usually below 10 µg/l, although much higher concentrations in groundwater may be measured under certain conditions
Basis of guideline value derivation	Multistage modelling of tumour incidence in an NTP bioassay without incorporation of a body surface area correction, recognizing that there are interspecies differences in metabolism between experimental animals and humans, with an important metabolite formed in rats being only a minor metabolite in humans
Limit of detection	0.005–0.01 µg/l by GC with ECD
Treatment performance	0.4 µg/l should be achievable using GAC
Additional comments	The concentration of PCP associated with a 10^{-5} upper-bound excess lifetime cancer risk is similar to the guideline value established in the second edition, so that guideline value is retained.
Assessment date	1998
Principal reference	WHO (2003) *Pentachlorophenol in drinking-water*

IARC classified PCP in Group 2B (possibly carcinogenic to humans) on the basis of inadequate evidence of carcinogenicity in humans but sufficient evidence in experimental animals. There is suggestive, although inconclusive, evidence of the carcinogenicity of PCP from epidemiological studies of populations exposed to mixtures that include PCP. Conclusive evidence of carcinogenicity has been obtained in one animal species (mice). Although there are notable variations in metabolism between experimental animals and humans, it was considered prudent to treat PCP as a potential carcinogen.

Petroleum products

Petroleum products are used in large quantities, primarily as fuels. They are complex mixtures of chemicals derived from crude oil by distillation and fractionation. They consist primarily of a wide range of aliphatic and aromatic hydrocarbons, many of which are of extremely low solubility in water. Petroleum products are widely stored and handled and are often spilt. The primary concern for drinking-water is the potential for spills into source water, penetration of distribution systems and contamination of drinking-water treatment works.

Reason for not establishing a guideline value	Taste and odour will in most cases be detectable at concentrations below those of health concern, particularly with short-term exposure
Assessment date	2004
Principal reference	WHO (2005) *Petroleum products in drinking-water*

Exposure to the constituents of petroleum products through drinking-water is frequently short term, as the result of an accidental spill or short-term incident. Such incidents may lead to high concentrations of total petroleum hydrocarbons. However,

a number of the most soluble aromatic hydrocarbons will be detectable by taste or odour at concentrations below those concentrations of concern for health, particularly for short-term exposure. Substances such as the alkyl benzenes and the alkyl naphthalenes have taste and odour thresholds of a few micrograms per litre. In view of the above, it is not considered appropriate to set a formal health-based guideline value for petroleum products in drinking-water.

In the event of a spill, it may be necessary to carry out a context-specific assessment of the risk to health. The fact that petroleum products are complex mixtures of many individual hydrocarbons is a complicating factor in determining the potential risks to consumers. The traditional approach of evaluating individual chemicals in assessing the risks from drinking-water is therefore largely inappropriate. In order to overcome this difficulty, it is more practical to consider a series of hydrocarbon fractions and to determine appropriate tolerable concentrations for those fractions. The most widely accepted approach is that developed by the Total Petroleum Hydrocarbons Criteria Working Group in the USA, which divided total petroleum hydrocarbons into a series of aliphatic and aromatic fractions based on the number of carbon atoms and the boiling point, to give equivalent carbon numbers.

This pragmatic approach provides a suitable basis for assessing the potential health risks associated with larger-scale contamination of drinking-water by petroleum products. The allocation of 10% of each of the reference doses, equivalent to TDIs, for the various fractions to drinking-water provides a conservative assessment of the risks. Although the approach is based on the analysis of hydrocarbon fractions, most are of low solubility, and the most soluble fractions, consisting largely of lower molecular weight aromatic hydrocarbons, will be present in the greatest concentration.

pH

No health-based guideline value is proposed for pH. Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters (see chapter 10).

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	An important operational water quality parameter
Assessment date	1993
Principal reference	WHO (2007) *pH in drinking-water*

2-Phenylphenol and its sodium salt

2-Phenylphenol (CAS No. 90-43-7) is used as a disinfectant, bactericide and virucide. In agriculture, it is used in disinfecting fruits, vegetables and eggs. It is also used as a general surface disinfectant in hospitals, nursing homes, veterinary hospitals, poultry farms, dairy farms, commercial laundries, barbershops and food processing plants. 2-Phenylphenol is readily degraded in surface waters, with a half-life of about 1 week in river water.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal references	FAO/WHO (2000) *Pesticide residues in food—1999 evaluations* WHO (2003) *2-Phenylphenol and its sodium salt in drinking-water*

2-Phenylphenol has been determined to be of low toxicity. Both 2-phenylphenol and its sodium salt are carcinogenic in male rats, and 2-phenylphenol is carcinogenic in male mice. However, urinary bladder tumours observed in male rats and liver tumours observed in male mice exposed to 2-phenylphenol appear to be threshold phenomena that are species and sex specific. JMPR concluded that 2-phenylphenol is unlikely to represent a carcinogenic risk to humans. Although a working group convened by IARC classified 2-phenylphenol, sodium salt, in Group 2B (possibly carcinogenic to humans) and 2-phenylphenol in Group 3 (not classifiable as to its carcinogenicity to humans), JMPR noted that the IARC classification is based on hazard identification, not risk assessment, and is furthermore limited to published literature, excluding unpublished studies on toxicity and carcinogenicity. JMPR also concluded that there are unresolved questions about the genotoxic potential of 2-phenylphenol.

A health-based value of 1 mg/l can be calculated for 2-phenylphenol on the basis of an ADI of 0–0.4 mg/kg body weight, based on a NOAEL of 39 mg/kg body weight per day in a 2-year toxicity study on the basis of decreased body weight gain and hyperplasia of the urinary bladder and carcinogenicity of the urinary bladder in male rats, using an uncertainty factor of 100 for interspecies and intraspecies variation. Because of its low toxicity, however, the health-based value derived for 2-phenylphenol is much higher than concentrations of 2-phenylphenol likely to be found in drinking-water. Under usual conditions, therefore, the presence of 2-phenylphenol in drinking-water is unlikely to represent a hazard to human health. For this reason, the establishment of a formal guideline value for 2-phenylphenol is not deemed necessary.

Polynuclear aromatic hydrocarbons

Polynuclear aromatic hydrocarbons, or PAHs, form a class of diverse organic compounds each containing two or more fused aromatic rings of carbon and hydrogen atoms. Most PAHs enter the environment via the atmosphere from a variety of combustion processes and pyrolysis sources. Owing to their low solubility and high affinity for particulate matter, they are not usually found in water in notable concentrations. The main source of PAH contamination in drinking-water is usually the coal tar coating of drinking-water distribution pipes, used to protect the pipes from corrosion. Fluoranthene is the most commonly detected PAH in drinking-water and is associated primarily with coal tar linings of cast iron or ductile iron distribution pipes. PAHs have been detected in a variety of foods as a result of the deposition of airborne PAHs and in fish from contaminated waters. PAHs are also formed during some methods of food preparation, such as char-broiling, grilling,

roasting, frying or baking. For the general population, the major routes of exposure to PAHs are from food and ambient and indoor air. The use of open fires for heating and cooking, which is common especially in developing countries, may increase PAH exposure. Where there are elevated levels of contamination by coal tar coatings of water pipes, PAH intake from drinking-water could equal or even exceed that from food.

Guideline value	*Benzo[a]pyrene*: 0.0007 mg/l (0.7 µg/l)
Occurrence	PAH levels in uncontaminated groundwater usually in range 0–5 ng/l; concentrations in contaminated groundwater may exceed 10 µg/l; typical concentration range for sum of selected PAHs in drinking-water is from about 1 ng/l to 11 µg/l
Basis of guideline value derivation	Based on an oral carcinogenicity study in mice and calculated using a two-stage birth–death mutation model, which incorporates variable dosing patterns and time of killing; quantification of dose–response for tumours, on the basis of new studies in which the carcinogenicity of benzo[*a*]pyrene was examined following oral administration in mice, but for which the number of dose groups was smaller, confirms this value
Limit of detection	0.01 µg/l by GC-MS and reversed-phase HPLC with a fluorescence detector
Treatment performance	0.05 µg/l should be achievable using coagulation
Additional comments	The presence of significant concentrations of benzo[*a*]pyrene in drinking-water in the absence of very high concentrations of fluoranthene indicates the presence of coal tar particles, which may arise from seriously deteriorating coal tar pipe linings.
	It is recommended that the use of coal tar–based and similar materials for pipe linings and coatings on storage tanks be discontinued.
Assessment date	1998
Principal reference	WHO (2003) *Polynuclear aromatic hydrocarbons in drinking-water*

Reason for not establishing a guideline value	*Fluoranthene:* Occurs in drinking-water at concentrations well below those of health concern
Assessment date	1998
Principal reference	WHO (2003) *Polynuclear aromatic hydrocarbons in drinking-water*

Evidence that mixtures of PAHs are carcinogenic to humans comes primarily from occupational studies of workers following inhalation and dermal exposure. No data are available for humans for the oral route of exposure. There are few data on the oral toxicity of PAHs other than benzo[*a*]pyrene, particularly in drinking-water. Relative potencies of carcinogenic PAHs have been determined by comparison of data from dermal and other studies. The order of potencies is consistent, and this scheme therefore provides a useful indicator of PAH potency relative to that of benzo[*a*]pyrene.

A health-based value of 4 µg/l can be calculated for fluoranthene on the basis of a NOAEL of 125 mg/kg body weight per day for increased serum glutamate–pyruvate transaminase levels, kidney and liver pathology, and clinical and haematological changes in a 13-week oral gavage study in mice, using an uncertainty factor of 10 000 (100 for interspecies and intraspecies variation, 10 for the use of a subchronic study and inadequate database and 10 because of clear evidence of co-carcinogenicity with benzo[*a*]pyrene in mouse skin painting studies). However, this health-based value is significantly above the concentrations normally found in drinking-water. Under usual conditions, therefore, the presence of fluoranthene in drinking-water does not represent a hazard to human health. For this reason, the establishment of a formal guideline value for fluoranthene is not deemed necessary.

Potassium

Potassium is an essential element in humans and is seldom, if ever, found in drinking-water at levels that could be a concern for healthy humans. The recommended daily requirement is greater than 3000 mg. Potassium occurs widely in the environment, including all natural waters. It can also occur in drinking-water as a consequence of the use of potassium permanganate as an oxidant in water treatment. In some countries, potassium chloride is being used in ion exchange for household water softening in place of, or mixed with, sodium chloride, so potassium ions would exchange with calcium and magnesium ions. Possible replacement or partial replacement of sodium salts with potassium salts for conditioning desalinated water has been suggested. The latter seems to be an unlikely development at this stage, in view of the cost difference.

Reason for not establishing a guideline value	Occurs in drinking-water at concentrations well below those of health concern
Assessment date	2009
Principal reference	WHO (2009) *Potassium in drinking-water*

Currently, there is no evidence that potassium levels in municipally treated drinking-water, even water treated with potassium permanganate, are likely to pose any risk for the health of consumers. It is not considered necessary to establish a health-based guideline value for potassium in drinking-water.

Although potassium may cause some health effects in susceptible individuals, potassium intake from drinking-water is well below the level at which adverse health effects may occur. Health concerns would be related to the consumption of drinking-water treated by potassium-based water treatment (principally potassium chloride for regeneration of ion exchange water softeners), affecting only individuals in high-risk groups (i.e. individuals with kidney dysfunction or other diseases, such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia; people taking medications that interfere with normal potassium-dependent functions in the body; and older individuals or infants). It is recommended that susceptible individuals seek medical advice to determine whether they should avoid the consumption of water (for drinking or cooking) treated by water softeners using potassium chloride.

When high-risk individuals have been advised by a physician to avoid elevated potassium intake from water, the recommended strategy is to limit the addition of potassium to water that will be ingested or to avoid ingesting such water. This can be done by having a proportion of the water bypass the softener altogether; this approach is recommended by several countries. Although technologies are available to remove potassium, they are generally more expensive and redundant when combined with the softening treatment.

Propanil

Propanil (CAS No. 709-98-8) is a contact post-emergence herbicide used to control broad-leaved and grassy weeds, mainly in rice. It is a mobile compound with affinity for the water compartment. Propanil is not, however, persistent, being easily transformed under natural conditions to several metabolites. Two of these metabolites, 3,4-dichloroaniline and 3,3′,4,4′-tetrachloroazobenzene, are more toxic and more persistent than the parent compound. Although used in a number of countries, propanil has only occasionally been detected in groundwater.

Reason for not establishing a guideline value	Readily transformed into metabolites that are more toxic; a guideline value for the parent compound is considered inappropriate, and there are inadequate data to enable the derivation of guideline values for the metabolites
Assessment date	2003
Principal reference	WHO (2003) *Propanil in drinking-water*

Although a health-based value for propanil can be derived, this has not been done, because propanil is readily transformed into metabolites that are more toxic. Therefore, a guideline value for the parent compound is considered inappropriate, and there are inadequate data on the metabolites to allow the derivation of guideline values for them. Authorities should consider the possible presence in water of more toxic environmental metabolites.

Selenium

Selenium is present in Earth's crust, often in association with sulfur-containing minerals. Selenium is an essential trace element, and foodstuffs such as cereals, meat and fish are the principal source of selenium for the general population. Levels in food also vary greatly according to geographical area of production. However, even in high-selenium areas, the relative contribution of selenium from drinking-water is likely to be small in comparison with that from locally produced food.

Provisional guideline value	0.04 mg/l (40 µg/l)
	The guideline value is designated as provisional because of the uncertainties inherent in the scientific database.
Occurrence	Most drinking-water contains concentrations of selenium that are much lower than 10 µg/l, except in certain seleniferous areas

Basis of guideline value derivation	An allocation of 20% of the upper tolerable intake of 400 µg/day to drinking-water provides a sensible balance that will assist regulators and suppliers in making decisions about whether further action is needed
Limit of detection	0.5 µg/l by hydride generation AAS
Treatment performance	Selenium is not removed by conventional treatment processes; significant removals of selenium from water using activated alumina adsorption, ion exchange, reverse osmosis and nanofiltration have been reported.
Guideline value derivation	
• allocation to water	20% of upper tolerable intake
• consumption	2 litres/day
Additional comments	It is important that a proper balance be achieved between recommended intakes and undesirable intakes in determining an appropriate guideline value for selenium in drinking-water. While for most parts of the world, the concentration of selenium in drinking-water will not exceed 10 µg/l, there are circumstances in which selenium may be elevated significantly above normal concentrations, and guidance may be required. Where selenium intake from the diet is known, this should be used in determining a concentration that ensures that intake is safe and sufficient. Where selenium intake from the diet is not known, guidance may be required.
	For most Member States, a drinking-water guideline for selenium is unnecessary. Where there are regions of high intake from a number of sources, of which drinking-water may be one, then Member States should take into consideration exposure from all sources in determining actions to reduce exposure. For drinking-water, this may include using alternative sources, blending low-selenium sources with high-selenium sources as well as considering selenium removal.
Assessment date	2010
Principal references	FAO/WHO (2004) *Vitamin and mineral requirements in human nutrition* WHO (2011) *Selenium in drinking-water*

Selenium is an essential element for humans, and there are indications that selenium status may be marginal in many parts of the world, including western Europe. The potential for adverse effects from selenium deficiency appears to be dependent on a number of factors, including overall health and nutritional status. Very low selenium status in humans has been associated with a juvenile, multifocal myocarditis called Keshan disease and a chondrodystrophy called Kaschin-Beck disease. Several studies have also found blood selenium levels to be inversely associated with the prevalence of several types of cancer.

High intakes of selenium are also associated with a number of specific diseases and the potential for adverse effects, but, again, this seems to be strongly influenced by other factors. Symptoms in people with high urinary selenium levels included gastrointestinal disturbances, discoloration of the skin, decayed teeth, hair or nail loss, nail abnormalities and changes in peripheral nerves. Slight biochemical changes have also been observed. One case of selenium toxicity directly attributable to a water source (well water containing selenium at a concentration of 9 mg/l) has been reported. The

average dietary intake that is associated with selenosis has been found to be in excess of 900 μg/day.

As selenium is an essential element, various national and international organizations have established recommended daily intakes of selenium. A joint FAO/WHO consultation recommended intakes of 6–21 μg of selenium per day for infants and children, according to age, 26 and 30 μg of selenium per day for adolescent females and males, respectively, and 26 and 35 μg of selenium per day for adult females and males, respectively.

Because of concern about the adverse effects resulting from exposure to excessive levels of selenium, various national and international organizations have established upper limits of exposure for selenium. FAO/WHO established an upper tolerable limit for selenium of 400 μg/day.

Silver

Silver occurs naturally, mainly in the form of its very insoluble and immobile oxides, sulfides and some salts. It has occasionally been found in groundwater, surface water and drinking-water at concentrations above 5 μg/l. Levels in drinking-water treated with silver for disinfection may be above 50 μg/l. Recent estimates of daily intake are about 7 μg per person.

Reason for not establishing a guideline value	Available data inadequate to permit derivation of health-based guideline value
Assessment date	1993
Principal reference	WHO (2003) *Silver in drinking-water*

Only a small percentage of silver is absorbed. Retention rates in humans and laboratory animals range between 0% and 10%.

The only obvious sign of silver overload is argyria, a condition in which skin and hair are heavily discoloured by silver in the tissues. An oral NOAEL for argyria in humans for a total lifetime intake of 10 g of silver was estimated on the basis of human case reports and long-term experiments with laboratory animals.

The low levels of silver in drinking-water, generally below 5 μg/l, are not relevant to human health with respect to argyria. In contrast, special situations exist where silver salts may be used to maintain the bacteriological quality of drinking-water. Higher levels of silver, up to 0.1 mg/l (this concentration gives a total dose over 70 years of half the human NOAEL of 10 g), could be tolerated in such cases without risk to health.

There are no adequate data with which to derive a health-based guideline value for silver in drinking-water.

Simazine

Simazine (CAS No. 122-34-9) is a pre-emergence herbicide used on a number of crops as well as in non-crop areas. It is fairly resistant to physical and chemical dissipation processes in the soil. It is persistent and mobile in the environment.

Guideline value	0.002 mg/l (2 µg/l)
Occurrence	Frequently detected in groundwater and surface water at concentrations of up to a few micrograms per litre
TDI	0.52 µg/kg body weight, based on a NOAEL of 0.52 mg/kg body weight from a long-term study in the rat (based on weight changes, effects on haematological parameters and an increase in mammary tumours) and an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for possible non-genotoxic carcinogenicity)
Limit of detection	0.01 µg/l by GC-MS; 0.1–0.2 µg/l by GC with flame thermionic detection
Treatment performance	0.1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Simazine in drinking-water*

Simazine does not appear to be genotoxic in mammalian systems. Recent studies have shown an increase in mammary tumours in the female rat but no effects in the mouse. IARC has classified simazine in Group 3 (not classifiable as to its carcinogenicity to humans).

Sodium

Sodium salts (e.g. sodium chloride) are found in virtually all food (the main source of daily exposure) and drinking-water. Although concentrations of sodium in potable water are typically less than 20 mg/l, they can greatly exceed this in some countries. The levels of sodium salts in air are normally low in relation to those in food or water. It should be noted that some water softeners can add significantly to the sodium content of drinking-water.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	1993
Principal reference	WHO (2003) *Sodium in drinking-water*

No firm conclusions can be drawn concerning the possible association between sodium in drinking-water and the occurrence of hypertension. Therefore, no health-based guideline value is proposed. However, concentrations in excess of 200 mg/l may give rise to unacceptable taste (see chapter 10).

Sodium dichloroisocyanurate

Sodium dichloroisocyanurate is the sodium salt of a chlorinated hydroxytriazine and is used as a source of free available chlorine, in the form of hypochlorous acid, for the disinfection of water. It is widely used as a stable source of chlorine for the disinfection of swimming pools and in the food industry. It is also used as a means of disinfecting drinking-water, primarily in emergencies, when it provides an easy-to-use source of free chlorine, and, more recently, as the form of chlorine for household point-of-use water treatment.

Guideline values	*Sodium dichloroisocyanurate:* 50 mg/l (50 000 µg/l)
	Cyanuric acid: 40 mg/l (40 000 µg/l)
Occurrence	Where sodium dichloroisocyanurate is used for the disinfection of drinking-water, exposure will be to both the chlorinated species and residual cyanuric acid. The concentrations will relate directly to the quantities added to achieve adequate disinfection.
TDI	2.2 mg/kg body weight for anhydrous sodium dichloroisocyanurate and 1.54 mg/kg body weight for cyanuric acid, based on a NOEL of 154 mg/kg body weight per day (equivalent to 220 mg/kg body weight per day as anhydrous sodium dichloroisocyanurate) for urinary tract and cardiac lesions from a 2-year study of rats exposed to sodium cyanurate and using an uncertainty factor of 100 for interspecies and intraspecies variation
Limit of detection	0.001 mg/l by GC with flame thermionic specific detection; 0.05 mg/l by reversed-phase LC with UV detection; 0.09 mg/l by GC with MS selective ion monitoring
Treatment performance	At very high chlorine doses (up to 10 mg/l), the sodium cyanurate concentration would be below 11 mg/l. In emergency situations, "topping up" might be done in an attempt to maintain a free chlorine residual, but this practice should be discouraged. In this case, it would be possible for the sodium cyanurate concentration to build up to undesirable levels. In such cases, it would be very desirable to monitor the concentration of sodium cyanurate.
Guideline value derivation	
• allocation to water	80% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The controlling factors are the level of free chlorine and the residue of cyanuric acid, particularly if there is topping up of chlorine in a static system under emergency conditions. The concentration of free chlorine should normally be such that it should not give rise to unacceptable tastes and should not normally exceed the guideline value of 5 mg/l for free chlorine.
	Sodium dichloroisocyanurate used for disinfecting drinking-water should be of adequate purity so that there is no increase in any inorganic or organic contaminants in the drinking-water. The amounts of sodium dichloroisocyanurate used should be the lowest consistent with adequate disinfection, and the concentrations of cyanuric acid should be managed to be kept as low as is reasonably possible.

Assessment date	2007
Principal references	FAO/WHO (2004) *Evaluation of certain food additives and contaminants* WHO (2008) *Sodium dichloroisocyanurate in drinking-water*

Studies of the toxicity of sodium cyanurate are appropriate for assessing the safety of sodium dichloroisocyanurate, because any residues of intact sodium dichloroisocyanurate in drinking-water would be rapidly converted to cyanuric acid on contact with saliva. Both sodium dichloroisocyanurate and sodium cyanurate have low acute oral toxicity. Sodium cyanurate does not induce any genotoxic, carcinogenic or teratogenic effects. The NOEL from which the guideline value was derived was based on multiple lesions of the urinary tract (calculi and hyperplasia, bleeding and inflammation of the bladder epithelium, dilated and inflamed ureters and renal tubular nephrosis) and cardiac lesions (acute myocarditis, necrosis and vascular mineralization) in male rats exposed at the next higher dose.

Styrene

Styrene, which is used primarily for the production of plastics and resins, is found in trace amounts in surface water, drinking-water and food. In industrial areas, exposure via air can result in intake of a few hundred micrograms per day. Smoking may increase daily exposure by up to 10-fold.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Has been detected in drinking-water and surface water at concentrations below 1 µg/l
TDI	7.7 µg/kg body weight, based on a NOAEL of 7.7 mg/kg body weight per day for decreased body weight observed in a 2-year drinking-water study in rats, and using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for the carcinogenicity and genotoxicity of the reactive intermediate styrene-7,8-oxide)
Limit of detection	0.3 µg/l by GC with photoionization detection and confirmation by MS
Treatment performance	0.02 mg/l may be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	May affect the acceptability of drinking-water at the guideline value
Assessment date	1993
Principal reference	WHO (2003) *Styrene in drinking-water*

Following oral or inhalation exposure, styrene is rapidly absorbed and widely distributed in the body, with a preference for lipid depots. It is metabolized to the active intermediate styrene-7,8-oxide, which is conjugated with glutathione or further metabolized. Metabolites are rapidly and almost completely excreted in urine. Styrene

has a low acute toxicity. In short-term toxicity studies in rats, impairment of glutathione transferase activity and reduced glutathione concentrations were observed. In in vitro tests, styrene has been shown to be mutagenic in the presence of metabolic activation only. In in vitro as well as in vivo studies, chromosomal aberrations have been observed, mostly at high doses of styrene. The reactive intermediate styrene-7,8-oxide is a direct-acting mutagen. In long-term studies, orally administered styrene increased the incidence of lung tumours in mice at high dose levels but had no carcinogenic effect in rats. Styrene-7,8-oxide was carcinogenic in rats after oral administration. IARC has classified styrene in Group 2B (possibly carcinogenic to humans). The available data suggest that the carcinogenicity of styrene is due to overloading of the detoxification mechanism for styrene-7,8-oxide (e.g. glutathione depletion).

Sulfate

Sulfates occur naturally in numerous minerals and are used commercially, principally in the chemical industry. They are discharged into water in industrial wastes and through atmospheric deposition; however, the highest levels usually occur in groundwater and are from natural sources. In general, the average daily intake of sulfate from drinking-water, air and food is approximately 500 mg, food being the major source. However, in areas with drinking-water supplies containing high levels of sulfate, drinking-water may constitute the principal source of intake.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	2003
Principal reference	WHO (2003) *Sulfate in drinking-water*

The existing data do not identify a level of sulfate in drinking-water that is likely to cause adverse human health effects. The data from a liquid diet study with piglets and from tap water studies with human volunteers indicate a laxative effect at concentrations of 1000–1200 mg/l, but no increase in diarrhoea, dehydration or weight loss.

No health-based guideline is proposed for sulfate. However, because of the gastrointestinal effects resulting from ingestion of drinking-water containing high sulfate levels, it is recommended that health authorities be notified of sources of drinking-water that contain sulfate concentrations in excess of 500 mg/l. The presence of sulfate in drinking-water may also cause noticeable taste (see chapter 10) and may contribute to the corrosion of distribution systems.

2,4,5-T

The half-lives for degradation of chlorophenoxy herbicides, including 2,4,5-T (CAS No. 93-76-5), also known as 2,4,5-trichlorophenoxyacetic acid, in the environment are in the order of several days. Chlorophenoxy herbicides are not often found in food.

Guideline value	0.009 mg/l (9 µg/l)
Occurrence	Chlorophenoxy herbicides not frequently found in drinking-water; when detected, concentrations usually no greater than a few micrograms per litre
TDI	3 µg/kg body weight, based on a NOAEL of 3 mg/kg body weight for reduced body weight gain, increased liver and kidney weights and renal toxicity in a 2-year study in rats, with an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 to take into consideration the suggested association between 2,4,5-T and soft tissue sarcoma and non-Hodgkin lymphoma in epidemiological studies)
Limit of detection	0.02 µg/l by GC with ECD
Treatment performance	1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Chlorophenoxy herbicides (excluding 2,4-D and MCPA) in drinking-water*

Chlorophenoxy herbicides, as a group, have been classified in Group 2B (possibly carcinogenic to humans) by IARC. However, the available data from studies in exposed populations and experimental animals do not permit assessment of the carcinogenic potential to humans of any specific chlorophenoxy herbicide. Therefore, drinking-water guidelines for these compounds are based on a threshold approach for other toxic effects. The NOAEL for reproductive effects (reduced neonatal survival, decreased fertility, reduced relative liver weights and thymus weights in litters) of dioxin-free (< 0.03 µg/kg) 2,4,5-T in a three-generation reproduction study in rats is the same as the NOAEL for reduced body weight gain, increased liver and kidney weights and renal toxicity in a toxicity study in which rats were fed 2,4,5-T (practically free from dioxin contamination) in the diet for 2 years.

Terbuthylazine

Terbuthylazine (CAS No. 5915-41-3), or TBA, a herbicide that belongs to the chlorotriazine family, is used in both pre-emergence and post-emergence treatment of a variety of agricultural crops and in forestry. Degradation of TBA in natural water depends on the presence of sediments and biological activity.

Guideline value	0.007 mg/l (7 µg/l)
Occurrence	Concentrations in water seldom exceed 0.2 µg/l, although higher concentrations have been observed.
TDI	2.2 µg/kg body weight, based on a NOAEL of 0.22 mg/kg body weight for decreased body weight gain at the next higher dose in a 2-year toxicity/carcinogenicity study in rats, with an uncertainty factor of 100 (for interspecies and intraspecies variation)

Limit of detection	0.1 µg/l by HPLC with UV detection
Treatment performance	0.1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1998
Principal reference	WHO (2003) *Terbuthylazine in drinking-water*

There is no evidence that TBA is carcinogenic or mutagenic. In long-term dietary studies in rats, effects on red blood cell parameters in females, an increased incidence of non-neoplastic lesions in the liver, lung, thyroid and testis and a slight decrease in body weight gain were observed.

Tetrachloroethene

Tetrachloroethene has been used primarily as a solvent in dry cleaning industries and to a lesser extent as a degreasing solvent. It is widespread in the environment and is found in trace amounts in water, aquatic organisms, air, foodstuffs and human tissue. The highest environmental levels of tetrachloroethene are found in the commercial dry cleaning and metal degreasing industries. Emissions can sometimes lead to high concentrations in groundwater. Tetrachloroethene in anaerobic groundwater may degrade to more toxic compounds, including vinyl chloride.

Guideline value	0.04 mg/l (40 µg/l)
Occurrence	Concentrations in drinking-water are generally below 3 µg/l, although much higher concentrations have been detected in well water (23 mg/l) and in contaminated groundwater (1 mg/l)
TDI	14 µg/kg body weight, based on hepatotoxic effects observed in a 6-week gavage study in male mice and a 90-day drinking-water study in male and female rats, and taking into consideration carcinogenic potential (but not the short length of the study, in view of the database and considerations regarding the application of the dose via drinking-water in one of the two critical studies)
Limit of detection	0.2 µg/l by GC with ECD; 4.1 µg/l by GC-MS
Treatment performance	0.001 mg/l should be achievable using air stripping
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Tetrachloroethene in drinking-water*

At high concentrations, tetrachloroethene causes central nervous system depression. Lower concentrations of tetrachloroethene have been reported to damage the liver and the kidneys. IARC has classified tetrachloroethene in Group 2A (probably carcinogenic to humans). Tetrachloroethene has been reported to produce liver tumours in male and female mice, with some evidence of mononuclear cell leukaemia in male and female rats and kidney tumours in male rats. The overall evidence from studies conducted to assess the genotoxicity of tetrachloroethene, including induction of single-strand DNA breaks, mutation in germ cells and chromosomal aberrations in vitro and in vivo, indicates that tetrachloroethene is not genotoxic.

Toluene

Most toluene (in the form of benzene–toluene–ethylbenzene–xylene mixtures) is used in the blending of petrol. It is also used as a solvent and as a raw material in chemical production. The main exposure is via air. Exposure is increased by smoking and in traffic.

Guideline value	0.7 mg/l (700 µg/l)
Occurrence	Concentrations of a few micrograms per litre have been found in surface water, groundwater and drinking-water; point emissions can lead to higher concentrations in groundwater (up to 1 mg/l); it may also penetrate plastic pipes from contaminated soil
TDI	223 µg/kg body weight, based on a LOAEL of 312 mg/kg body weight per day for marginal hepatotoxic effects observed in a 13-week gavage study in mice, adjusting for daily dosing and using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for the short duration of the study and use of a LOAEL instead of a NOAEL)
Limit of detection	0.13 µg/l by GC with FID; 6 µg/l by GC-MS
Treatment performance	0.001 mg/l should be achievable using air stripping
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The guideline value exceeds the lowest reported odour threshold for toluene in water.
Assessment date	2003
Principal reference	WHO (2003) *Toluene in drinking-water*

Toluene is absorbed completely from the gastrointestinal tract and rapidly distributed in the body, with a preference for adipose tissue. Toluene is rapidly metabolized and, following conjugation, excreted predominantly in urine. With occupational exposure to toluene by inhalation, impairment of the central nervous system and irritation of mucous membranes are observed. The acute oral toxicity is low. Toluene exerts embryotoxic and fetotoxic effects, but there is no clear evidence of teratogenic activity in laboratory animals and humans. In long-term inhalation studies in rats

and mice, there is no evidence for carcinogenicity of toluene. Genotoxicity tests in vitro were negative, whereas in vivo assays showed conflicting results with respect to chromosomal aberrations. IARC has concluded that there is inadequate evidence for the carcinogenicity of toluene in both experimental animals and humans and classified it as Group 3 (not classifiable as to its carcinogenicity to humans).

Total dissolved solids

Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. TDS in drinking-water originates from natural sources, sewage, urban runoff and industrial wastewater. Salts used for road de-icing in some countries may also contribute to the TDS content of drinking-water. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubilities of minerals.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	1993
Principal reference	WHO (2003) *Total dissolved solids in drinking-water*

Reliable data on possible health effects associated with the ingestion of TDS in drinking-water are not available, and no health-based guideline value is proposed. However, the presence of high levels of TDS in drinking-water may be objectionable to consumers (see chapter 10).

Trichloroacetic acid

Chlorinated acetic acids are formed from organic material during water chlorination.

Guideline value	0.2 mg/l (200 µg/l)
Occurrence	Detected in groundwater and surface water distribution systems in the USA at mean concentrations of 5.3 µg/l (up to a maximum of 80 µg/l) and 16 µg/l (up to a maximum of 174 µg/l), respectively; maximum concentration (200 µg/l) measured in chlorinated water in Australia
TDI	32.5 µg/kg body weight, based on a NOAEL of 32.5 mg/kg body weight per day from a study in which decreased body weight, increased liver serum enzyme activity and liver histopathology were seen in rats exposed to trichloroacetate in drinking-water for 2 years, incorporating an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for database deficiencies, including the absence of a multigeneration reproductive study, the lack of a developmental study in a second species and the absence of full histopathological data in a second species)
Limit of detection	1 µg/l by GC-MS or GC-ECD

Treatment performance	Concentrations may be reduced by installing or optimizing coagulation to remove precursors or by controlling the pH during chlorination.
Guideline value derivation	
• allocation to water	20% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	A similar TDI for trichloroacetate was established by IPCS based on a NOAEL for hepatic toxicity in a long-term study in mice.
Assessment date	2003
Principal reference	WHO (2003) *Trichloroacetic acid in drinking-water*

Trichloroacetic acid has been shown to induce tumours in the liver of mice. It has given mixed results in in vitro assays for mutations and chromosomal aberrations and has been reported to cause chromosomal aberrations in in vivo studies. IARC has classified trichloroacetic acid in Group 3, not classifiable as to its carcinogenicity to humans. The weight of evidence indicates that trichloroacetic acid is not a genotoxic carcinogen.

Trichlorobenzenes (total)

Releases of trichlorobenzenes (TCBs) into the environment occur through their manufacture and use as industrial chemicals, chemical intermediates and solvents. TCBs are found in drinking-water, but rarely at levels above 1 µg/l. General population exposure will primarily result from air and food.

Reason for not establishing a guideline value	Occur in drinking-water at concentrations well below those of health concern, and health-based value would exceed lowest reported odour threshold
Assessment date	2003
Principal reference	WHO (2003) *Trichlorobenzenes in drinking-water*

The TCBs are of moderate acute toxicity. After short-term oral exposure, all three isomers show similar toxic effects, predominantly on the liver. Long-term toxicity and carcinogenicity studies via the oral route have not been carried out, but the data available suggest that all three isomers are non-genotoxic.

A health-based value of 20 µg/l can be calculated for total TCBs on the basis of a TDI of 7.7 µg/kg body weight, based on liver toxicity identified in a 13-week rat study, taking into consideration the short duration of the study. However, because TCBs occur at concentrations well below those of health concern, it is not considered necessary to derive a formal guideline value. It should be noted that the health-based value exceeds the lowest reported odour threshold in water.

1,1,1-Trichloroethane

1,1,1-Trichloroethane is widely used as a cleaning solvent for electrical equipment, as a solvent for adhesives, coatings and textile dyes and as a coolant and lubricant. It is

found mainly in the atmosphere, although it is mobile in soils and readily migrates to groundwaters. 1,1,1-Trichloroethane has been found in only a small proportion of surface waters and groundwaters, usually at concentrations of less than 20 µg/l; higher concentrations (up to 150 µg/l) have been observed in a few instances. There appears to be increasing exposure to 1,1,1-trichloroethane from other sources.

Reason for not establishing a guideline value	Occur in drinking-water at concentrations well below those of health concern
Assessment date	2003
Principal reference	WHO (2003) *1,1,1-Trichloroethane in drinking-water*

1,1,1-Trichloroethane is rapidly absorbed from the lungs and gastrointestinal tract, but only small amounts—about 6% in humans and 3% in experimental animals—are metabolized. Exposure to high concentrations can lead to hepatic steatosis (fatty liver) in both humans and laboratory animals. In a well-conducted oral study in mice and rats, effects included reduced liver weight and changes in the kidney consistent with hyaline droplet neuropathy. IARC has placed 1,1,1-trichloroethane in Group 3. 1,1,1-Trichloroethane does not appear to be mutagenic.

A health-based value of 2 mg/l can be calculated for 1,1,1-trichloroethane on the basis of a TDI of 0.6 mg/kg body weight, based on changes in the kidney that were consistent with hyaline droplet nephropathy observed in a 13-week oral study in male rats, and taking into account the short duration of the study. However, because 1,1,1-trichloroethane occurs at concentrations well below those of health concern, it is not considered necessary to derive a formal guideline value.

Trichloroethene

Trichloroethene is used primarily in metal degreasing. It is emitted mainly to the atmosphere, but it may also be introduced into groundwater and, to a lesser extent, surface water in industrial effluents. Poor handling as well as improper disposal of trichloroethene in landfills have been the main causes of groundwater contamination. It is expected that exposure to trichloroethene from air will be greater than that from food or drinking-water, unless the drinking-water contains trichloroethene at levels above about 10 µg/l.

Provisional guideline value	0.02 mg/l (20 µg/l)
	The guideline value is designated as provisional because of deficiencies in the toxicological database.
Occurrence	Owing to its high volatility, concentrations are normally low (< 1 µg/l) in surface water; concentrations may be higher (usually below 100 µg/l) in groundwater systems where volatilization and biodegradation are limited
TDI	1.46 µg/kg body weight per day in a developmental toxicity study in rats, based on a $BMDL_{10}$ (the lower 95% confidence limit corresponding to a 10% increase in extra risk of fetal heart malformations over background) of 0.146 mg/kg body weight per day and using an uncertainty factor of 100 for intraspecies and interspecies variation

Limit of detection	0.01–3.0 µg/l by purge-and-trap capillary GC with photoionization detectors or with photoionization detectors and ECD in series; 0.5 µg/l by purge-and-trap capillary GC with MS; 0.01 µg/l by liquid–liquid extraction and GC-ECD; practical quantification limit considered to be achievable by most good laboratories is 5 µg/l
Treatment performance	0.002 mg/l should be achievable by air stripping, possibly in combination with GAC adsorption
Guideline value derivation	
• allocation to water	50% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The guideline value is protective for both cancer and non-cancer end-points.
	In countries with low rates of ventilation in houses and high rates of showering and bathing, authorities may wish to take the additional exposures through the dermal and inhalation routes into consideration in developing national standards from the provisional guideline value.
Assessment date	2004
Principal reference	WHO (2005) *Trichloroethene in drinking-water*

Although trichloroethene appears to be weakly genotoxic in in vitro and in vivo assays, several of its metabolites are genotoxic, and some are established as known or likely human carcinogens. In view of the sufficient weight of evidence of carcinogenicity in two species of experimental animals with supporting human data, IARC classified trichloroethene as Group 2A (probably carcinogenic to humans). Developmental toxicity is considered to be the critical non-cancer effect, because of the low adverse effect level, the severity of the end-point (heart malformations) and the presence of evidence for similar effects (e.g. cardiac anomalies) from epidemiological studies.

Trifluralin

Trifluralin (CAS No. 1582-09-8) is a pre-emergence herbicide used in a number of crops. It has low water solubility and a high affinity for soil. However, biodegradation and photodegradation processes may give rise to polar metabolites that may contaminate drinking-water sources. Although this compound is used in many countries, relatively few data are available concerning contamination of drinking-water.

Guideline value	0.02 mg/l (20 µg/l)
Occurrence	Not detected in the small number of drinking-water samples analysed; has been detected in surface water at concentrations above 0.5 µg/l and rarely in groundwater
TDI	7.5 µg/kg body weight, based on a NOAEL of 0.75 mg/kg body weight for mild hepatic effects in a 1-year feeding study in dogs, with an uncertainty factor of 100 (for interspecies and intraspecies variation)
Limit of detection	0.05 µg/l by GC with nitrogen–phosphorus detection

Treatment performance	1 µg/l should be achievable using GAC
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	Authorities should note that some impure technical grades of trifluralin could contain potent carcinogenic compounds and therefore should not be used.
Assessment date	1993
Principal reference	WHO (2003) *Trifluralin in drinking-water*

Trifluralin of high purity does not possess mutagenic properties. Technical trifluralin of low purity may contain nitroso contaminants and has been found to be mutagenic. No evidence of carcinogenicity was demonstrated in a number of long-term toxicity/carcinogenicity studies with pure (99%) test material. IARC has assigned technical-grade trifluralin to Group 3 (not classifiable as to its carcinogenicity to humans).

Trihalomethanes (bromoform, bromodichloromethane, chloroform, dibromochloromethane)

THMs are formed in drinking-water primarily as a result of chlorination of organic matter present naturally in raw water supplies. The rate and degree of THM formation increase as a function of the chlorine and humic acid concentration, temperature, pH and bromide ion concentration. Chloroform is the most common THM and the principal disinfection by-product in chlorinated drinking-water. In the presence of bromides, brominated THMs are formed preferentially, and chloroform concentrations decrease proportionally. It is assumed that most THMs present in water are ultimately transferred to air as a result of their volatility. For chloroform, for example, individuals may be exposed during showering to elevated concentrations from chlorinated tap water. For the volatile THMs, approximately equal contributions to total exposure come from four areas: ingestion of drinking-water, inhalation of indoor air largely due to volatilization from drinking-water, inhalation and dermal exposure during showering or bathing and ingestion of food, with all but food exposure arising primarily from drinking-water. Indoor air exposure to the volatile THMs is particularly important in countries with low rates of ventilation in houses and high rates of showering and bathing.

Guideline values	*Chloroform:* 0.3 mg/l (300 µg/l)
	Bromoform: 0.1 mg/l (100 µg/l)
	Dibromochloromethane (DBCM): 0.1 mg/l (100 µg/l)
	Bromodichloromethane (BDCM): 0.06 mg/l (60 µg/l)

Occurrence	THMs are not expected to be found in raw water (unless near a pollution source), but are usually present in finished or chlorinated water; concentrations are generally below 100 µg/l; in most circumstances, chloroform is the dominant compound
TDIs	*Chloroform:* 15 µg/kg body weight, derived from the lower 95% confidence limit for 5% incidence of hepatic cysts, generated by physiologically based pharmacokinetic modelling, in dogs that ingested chloroform in toothpaste for 7.5 years, using an uncertainty factor of 25 (10 for intraspecies differences in toxicokinetics and toxicodynamics and 2.5 for differences in interspecies toxicodynamics)
	Bromoform: 17.9 µg/kg body weight, based on the absence of histopathological lesions in the liver in a well-conducted and well-documented 90-day study in rats, using an uncertainty factor of 1000 (100 for intraspecies and interspecies variation and 10 for possible carcinogenicity and short duration of exposure)
	DBCM: 21.4 µg/kg body weight, based on the absence of histopathological effects in the liver in a well-conducted and well-documented 90-day study in rats, using an uncertainty factor of 1000 (100 for intraspecies and interspecies variation and 10 for the short duration of the study); an additional uncertainty factor for potential carcinogenicity was not applied because of the questions regarding mouse liver tumours from corn oil vehicles and inconclusive evidence of genotoxicity
Basis of guideline value derivation	*BDCM:* Application of the linearized multistage model for the observed increases in incidence of kidney tumours in male mice observed in an NTP bioassay
Limit of detection	0.1–0.2 µg/l (method detection limits) by purge-and-trap and liquid–liquid extraction and direct aqueous injection in combination with a chromatographic system; 0.1 µg/l by GC-ECD; 2.2 µg/l by GC-MS
Treatment performance	Concentrations can be reduced by changes to disinfection practice (e.g. reducing organic THM precursors) or using air stripping.
Guideline value derivation	
• allocation to water	20% of TDI for bromoform and DBCM 75% of TDI for chloroform
• weight	60 kg adult
• consumption	2 litres/day
Additional comments on THMs	For authorities wishing to establish a total THM standard to account for additive toxicity, the following fractionation approach could be taken: $\frac{C_{bromoform}}{GV_{bromoform}} + \frac{C_{DBCM}}{GV_{DBCM}} + \frac{C_{BDCM}}{GV_{BDCM}} + \frac{C_{chloroform}}{GV_{chloroform}} \leq 1$ where C = concentration and GV = guideline value. Authorities wishing to use a guideline value for total THMs should not simply add up the guideline values for the individual compounds in order to arrive at a standard.
	It is emphasized that adequate disinfection should never be compromised in attempting to meet guidelines for THMs. Nevertheless, in view of the potential link between adverse reproductive outcomes and THMs, particularly brominated THMs, it is recommended that THM levels in drinking-water be kept as low as practicable.

Additional comments on chloroform	In countries with low rates of ventilation in houses and high rates of showering and bathing, the guideline value could be lowered to account for the additional exposures from inhalation of indoor air largely due to volatilization from drinking-water and inhalation and dermal exposure during showering or bathing.
	The guideline value is based on the same study as in the third edition; the increase in value is primarily a result of an increase in the allocation of exposure in drinking-water from 50% to 75% to account for the fact that chloroform is used less now than it was in 1993 when the original guideline was developed.
Additional comments on BDCM	Although a health-based value of 21 µg/l is derived, the previous guideline value of 60 µg/l has been retained for two reasons: 1) both calculations were based on the same study, the only differences being the model and model assumptions used to derive the guideline value; there is therefore no scientific basis on which to justify a change in the guideline value; and 2) BDCM concentrations below 50 µg/l may be difficult to achieve using currently available technology without compromising the effectiveness of disinfection.
	As with chloroform, countries with low rates of ventilation and high rates of showering and bathing may wish to lower the guideline value to account for dermal and inhalation exposures, although, as noted above, concentrations below 50 µg/l may be difficult to achieve using currently available technology without compromising the effectiveness of disinfection.
	As BDCM was negative for carcinogenicity in a recent NTP bioassay in which it was dosed in drinking-water, exceedances of the guideline value are not likely to result in an increased risk of cancer.
Assessment date	2004
Principal references	IPCS (2000) *Disinfectants and disinfectant by-products* IPCS (2004) *Chloroform* WHO (2005) *Trihalomethanes in drinking-water*

Chloroform

The weight of evidence for genotoxicity of chloroform is considered negative. IARC has classified chloroform as possibly carcinogenic to humans (Group 2B) based on limited evidence of carcinogenicity in humans but sufficient evidence of carcinogenicity in experimental animals. The weight of evidence for liver tumours in mice is consistent with a threshold mechanism of induction. Although it is plausible that kidney tumours in rats may similarly be associated with a threshold mechanism, there are some limitations of the database in this regard. The most universally observed toxic effect of chloroform is damage to the centrilobular region of the liver. The severity of these effects per unit dose administered depends on the species, vehicle and method by which the chloroform is administered.

Bromoform

In an NTP bioassay, bromoform induced a small increase in relatively rare tumours of the large intestine in rats of both sexes but did not induce tumours in mice. Data from

a variety of assays on the genotoxicity of bromoform are equivocal. IARC has classified bromoform in Group 3 (not classifiable as to its carcinogenicity to humans).

Dibromochloromethane

In an NTP bioassay, DBCM induced hepatic tumours in female mice and possibly in male mice but not in rats. The genotoxicity of DBCM has been studied in a number of assays, but the available data are considered inconclusive. IARC has classified DBCM in Group 3 (not classifiable as to its carcinogenicity to humans).

Bromodichloromethane

IARC has classified BDCM in Group 2B (possibly carcinogenic to humans). BDCM gave both positive and negative results in a variety of in vitro and in vivo genotoxicity assays. In an NTP bioassay, BDCM induced renal adenomas and adenocarcinomas in both sexes of rats and male mice, rare tumours of the large intestine (adenomatous polyps and adenocarcinomas) in both sexes of rats and hepatocellular adenomas and adenocarcinomas in female mice. However, BDCM was negative for carcinogenicity in a recent NTP bioassay in which it was dosed in drinking-water. Exposure to BDCM has also been linked to a possible increase in reproductive effects (increased risk for spontaneous abortion or stillbirth).

Uranium

Uranium is widespread in nature, occurring in granites and various other mineral deposits. It is used mainly as fuel in nuclear power stations. Uranium is present in the environment as a result of leaching from natural deposits, release in mill tailings, emissions from the nuclear industry, the combustion of coal and other fuels and the use of phosphate fertilizers that contain uranium. Intake of uranium through air is low, and it appears that intake through food is between 1 and 4 µg/day. Intake through drinking-water is normally extremely low; however, in circumstances in which uranium is present in a drinking-water source, the majority of intake can be through drinking-water.

Provisional guideline value	0.03 mg/l (30 µg/l)
	The guideline value is designated as provisional because of scientific uncertainties surrounding uranium toxicity.
Occurrence	Levels in drinking-water are generally less than 1 µg/l, although concentrations as high as 700 µg/l have been measured in private supplies.
TDI	60 µg, derived from the lower 95% confidence limit on the 95th percentile uranium exposure distribution in a study from Finland, using an uncertainty factor of 10 for intraspecies variation
Limit of detection	0.01 µg/l by ICP-MS; 0.1 µg/l by solid fluorimetry with either laser excitation or UV light; 0.2 µg/l by ICP using adsorption with chelating resin
Treatment performance	1 µg/l should be achievable using conventional treatment (e.g. coagulation or ion exchange)

Guideline value derivation	
• consumption	2 litres/day
Additional comments	Where supplies exceed 30 µg/l, it is important that precipitate action be avoided. Consideration should first be given to exposure from all sources and the availability of alternative safe sources.
	Only chemical, not radiological, aspects of uranium toxicity have been addressed here; for radiological aspects, see chapter 9.
Assessment date	2003, revised in 2011
Principal reference	WHO (2011) *Uranium in drinking-water*

There are insufficient data regarding the carcinogenicity of uranium in humans and experimental animals. Nephritis is the primary chemically induced effect of uranium in humans. Little information is available on the chronic health effects of exposure to environmental uranium in humans. A number of epidemiological studies of populations exposed to uranium in drinking-water have shown a correlation with alkaline phosphatase and β-microglobulin in urine along with modest alterations in proximal tubular function. However, the actual measurements were still within the normal physiological range, and these findings are not consistent between studies.

No clear no-effect concentration has emerged from the human studies to date. This is not surprising, as most of the study populations are quite small, and there is substantial normal variation in the measured parameters in the human population. However, the overall indications are that there is no clear evidence of effects below an exposure concentration of 30 µg/l. In fact, the evidence for effects on the kidney, which appears to be the most sensitive organ, is equivocal until much higher exposure concentrations.

The provisional guideline value of 30 µg/l, which is derived from new epidemiological studies on populations exposed to high uranium concentrations, replaces the previous value derived from experimental animal studies and designated as provisional on the basis of uncertainties regarding the toxicology and epidemiology of uranium as well as difficulties concerning its technical achievability in smaller supplies. It is noted that studies on human populations, when available and of good quality, are the preferred source of health-related information to be used in deriving guideline values.

Vinyl chloride

Vinyl chloride is used primarily for the production of PVC. Owing to its high volatility, vinyl chloride has rarely been detected in surface waters, except in contaminated areas. Unplasticized PVC is increasingly being used in some countries for water mains supplies. Migration of vinyl chloride monomer from unplasticized PVC is a possible source of vinyl chloride in drinking-water. It appears that inhalation is the most important route of vinyl chloride intake, although drinking-water may contribute a substantial portion of daily intake where PVC piping with a high residual content of vinyl chloride monomer is used in the distribution network. Vinyl chloride has been reported in groundwater as a degradation product of the chlorinated solvents trichloroethene and tetrachloroethene.

Guideline value	0.0003 mg/l (0.3 µg/l)
Occurrence	Rarely detected in surface waters, the concentrations measured generally not exceeding 10 µg/l; much higher concentrations found in groundwater and well water in contaminated areas; concentrations up to 10 µg/l detected in drinking-water
Basis of guideline value derivation	Application of a linear extrapolation by drawing a straight line between the dose, determined using a pharmocokinetic model, resulting in tumours in 10% of animals in rat bioassays involving oral exposure and the origin (zero dose), determining the value associated with the upper-bound risk of 10^{-5} and assuming a doubling of the risk for exposure from birth
Limit of detection	0.01 µg/l by GC-ECD or GC-FID with MS for confirmation
Treatment performance	0.001 mg/l should be achievable using air stripping
Additional comments	The results of the linear extrapolation are nearly identical to those derived using the linearized multistage model.
	As vinyl chloride is a known human carcinogen, exposure to this compound should be avoided as far as practicable, and levels should be kept as low as technically feasible.
	Vinyl chloride is primarily of concern as a potential contaminant from some grades of PVC pipe and is best controlled by specification of material quality.
Assessment date	2003
Principal references	IPCS (1999) *Vinyl chloride* WHO (2003) *Vinyl chloride in drinking-water*

There is sufficient evidence of the carcinogenicity of vinyl chloride in humans from industrial populations exposed to high concentrations via the inhalation route, and IARC has classified vinyl chloride in Group 1 (carcinogenic to humans). Studies of workers employed in the vinyl chloride industry showed a marked exposure–response for all liver cancers, angiosarcomas and hepatocellular carcinoma, but no strong relationship between cumulative vinyl chloride exposure and other cancers. Experimental animal data show vinyl chloride to be a multisite carcinogen. When administered orally or by inhalation to mice, rats and hamsters, it produced tumours in the mammary gland, lungs, Zymbal gland and skin, as well as angiosarcomas of the liver and other sites. Evidence indicates that vinyl chloride metabolites are genotoxic, interacting directly with DNA. DNA adducts formed by the reaction of DNA with a vinyl chloride metabolite have also been identified. Occupational exposure has resulted in chromosomal aberrations, micronuclei and sister chromatid exchanges; response levels were correlated with exposure levels.

Xylenes

Xylenes are used in blending petrol, as a solvent and as a chemical intermediate. They are released to the environment largely via air. Exposure to xylenes is mainly from air, and exposure is increased by smoking.

Guideline value	0.5 mg/l (500 µg/l)
Occurrence	Concentrations of up to 8 µg/l have been reported in surface water, groundwater and drinking-water; levels of a few milligrams per litre were found in groundwater polluted by point emissions; xylenes can also penetrate plastic pipe from contaminated soil
TDI	179 µg/kg body weight, based on a NOAEL of 250 mg/kg body weight per day for decreased body weight in a 103-week gavage study in rats, adjusting for daily dosing and using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for the limited toxicological end-points)
Limit of detection	0.1 µg/l by GC-MS; 1 µg/l by GC-FID
Treatment performance	0.005 mg/l should be achievable using GAC or air stripping
Guideline value derivation	
• allocation to water	10% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Additional comments	The guideline value exceeds the lowest reported odour threshold for xylenes in drinking-water.
Assessment date	1993
Principal reference	WHO (2003) *Xylenes in drinking-water*

Xylenes are rapidly absorbed by inhalation. Data on oral exposure are lacking. Xylenes are rapidly distributed in the body, predominantly in adipose tissue. They are almost completely metabolized and excreted in urine. The acute oral toxicity of xylenes is low. No convincing evidence for teratogenicity has been found. Long-term carcinogenicity studies have shown no evidence for carcinogenicity. In vitro as well as in vivo mutagenicity tests have proved negative.

Zinc

Zinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. The diet is normally the principal source of zinc. Although levels of zinc in surface water and groundwater normally do not exceed 0.01 and 0.05 mg/l, respectively, concentrations in tap water can be much higher as a result of dissolution of zinc from pipes.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	1993
Principal reference	WHO (2003) *Zinc in drinking-water*

In 1982, JECFA proposed a PMTDI for zinc of 1 mg/kg body weight. The daily requirement for adult men is 15–20 mg/day. It was considered that, taking into account

recent studies on humans, the derivation of a formal guideline value is not required at this time. However, drinking-water containing zinc at levels above 3 mg/l may not be acceptable to consumers (see chapter 10).

12.2 Pesticides used for vector control in drinking-water sources and containers

In setting local guidelines or standards in the context of local storage practices and realistic insecticide application regimes, health authorities should take into consideration the potential for higher rates of water consumption in the area or region under consideration. However, exceeding the ADIs will not necessarily result in adverse effects. The diseases spread by vectors are significant causes of morbidity and mortality. It is therefore important to achieve an appropriate balance between the intake of the pesticides from drinking-water and the control of disease-carrying insects. Better than establishing guideline values are the formulation and implementation of a comprehensive management plan for household water storage and domestic waste management that does not rely exclusively on larviciding by insecticides, but also includes other environmental management measures and social behavioural changes.

Formulations of pesticides used for vector control in drinking-water should strictly follow the label recommendations and should only be those approved for such a use by national authorities, taking into consideration the ingredients and formulants used in making the final product. National authorities should note that these assessments refer only to the active ingredients and do not consider the additives in different formulations.

Bacillus thuringensis israelensis

Two *Bacillus thuringiensis israelensis* (Bti) (strain AM65-52) products (water-dispersible granule and ready-to-use tablet) have been evaluated by WHOPES and recommended as mosquito larvicides, including their use against container-breeding mosquitoes. Quality control specifications and efficacy evaluations for Bti water-dispersible granule have been published. WHO recommendations on the use of pesticides in public health are valid only if linked to WHO specifications for their quality control.

Reason for not establishing a guideline value	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Assessment date	2009
Principal references	IPCS (1999) *Bacillus thuringiensis* WHO (2004) *Report of the seventh WHOPES working group meeting* WHO (2006) *Report of the ninth WHOPES working group meeting* WHO (2007) *WHO specifications and evaluations for public health pesticides* WHO (2009) *Bacillus thuringiensis israelensis (Bti) in drinking-water*

Preparations of Bti are widely used against mosquitoes, chironomids and blackflies, and this specific activity against disease vector species has resulted in the use of

Bti in water. Bti is recommended under WHOPES for use in vector control, including against container-breeding mosquitoes, and can be used in drinking-water that will receive little or no further treatment for control of *Aedes aegypti*. It is essential that Bti for larvicidal use be prepared under carefully controlled conditions and properly assayed before use for evidence of potency, for excessive levels of expressed Bti constituents or metabolites that are toxic and for contamination by other undesirable microbes.

Bti itself is not considered to pose a hazard to humans through drinking-water. Therefore, it is not considered necessary or appropriate to establish a health-based value for its use for controlling vector larvae in drinking-water. However, it is vital that authorities can be assured that Bti has been prepared to the highest quality and hygienic standards under appropriate conditions that will meet the WHOPES specifications. It is important that the possible risks are set against the risks from vector-borne diseases such as dengue fever.

Application should be carried out by trained applicators and Bti used in conjunction with other approaches to vector control, including exclusion of mosquitoes from containers and other control options.

Diflubenzuron

Diflubenzuron is a direct-acting insecticide normally applied directly to plants or water. It is used in public health applications against mosquito and noxious fly larvae. WHO is considering diflubenzuron for use as a mosquito larvicide in drinking-water in containers, particularly to control dengue fever. The recommended dosage of diflubenzuron in potable water in containers should not exceed 0.25 mg/l under WHOPES.

It is reported that public exposure to diflubenzuron through either food or drinking-water is negligible. However, there is a potential for direct exposure through drinking-water when diflubenzuron is directly applied to drinking-water storage containers.

Reason for not establishing a guideline value	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Assessment date	2007
Principal references	FAO/WHO (2002) *Pesticide residues in food—2001 evaluations* WHO (2008) *Diflubenzuron in drinking-water*

Diflubenzuron is considered to be of very low acute toxicity. The primary target for toxicity is the erythrocytes, although the mechanism of haematotoxicity is uncertain. There is no evidence that diflubenzuron is either genotoxic or carcinogenic. It also does not appear to be fetotoxic or teratogenic and does not show significant signs of reproductive toxicity. There is evidence that young animals are not significantly more sensitive than adults to the effects of diflubenzuron.

It is not considered appropriate to set a formal guideline value for diflubenzuron used as a vector control agent in drinking-water. Where diflubenzuron is used for vector control in potable water, this will involve considerably less than lifetime exposure.

The ADI determined by JMPR in 2001 was 0–0.02 mg/kg body weight. The maximum dosage in drinking-water of 0.25 mg/l would be equivalent to approximately 40% of the upper limit of the ADI allocated to drinking-water for a 60 kg adult drinking 2 litres of water per day. For a 10 kg child drinking 1 litre of water, the exposure would be 0.25 mg, compared with an exposure of 0.2 mg at the upper limit of the ADI. For a 5 kg bottle-fed infant drinking 0.75 litre per day, the exposure would be 0.19 mg, compared with an exposure of 0.1 mg at the upper limit of the ADI. Diflubenzuron is unlikely to remain in solution at the maximum recommended applied dose, and the actual levels of exposure are likely to be much lower than those calculated.

Consideration should be given to using alternative sources of water for bottle-fed infants for a period after an application of diflubenzuron, where this is practical. However, exceeding the ADI will not necessarily result in adverse effects.

Methoprene

WHO has assessed methoprene for use as a mosquito larvicide in drinking-water in containers, particularly to control dengue fever. The recommended dosage of methoprene in potable water in containers should not exceed 1 mg/l under WHOPES.

Reason for not establishing a guideline value	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Assessment date	2007
Principal references	FAO/WHO (2002) *Pesticide residues in food—2001 evaluations* WHO (2008) *Methoprene in drinking-water*

In 2001, JMPR reaffirmed the basis of the ADI for racemic methoprene established in 1987, but lowered the value to 0–0.09 mg/kg body weight to correct for the purity of the racemate tested. The basis for the ADI was the NOAEL of 500 mg/kg diet, equivalent to 8.6 mg/kg body weight per day (corrected for purity), in a 90-day study in dogs (the main effect was increased relative liver weight) and a safety factor of 100. Young animals do not appear to be significantly more sensitive than adults. As no bridging studies with repeated doses were available for (*S*)-methoprene, JMPR made the conservative assumption that, in the absence of any information to the contrary, all the toxicity of the racemate was due to the S enantiomer. On this basis, JMPR established an ADI for (*S*)-methoprene of 0–0.05 mg/kg body weight, equal to one half the ADI for the racemate (which is a 1:1 mixture of the R and S enantiomers).

It is not considered appropriate to set a formal guideline value for methoprene used as a vector control agent in drinking-water. Where methoprene is used for vector control in potable water, this will involve less than lifetime exposure. The maximum dosage in drinking-water of 1 mg/l would be equivalent to approximately 66% of the upper limit of the ADI (0.033 mg/kg body weight) for a 60 kg adult drinking 2 litres of water per day. The exposure for a 10 kg child drinking 1 litre of water would be approximately 0.1 mg/kg body weight, and for a 5 kg bottle-fed infant, the exposure

would be approximately 0.15 mg/kg body weight, compared with the upper limit of the ADI of 0.05 mg/kg body weight. However, the low solubility and the high log octanol–water partition coefficient of methoprene indicate that it is unlikely to remain in solution at the maximum recommended applied dose, and the actual levels of exposure are likely to be much lower than those calculated. Exposure from food is considered to be low.

Consideration should be given to using alternative sources of water for small children and bottle-fed infants for a period after an application of methoprene, where this is practical. However, exceeding the ADI will not necessarily result in adverse effects.

Novaluron

Novaluron has been registered as an insecticide for food crops and ornamentals in a number of countries. WHO has assessed novaluron for use as a mosquito larvicide in drinking-water in containers, particularly to control dengue fever. The recommended dosage of novaluron in potable water in containers should not exceed 0.05 mg/l under WHOPES.

Reason for not establishing a guideline value	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Assessment date	2007
Principal references	FAO/WHO (2006) *Pesticide residues in food—2005 evaluations* WHO (2008) *Novaluron in drinking-water.*

In view of the absence of a carcinogenic potential in rodents and the lack of genotoxic potential in vitro and in vivo, JMPR concluded that novaluron is unlikely to pose a carcinogenic risk to humans. JMPR also concluded that novaluron is not a developmental toxicant. JMPR established an ADI of 0–0.01 mg/kg body weight on the basis of the NOAEL of 1.1 mg/kg body weight per day for erythrocyte damage and secondary splenic and liver changes in a 2-year dietary study in rats, using a safety factor of 100.

It is not considered appropriate to set a formal guideline value for novaluron as a vector control agent in drinking-water. At the maximum recommended dosage for drinking-water of 0.05 mg/l, the intake of a 60 kg adult drinking 2 litres of water would represent only 17% of the upper limit of the ADI. Similarly, the intake for a 10 kg child drinking 1 litre of water would be 50% of the upper limit of the ADI, whereas a 5 kg bottle-fed infant drinking 0.75 litre of water would receive an intake of 75% of the upper limit of the ADI.

The high log octanol–water partition coefficient of 4.3 indicates that novaluron is likely to adsorb to the sides of containers, and so the actual concentration is likely to be less than the recommended dose. Exposure to novaluron through food is not expected to be significant.

Permethrin

Permethrin (CAS No. 52645-53-1) is a contact insecticide effective against a broad range of pests in agriculture, forestry and public health. It has been used as a larvicide to control aquatic invertebrates in water mains. Permethrin is photodegraded both in water and on soil surfaces. In soil, permethrin is rapidly degraded by hydrolysis and microbial action under aerobic conditions. Exposure of the general population to permethrin is mainly via the diet.

Reason for not establishing a guideline value	Not recommended for direct addition to drinking-water as part of WHO's policy to exclude the use of any pyrethroids for larviciding of mosquito vectors of human disease
Assessment date	2011
Principal references	FAO/WHO (2000) *Pesticide residues in food—1999 evaluations* WHO (2011) *Permethrin in drinking-water*

Technical-grade permethrin is of low acute toxicity. The *cis* isomer is considerably more toxic than the *trans* isomer. IARC has classified permethrin in Group 3 (not classifiable as to its carcinogenicity to humans), as there are no human data and only limited data from experimental animal studies. Permethrin is not genotoxic. JMPR concluded that technical-grade permethrin is not a reproductive or developmental toxin.

For guidance purposes, a health-based value can be derived from an ADI of 0–0.05 mg/kg body weight, established for technical-grade permethrin with *cis:trans* ratios of 25:75 to 40:60 on the basis of a NOAEL of 5 mg/kg body weight per day in a 2-year dietary study in rats, which was based on clinical signs and changes in body and organ weights and blood chemistry at the next higher dose, and a NOAEL of 5 mg/kg body weight per day in a 1-year study in dogs, based on reduced body weight at 100 mg/kg body weight per day, and applying an uncertainty factor of 100 for interspecies and intraspecies variation. Assuming a 60 kg adult drinking 2 litres of water per day and allocating 20% of the upper limit of the ADI to drinking-water, a health-based value of 0.3 mg/l can be derived.

Adding permethrin directly to drinking-water for public health purposes is not recommended by WHO, as part of its policy to exclude the use of any pyrethroids for larviciding of mosquito vectors of human disease. This policy is based on concern over the possible accelerated development of vector resistance to synthetic pyrethroids, which, in their application to insecticide-treated mosquito nets, are crucial in the current global anti-malaria strategy.

Pirimiphos-methyl

Pirimiphos-methyl is an organophosphorus compound that is used in a wide range of pesticidal applications. Pirimiphos-methyl is being considered by WHO for addition to potable water in containers as a mosquito larvicide treatment, particularly to control dengue fever. The manufacturer recommends the direct addition of 1 mg/l to water.

Reason for not establishing a guideline value	Not recommended for direct application to drinking-water unless no other effective and safe treatments are available
Assessment date	2007
Principal references	FAO/WHO (1993) *Pesticide residues in food—1992 evaluations* FAO/WHO (2008) *Pesticide residues in food—2006 evaluations* WHO (2008) *Pirimiphos-methyl in drinking-water*

The only biochemical effect consistently observed with pirimiphos-methyl in acute, short-term or long-term studies is cholinesterase inhibition. Studies with mice, rats and dogs showed NOAELs of 0.5 mg/kg body weight per day and above. Young animals do not appear to be significantly more sensitive than adults. In human studies, no cholinesterase inhibition was seen at 0.25 mg/kg body weight per day (the highest dose tested). On this basis, JMPR revised the ADI to 0–0.03 mg/kg body weight by applying a 10-fold safety factor to the NOAEL in the human studies.

At the maximum recommended dosage for drinking-water of 1 mg/l, a 60 kg adult drinking 2 litres of water would have an intake of 0.033 mg/kg body weight, compared with the upper limit of the ADI of 0.03 mg/kg body weight. The intake for a 10 kg child drinking 1 litre of water would be 0.1 mg/kg body weight; for a 5 kg bottle-fed infant drinking 0.75 litre, it would be 0.15 mg/kg body weight. There is uncertainty regarding the level that would cause effects in humans, as the NOAEL on which the ADI is based was the highest dose tested, and so the ADI may be more conservative than is at first apparent. These intake figures are all below the acute reference dose of 0.2 mg/kg body weight and would not result in an acute exposure risk from the initial application of pirimiphos-methyl to drinking-water containers at the recommended dose. In addition, the low solubility and the high log octanol–water partition coefficient of pirimiphos-methyl indicate that the larvicide is very unlikely to remain in solution at the maximum recommended applied dose, so the actual levels of exposure are expected to be lower than those calculated. Exposure from food is generally considered to be low, but occasional high exposures can be experienced.

Based on the above calculations, pirimiphos-methyl is not recommended for direct application to drinking-water unless no other effective and safe treatments are available. If pirimiphos-methyl is applied directly to drinking-water, consideration should be given to using alternative sources of water for bottle-fed infants and small children for a period after its application, where this is practical. However, it is noted that exceeding the ADI will not necessarily result in adverse effects.

Pyriproxyfen

Pyriproxyfen is a broad-spectrum insect growth regulator with insecticidal activity against public health insect pests, including mosquitoes. WHO has assessed pyriproxyfen for use as a mosquito larvicide in drinking-water in containers, particularly to control dengue fever. The recommended dosage of pyriproxyfen in potable water in containers should not exceed 0.01 mg/l under WHOPES.

Reason for not establishing a guideline value	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Assessment date	2007
Principal references	FAO/WHO (2000) *Pesticide residues in food—1999 evaluations* WHO (2010) *Pyriproxyfen in drinking-water*

JMPR evaluated pyriproxyfen and concluded that it was not genotoxic and does not pose a carcinogenic risk to humans. Young animals do not appear to be significantly more sensitive than adults.

JMPR established an ADI of 0–0.1 mg/kg body weight on the basis of an overall NOAEL of 10 mg/kg body weight per day, based on increased relative liver weight and increased total plasma cholesterol concentration in male dogs in two 1-year studies of toxicity and using a safety factor of 100.

It is not considered appropriate to set a formal guideline value for pyriproxyfen used for vector control in drinking-water. The maximum recommended dosage in drinking-water of 0.01 mg/l would be equivalent to less than 1% of the upper limit of the ADI allocated to drinking-water for a 60 kg adult drinking 2 litres of water per day. For a 10 kg child drinking 1 litre of water, the exposure would be 0.01 mg, compared with an exposure of 1 mg at the upper limit of the ADI. For a 5 kg bottle-fed infant drinking 0.75 litre per day, the exposure would be 0.0075 mg, compared with an exposure of 0.5 mg at the upper limit of the ADI. The low solubility and the high log octanol–water partition coefficient of pyriproxyfen indicate that it is unlikely to remain in solution at the maximum recommended applied dose, and the actual levels of exposure are likely to be even lower than those calculated.

Spinosad

Spinosad is a natural product derived from the bacterium *Saccharopolyspora spinosa.* Spinosad DT is a mixture of spinosyn A and spinosyn D. It is used for mosquito control in potable water in containers.

Spinosad DT 7.48% is specified for use as a vector control agent in drinking-water sources against *Aedes aegypti* by WHO under WHOPES. Formulations for control of vectors are specified by WHO at a dose of 0.25–0.5 mg/l. The expected duration of efficacy under field conditions is 4–6 weeks.

Three formulations of spinosad have been evaluated by WHOPES for mosquito larviciding. WHO specifications for quality control and international trade have been published for the three formulations: i.e. spinosad granules (636/GR), aqueous suspension concentrate (636/SC) and tablets for direct application (636/DT). Only the tablet formulation is used for mosquito larviciding in potable water at the dosage of 0.25–0.5 mg/l of the active ingredient.

In a 14-day study conducted by the manufacturer, a single tablet was added to a 200-litre container of water, and 10% of the water in this container was replenished each day of the study. The concentration of spinosad was found to be in the range 26.5–51.7 µg/l.

Reason for not establishing a guideline value	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Assessment date	2009
Principal references	FAO/WHO (2002) *Pesticide residues in food—2001 evaluations* WHO (2010) *Spinosad in drinking-water*

It is not appropriate to set a formal guideline value for spinosad DT for use to control vectors breeding in drinking-water containers; however, it is appropriate to compare the probable intakes with the ADI of 0–0.02 mg/kg body weight, with no acute reference dose set because of its low acute toxicity. The maximum concentration actually achieved with the slow-release formulation was approximately 52 µg/l. The intake would therefore be:

- 39 µg for a 5 kg bottle-fed infant assuming consumption of 0.75 litre = 7.8 µg/kg body weight
- 52 µg for a 10 kg child assuming consumption of 1 litre = 5.2 µg/kg body weight
- 104 µg for a 60 kg adult assuming consumption of 2 litres = 1.7 µg/kg body weight.

However, this could be higher if drinking-water consumption is also higher.

This means that the exposure is well below the upper limit of the ADI for all sectors of the population. Even the application of a double dose would result in exposure below the upper limit of the ADI.

The ADI is, of course, set for lifetime exposure, and the average exposure over time will be lower than the exposures indicated above.

Temephos

Temephos is an organophosphorus insecticide that is used mainly as a larvicide to control mosquitoes on ponds, marshes and swamps and midges, black flies and other insects in public health. It is also used for mosquito control in potable water in containers. It is specified for use as a vector control agent in drinking-water sources by WHO under WHOPES. Formulations for control of vectors are specified by WHO, and only those approved by WHOPES should be used for this purpose. The recommendation for the use of temephos in potable water is that the dosage should not exceed 1 mg/l.

Reason for not establishing a guideline value	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Assessment date	2009
Principal references	FAO/WHO (2008) *Pesticide residues in food—2006 evaluations* WHO (2009) *Temephos in drinking-water*

The NOAEL for human risk assessment for temephos is 2.3 mg/kg body weight per day on the basis of inhibition of brain acetylcholinesterase activity in rats, as determined by JMPR in 2006. Although JMPR considered that the database was

insufficiently robust to serve as the basis for establishing an ADI, for the purposes of these Guidelines, a TDI of 0.023 mg/kg body weight can be calculated from this NOAEL, using an uncertainty factor of 100. Young animals do not appear to be significantly more sensitive than adults, and exposure from food is considered to be low.

It is not appropriate to set a formal guideline value for temephos used as a vector control agent in drinking-water. Where temephos is used for vector control in potable water, this will involve less than lifetime exposure. The maximum dosage in drinking-water of 1 mg/l for a 60 kg adult drinking 2 litres of water per day would be equivalent to approximately 0.033 mg/kg body weight, compared with the TDI of 0.023 mg/kg body weight. The exposure for a 10 kg child drinking 1 litre of water would be approximately 0.1 mg/kg body weight; for a 5 kg bottle-fed infant, the exposure would be approximately 0.15 mg/kg body weight, compared with the TDI of 0.023 mg/kg body weight.

Consideration should be given to using alternative sources of water for small children and bottle-fed infants for a period after an application of temephos, where this is practical.

However, exceeding the TDI does not necessarily mean that this will result in adverse effects. Indeed, the low solubility and the high log octanol–water partition coefficient of temephos indicate that it is unlikely to remain in solution at the maximum recommended applied dose, and the use of the slow-release formulation should result in very much lower concentrations than the approved dose of 1 mg/l and actual exposures much lower than the theoretical exposures calculated above.

ANNEX 1

Supporting documentation to the Guidelines

The *Guidelines for drinking-water quality* 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, through the Internet (http://www.who.int/water_sanitation_health/dwq/en/) and on CD-ROM. These can be ordered at http://www.who.int/bookorders.

Published supporting documents

Assessing microbial safety of drinking water: Improving approaches and methods
Edited by A. Dufour et al.
Published in 2003 by IWA Publishing on behalf of the World Health Organization and the Organisation for Economic Co-operation and Development
A state-of-the-art review of approaches and methods used in assessing the microbial safety of drinking-water.
http://www.who.int/entity/water_sanitation_health/dwq/9241546301full.pdf

Calcium and magnesium in drinking-water: Public health significance
Edited by J. Cotruvo and J. Bartram
Published in 2009 by the World Health Organization
A review of the contribution of drinking-water to total daily intake of calcium and magnesium, and an assessment of possible health benefits, including reducing cardiovascular disease mortality and osteoporosis.
http://whqlibdoc.who.int/publications/2009/9789241563550_eng.pdf

Chemical safety of drinking-water: Assessing priorities for risk management
T. Thompson et al.
Published in 2007 by the World Health Organization
A tool to assist in undertaking a systematic assessment of water supply systems to prioritize, control or eliminate chemicals in drinking-water.
http://whqlibdoc.who.int/publications/2007/9789241546768_eng.pdf

Domestic water quantity, service level and health

G. Howard and J. Bartram

Published in 2003 by the World Health Organization

Requirements for water for health-related purposes to determine acceptable minimum needs for consumption (hydration and food preparation) and basic hygiene.

http://www.who.int/water_sanitation_health/diseases/WSH03.02.pdf

Evaluating household water treatment options: Health-based targets and microbiological performance specifications

J. Brown and M. Sobsey

Published in 2011 by the World Health Organization

Establishes health-based targets and testing protocols for point-of-use water treatment approaches, including to inform development of country certification programmes.

http://www.who.int/water_sanitation_health/publications/en/

Evaluation of the H_2S method for detection of fecal contamination of drinking water

M. Sobsey and F. Pfaender

Published in 2002 by the World Health Organization

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.

http://www.who.int/entity/water_sanitation_health/dwq/WSH02.08.pdf

Fluoride in drinking-water

J.K. Fawell et al.

Published in 2006 by IWA Publishing on behalf of the World Health Organization

Provides information on the occurrence of fluoride in drinking-water, its health effects, ways of reducing excess levels and methods for analysis of fluoride in water.

http://www.who.int/water_sanitation_health/publications/fluoride_drinking_water_full.pdf

Guide to hygiene and sanitation in aviation, 3rd edition. Module 1: Water; Module 2: Cleaning and disinfection of facilities

Published in 2009 by the World Health Organization

Addresses water and cleaning and disinfection of facilities with the ultimate goal of assisting all types of airport and aircraft operators and other responsible bodies in achieving high standards of hygiene and sanitation, to protect travellers.

http://www.who.int/water_sanitation_health/hygiene/ships/guide_hygiene_sanitation_aviation_3_edition.pdf

Guide to ship sanitation, 3rd edition

Published in 2011 by the World Health Organization

Presents the public health significance of ships in terms of disease and highlights the importance of applying appropriate control measures.

http://www.who.int/water_sanitation_health/publications/en/index.html

Hazard characterization for pathogens in food and water: Guidelines

Published in 2003 by the Food and Agriculture Organization of the United Nations and the World Health Organization

A practical framework and structured approach for the characterization of microbial hazards in food and water, to assist governmental and research scientists.

http://whqlibdoc.who.int/publications/2003/9241562374.pdf

Health aspects of plumbing

Published in 2006 by the World Health Organization and the World Plumbing Council

A description of the processes involved in the design, installation and maintenance of effective plumbing systems and consideration of the microbial, chemical, physical and financial concerns associated with plumbing.

http://www.who.int/water_sanitation_health/publications/plumbinghealthasp.pdf

Heterotrophic plate counts and drinking-water safety: The significance of HPCs for water quality and human health

Edited by J. Bartram et al.

Published in 2003 by IWA Publishing on behalf of the World Health Organization

Assessment of the role of the heterotrophic plate count measurement in drinking-water safety management.

http://www.who.int/entity/water_sanitation_health/dwq/HPCFull.pdf

Legionella and the prevention of legionellosis

Edited by J. Bartram et al.

Published in 2007 by the World Health Organization

An overview of the sources, ecology and laboratory detection of *Legionella* bacteria, risk assessment and risk management of susceptible environments, the necessary measures to prevent or adequately control the risks and the policies and practices for outbreak management.

http://www.who.int/water_sanitation_health/emerging/legionella.pdf

Managing water in the home: Accelerated health gains from improved water supply

M. Sobsey

Published in 2002 by the World Health Organization

A review of the various methods and systems for household water collection, treatment and storage.

http://www.who.int/water_sanitation_health/dwq/WSH02.07.pdf

Pathogenic mycobacteria in water: A guide to public health consequences, monitoring and management

Edited by J. Bartram et al.

Published in 2004 by IWA Publishing on behalf of the World Health Organization

A description of the distribution, routes of transmission and infection, and guidance on the control of pathogenic environmental mycobacteria in water and other parts of the environment.

http://www.who.int/water_sanitation_health/emerging/pathmycobact/en/

Protecting groundwater for health: Managing the quality of drinking-water sources

Edited by O. Schmoll et al.

Published in 2006 by the World Health Organization

An analysis of the hazards to groundwater quality and the risk they may present to a specific supply. This is a tool for developing strategies to protect groundwater for health by managing the quality of drinking-water sources.

http://www.who.int/water_sanitation_health/publications/protecting_groundwater/en/

Quantifying public health risk in the WHO Guidelines for drinking-water quality: A burden of disease approach

A.H. Havelaar and J.M. Melse

Published in 2003 by the National Institute for Public Health and the Environment of the Netherlands

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.
http://www.who.int/entity/water_sanitation_health/dwq/rivmrep.pdf

Rapid assessment of drinking-water quality: A handbook for implementation
Published in 2011 by the World Health Organization and the United Nations Children's Fund
A practical guide to rapidly monitor water quality and safety, incorporating statistical methods, sanitary survey, and field approaches.
http://www.who.int/entity/water_sanitation_health and http://www.wssinfo.org

Review of latest available evidence on potential transmission of avian influenza (H5N1) through water and sewage and ways to reduce the risks to human health
Published in 2006 by the World Health Organization
A summary of the latest available studies and findings on avian influenza (H5N1) pertaining to water resources, water supplies, sanitation (human excreta, sewerage systems and health-care waste) and hygiene.
http://www.who.int/water_sanitation_health/emerging/h5n1background.pdf

Risk assessment of Cryptosporidium *in drinking water*
G. Medema et al.
Published in 2009 by the World Health Organization
A text supporting the *Guidelines for drinking-water quality* by providing further data on *Cryptosporidium* to assist country authorities in setting health-based targets and water suppliers in determining required performance of water treatment processes as part of a system-specific water safety plan.
http://whqlibdoc.who.int/hq/2009/WHO_HSE_WSH_09.04_eng.pdf

Safe drinking-water from desalination
Published in 2011 by the World Health Organization
Highlights the principal health risks related to different desalination processes and provides guidance on appropriate risk assessment and risk management procedures in order to ensure the safety of desalinated drinking-water.
http://www.who.int/water_sanitation_health/publications/en/index.html

Safe piped water: Managing microbial water quality in piped distribution systems
Edited by R. Ainsworth
Published in 2004 by IWA Publishing on behalf of the World Health Organization
A report on microbial contaminants and growth of microorganisms in distribution networks and the practices that contribute to ensuring drinking-water safety in piped distribution systems.
http://www.who.int/entity/water_sanitation_health/dwq/en/safepipedwater.pdf

Scaling up household water treatment among low-income populations
T. Clasen
Published in 2009 by the World Health Organization
Examines the evidence to date regarding the scalability of household water treatment systems. Its primary aims are to review the development and evolution of leading household water treatment technologies in their efforts to achieve scale, identify the main constraints that they have encountered and recommend ways forward.
http://whqlibdoc.who.int/hq/2009/WHO_HSE_WSH_09.02_eng.pdf

Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management

Edited by I. Chorus and J. Bartram

Published in 1999 by E & FN Spon on behalf of the World Health Organization

A report on all aspects of risk management, detailing the information needed for protecting drinking-water sources and recreational water bodies from the health hazards caused by cyanobacteria and their toxins.

http://www.who.int/entity/water_sanitation_health/resourcesquality/toxcyanobacteria.pdf

Upgrading water treatment plants

E.G. Wagner and R.G. Pinheiro

Published in 2001 by Spon Press on behalf of the World Health Organization

A practical guide to improving the performance of water treatment plants.

http://www.who.int/water_sanitation_health/hygiene/om/treatplants/en/

Water quality—Guidelines, standards and health: Assessment of risk and risk management for water-related infectious disease

Edited by L. Fewtrell and J. Bartram

Published in 2001 by IWA Publishing on behalf of the World Health Organization

Guidance on issues relating to microbial water quality and health, including environmental and public health scientists, water scientists, policy-makers and those responsible for developing standards and regulations.

http://www.who.int/water_sanitation_health/dwq/whoiwa/en/index.html

Water safety in buildings

Edited by D. Cunliffe et al.

Provides guidance for managing water supplies in buildings (e.g. hospitals, schools, care facilities, hotels) where people may drink water; use water for food preparation; wash, shower, swim or use water for other recreational activities; or be exposed to aerosols produced by water-using devices, such as cooling towers.

http://www.who.int/water_sanitation_health/publications/2011/9789241548106/en/index.html

Water safety plan manual: Step-by-step risk management for drinking-water suppliers

J. Bartram et al.

Published in 2009 by the World Health Organization

Guidance on developing and implementing a water safety plan through 11 learning modules, each representing a key step in the water safety plan development and implementation process.

http://whqlibdoc.who.int/publications/2009/9789241562638_eng.pdf

Water safety planning for small community water supplies

Published in 2011 by the World Health Organization

Step-by-step guidance for the planning, design and implementation of water safety plans by and for rural and remote communities, including communities with piped schemes, those served by point sources and community-wide water supply services using various technical options.

http://www.who.int/water_sanitation_health/publications/en/index.html

Water safety plans: Managing drinking-water quality from catchment to consumer

A. Davison et al.

Published in 2005 by the World Health Organization

Guidance on improved strategies for the preventive management, control and monitoring of drinking-water quality.
http://www.who.int/entity/water_sanitation_health/dwq/wsp170805.pdf

Water treatment and pathogen control: Process efficiency in achieving safe drinking-water
M.W. LeChevallier and K.K. Au
Published in 2004 by IWA Publishing on behalf of the World Health Organization
A critical analysis of the removal and inactivation of pathogenic microbes in water to aid the water quality specialist and design engineer in making decisions regarding microbial water quality.
http://www.who.int/entity/water_sanitation_health/dwq/en/watreatpath.pdf

Waterborne zoonoses: Identification, causes and control
Edited by J.A. Cotruvo et al.
Published in 2004 by IWA Publishing on behalf of the World Health Organization
An invaluable tool for all professionals concerned with assessing and managing waterborne zoonoses, which are diseases caused by microorganisms of animal origin that also infect humans.
http://www.who.int/entity/water_sanitation_health/diseases/zoonoses.pdf

ANNEX 2

References cited[1,2]

Chapter 1

Brikké F (2000) *Operation and maintenance of rural water supply and sanitation systems: a training package for managers and planners*. Delft, IRC International Water and Sanitation Centre; and Geneva, World Health Organization (http://www.who.int/water_sanitation_health/hygiene/om/omruralsystems/en/index.html).

Sawyer R, Simpson-Hébert M, Wood S (1998) *PHAST step-by-step guide: A participatory approach for the control of diarrhoeal disease.* Geneva, World Health Organization (WHO/EOS/98.3; http://www.who.int/water_sanitation_health/hygiene/envsan/phastep/en/).

Simpson-Hébert M, Sawyer R, Clarke L (1996) *The Participatory Hygiene and Sanitation Transformation (PHAST) initiative: a new approach to working with communities.* Geneva, World Health Organization, United Nations Development Programme/World Bank Water and Sanitation Program (WHO/EOS/96.11; http://www.who.int/water_sanitation_health/hygiene/envsan/phast/en/).

WHO (1976) *Surveillance of drinking-water quality*. Geneva, World Health Organization.

WHO (1997) *Guidelines for drinking-water quality*, 2nd ed. *Vol. 3. Surveillance and control of community supplies*. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/dwq/gdwq2v1/en/index2.html).

Chapter 3

Howard G et al. (2002) *Healthy villages: A guide for communities and community health workers*. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/hygiene/settings/hvintro.pdf).

Prüss A, Corvalan C (2006) *Preventing disease through healthy environments. Towards an estimate of the environmental burden of disease.* Geneva, World Health Organization (http://www.who.int/entity/quantifying_ehimpacts/publications/preventingdisease.pdf).

Prüss A et al. (2002) Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environmental Health Perspectives*, 110:537–542.

[1] This list includes all references cited in the text, except for the supporting documents to the Guidelines, which are listed separately in Annex 1, and the selected bibliographic references in chapter 11, which are cited following each microbial fact sheet in that chapter.

[2] The web links given in this annex were current as of January 2011.

Chapter 4

Bartram J, Ballance R, eds (1996) *Water quality monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes.* Published by E & FN Spon, London, on behalf of the United Nations Educational, Scientific and Cultural Organization, the World Health Organization and the United Nations Environment Programme (http://www.who.int/entity/water_sanitation_health/resourcesquality/waterqualmonitor.pdf).

WHO (1997) *Guidelines for drinking-water quality*, 2nd ed. *Vol. 3. Surveillance and control of community supplies*. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/dwq/gdwq2v1/en/index2.html).

Chapter 5

Lloyd B, Bartram J (1991) Surveillance solutions to microbiological problems in water quality control in developing countries. *Water Science and Technology*, 24(2):61–75.

WHO (1976) *Surveillance of drinking-water quality*. Geneva, World Health Organization.

WHO (1997) *Guidelines for drinking-water quality*, 2nd ed. *Vol. 3. Surveillance and control of community supplies*. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/dwq/gdwq2v1/en/index2.html).

Chapter 6

APHA, AWWA, WEF (2005) *Standard methods for the examination of water and wastewater*, 21st ed. Washington, DC, American Public Health Association, American Water Works Association and Water Environment Federation, pp. 7–15.

Bartram J, Ballance R, eds (1996) *Water quality monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes.* Published by E & FN Spon, London, on behalf of the United Nations Educational, Scientific and Cultural Organization, the World Health Organization and the United Nations Environment Programme (http://www.who.int/entity/water_sanitation_health/resourcesquality/waterqualmonitor.pdf).

Cotruvo JA et al. (2010) *Desalination technology: Health and environmental impacts*. Boca Raton, FL, CRC Press.

FAO/WHO (2009) *Benefits and risks of the use of chlorine-containing disinfectants in food production and food processing. Report of a Joint FAO/WHO Expert Meeting.* Geneva, Food and Agriculture Organization of the United Nations and World Health Organization (http://whqlibdoc.who.int/publications/2009/9789241598941_eng.pdf).

Hutin Y, Luby S, Paquet C (2003) A large cholera outbreak in Kano City, Nigeria: The importance of hand washing with soap and the danger of street-vended water. *Journal of Water and Health*, 1:45–52.

WHO (1997) *Guidelines for drinking-water quality*, 2nd ed. *Vol. 3. Surveillance and control of community supplies*. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/dwq/gdwq2v1/en/index2.html).

WHO (2005a) *International Health Regulations (2005)*, 2nd ed. Geneva, World Health Organization (http://whqlibdoc.who.int/publications/2008/9789241580410_eng.pdf).

WHO (2005b) *Nutrients in drinking water.* Geneva, World Health Organization (http://www.bvsde.paho.org/cd-gdwq/Biblioteca/Support%20docs%20GDWQ/nutrientsindw.pdf).

Wisner B, Adams J (2003) *Environmental health in emergencies and disasters: a practical guide.* Geneva, World Health Organization (http://www.who.int/water_sanitation_health/hygiene/emergencies/emergencies2002/en/).

Chapter 7

AWWA (1999) *Waterborne pathogens: AWWA manual M48*. Denver, CO, American Water Works Association.

Bitton G (2005) *Wastewater microbiology*, 3rd ed. New York, NY, John Wiley & Sons.

Chevrefils G et al. (2006) UV dose required to achieve incremental log inactivation of bacteria, protozoa and viruses. *IUVA News*, 8(1):38–45.

Clasen T et al. (2006) Interventions to improve water quality for preventing diarrhoea (Cochrane Review). In: *The Cochrane Library*, Issue 3. Oxford, Update Software (CD004794).

Cotruvo JA, Sobsey M (2006) Point-of-use water treatment for home and travel. In: Grabow W, ed. *UNESCO encyclopedia of life support systems*. Paris, United Nations Educational, Scientific and Cultural Organization (http://www.eolss.net).

Dullemont YJ et al. (2006) Removal of microorganisms by slow sand filtration. In: Gimbel R, Graham NJD, Collins MR, eds. *Recent progress in slow sand and alternative biofiltration processes*. London, IWA Publishing, pp. 12–20.

Feachem RG et al. (1983) *Sanitation and disease: Health aspects of excreta and wastewater management*. Chichester, John Wiley.

Fewtrell L, Colford J (2004) *Water, sanitation and hygiene: Interventions and diarrhoea—A systematic review and meta-analysis.* Health, Nutrition, and Population Family of the World Bank Human Development Network (http://siteresources.worldbank.org/HEALTHNUTRITIONANDPOPULATION/Resources/281627-1095698140167/Fewtrell%26ColfordJuly2004.pdf).

Gerba CP et al. (1996) Waterborne rotavirus: A risk assessment. *Water Research*, 30(12):2929–2940.

Haas CN, Rose JB, Gerba CP (1999) *Quantitative microbial risk assessment*. New York, NY, Wiley.

Hijnen WAM, Beerendonk EF, Medema GJ (2006) Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review. *Water Research*, 40:3–22.

Jones K, Betaieb M, Telford DR (1990) Seasonal variation of thermophilic campylobacters in sewage sludge. *Journal of Applied Bacteriology*, 69:185–189.

Koenraad PMFJ et al. (1994) Survey of *Campylobacter* in sewage plants in the Netherlands. *Food Microbiology*, 11:65–73.

Lodder WJ, de Roda Husman AM (2005) Presence of noroviruses and other enteric viruses in sewage and surface waters in the Netherlands. *Applied and Environmental Microbiology*, 71(3):1453–1461.

Lodder WJ et al. (2010) Presence of enteric viruses in source waters for drinking water production in the Netherlands. *Applied and Environmental Microbiology*, 76(17):5965–5971.

Maier RM, Pepper IL, Gerba CP (2000) *Environmental microbiology*. New York, NY, Academic Press.

Masini L et al. (2007) Research and characterization of pathogenic vibrios from bathing water along the Conero Riviera (central Italy). *Water Research*, 41(18):4031–4040.

Metcalf & Eddy, Inc. (2003) *Wastewater engineering: Treatment and reuse*. New York, NY, McGraw Hill.

Nath KJ, Bloomfield S, Jones M (2006) *Household water storage, handling and point-of-use treatment.* A review commissioned by the International Scientific Forum on Home Hygiene (http://www.ifh-homehygiene.org/2003/2library/low_res_water_paper.pdf).

Rutjes SA et al. (2009) Detection of infectious rotavirus in naturally contaminated source waters for drinking water production. *Journal of Applied Microbiology*, 107(1):97–105.

Schijven JF, de Roda Husman AM (2006) A survey of diving behaviour and accidental water ingestion among Dutch occupational and sport divers to assess the risk of infection with waterborne pathogenic microorganisms. *Environmental Health Perspectives*, 114:712–717.

Stampi S et al. (1992) Occurrence, removal, and seasonal variation of "thermophilic" campylobacters in a sewage treatment plant in Italy. *Zentralblatt für Hygiene und Umweltmedizin*, 193:199–210.

Stelzer W (1988) [Detection of *Campylobacter jejuni* and *C. coli* in waste water.] *Zentralblatt für Mikrobiologie*, 143(1):47–54 (in German).

WHO (2003) *Emerging issues in water and infectious disease*. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/emerging/emerging.pdf).

WHO (2005) *Preventing travellers' diarrhoea: How to make drinking water safe*. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/hygiene/envsan/sdwtravel.pdf).

World Health Assembly (1991) *Elimination of dracunculiasis: Resolution of the 44th World Health Assembly*. Geneva, World Health Organization (Resolution No. WHA 44.5).

Wright J, Gundry S, Conroy R (2003) Household drinking water in developing countries: A systematic review of microbiological contamination between source and point-of-use. *Tropical Medicine & International Health*, 9(1):106–117.

Chapter 8

FAO/WHO (2009) *Principles and methods for the risk assessment of chemicals in food*. Geneva, Food and Agriculture Organization of the United Nations and the World Health Organization (Environmental Health Criteria 240; http://www.who.int/ipcs/food/principles/en/index1.html).

IPCS (1994) *Assessing human health risks of chemicals: Derivation of guidance values for health-based exposure limits*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 170; http://www.inchem.org/documents/ehc/ehc/ehc170.htm).

IPCS (2000) *Disinfectants and disinfectant by-products*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 216; http://www.inchem.org/documents/ehc/ehc/ehc216.htm).

IPCS (2005) *Chemical-specific adjustment factors for interspecies differences and human variability: Guidance document for use of data in dose/concentration–response assessment*. Geneva, World Health Organization, International Programme on Chemical Safety (Harmonization Project Document No. 2; http://www.inchem.org/documents/harmproj/harmproj/harmproj2.pdf).

IPCS (2009) *Principles for modelling dose–response for risk assessment of chemicals*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 239; http://whqlibdoc.who.int/publications/2009/9789241572392_eng.pdf).

Solecki R et al. (2005) Guidance on setting of acute reference dose (ARfD) for pesticides. *Food and Chemical Toxicology*, 43:1569–1593 (http://www.who.int/ipcs/food/jmpr/arfd/en/index.html).

WHO (2006) *Guidelines for safe recreational water environments. Vol. 2. Swimming pools and similar environments*. Geneva, World Health Organization (http://whqlibdoc.who.int/publications/2006/9241546808_eng.pdf).

WHO/TDR (2009) *Dengue—Guidelines for diagnosis, treatment, prevention and control*. Geneva, World Health Organization and the Special Programme for Research and Training in Tropical Diseases (TDR) (http://whqlibdoc.who.int/publications/2009/9789241547871_eng.pdf).

Chapter 9

APHA, AWWA, WEF (2005) *Standard methods for the examination of water and wastewater*, 21st ed. Washington, DC, American Public Health Association, American Water Works Association and Water Environment Federation, pp. 7–15.

Auvinen A et al. (2005) Radon and other natural radionuclides in drinking water and risks of stomach cancer: A case–cohort study in Finland. *International Journal of Cancer*, 10:109–113.

Brenner D et al. (2003) Cancer risks attributable to low doses of ionizing radiation: Assessing what we really know. *Proceedings of the National Academy of Sciences of the United States of America*, 100(24):13761–13766.

Brown J, Hammond B, Wilkins DT (2008) *Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to operatives at water treatment works: Supporting scientific report.* Chilton, Oxfordshire, Health Protection Agency (HPA-RPD-041; http://www.dwi.gov.uk/research/completed-research/reports/DWI70-2-192_supporting.pdf).

European Commission (2001) Commission recommendation of 20 December 2001 on the protection of the public against exposure to radon in drinking water supplies. *Official Journal of the European Communities*, L344:85–87 (http://ec.europa.eu/energy/nuclear/radioprotection/doc/legislation/01928_en.pdf).

Health Canada (2009) *Guidelines for Canadian drinking water quality: Guideline technical document—Radiological parameters.* Ottawa, Ontario, Health Canada, Healthy Environments and Consumer Safety Branch, Radiation Protection Bureau (Catalogue No. H128-1/10-614E-PDF; http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/water-eau/radiological_para-radiologiques/radiological_para-radiologiques-eng.pdf).

IAEA (2002) *Safety requirements on preparedness and response for a nuclear or radiological emergency*. Vienna, International Atomic Energy Agency (Safety Standards Series No. GS-R-2).

IAEA, WHO (2005) *Development of an extended framework for emergency response criteria*. Vienna, International Atomic Energy Agency (TECDOC-1432).

IAEA, WHO (2010) *Criteria for use in planning response to nuclear and radiological emergencies*. Vienna, International Atomic Energy Agency (Safety Guide DS44).

ICRP (1996) Age-dependent doses to the members of the public from intake of radionuclides. Part 5. Compilation of ingestion and inhalation coefficients. ICRP Publication 72. *Annals of the ICRP*, 26(1).

ICRP (2000) Protection of the public in situations of prolonged radiation exposure. Recommendations of the International Commission on Radiological Protection. ICRP Publication 82. *Annals of the ICRP*, 29(1–2).

ICRP (2008) The 2007 recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Annals of the ICRP*, 37(2–4).

ICRP (2009a) Application of the Commission's recommendations for the protection of people in emergency exposure situations. ICRP Publication 109. *Annals of the ICRP*, 39(1).

ICRP (2009b) International Commission on Radiological Protection statement on radon (ICRP Ref 00/902/09; http://www.icrp.org/docs/ICRP_Statement_on_Radon%28November_2009%29.pdf).

ISO (2003) *Standard ISO 5667-3: Water quality—Sampling—Part 3: Guidance on the preservation and handling of water samples.* Geneva, International Organization for Standardization.

ISO (2006a) *Standard ISO 5667-1: Water quality—Sampling—Part 1: Guidance on the design of sampling programmes and sampling techniques.* Geneva, International Organization for Standardization.

ISO (2006b) *Standard ISO 5667-5: Water quality—Sampling—Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems.* Geneva, International Organization for Standardization.

ISO (2007) *Standard ISO 9696: Water quality—Measurement of gross alpha activity in non-saline water—Thick source method*. Geneva, International Organization for Standardization.

ISO (2008) *Standard ISO 9697: Water quality—Measurement of gross beta activity in non-saline water—Thick source method*. Geneva, International Organization for Standardization.

ISO (2009a) *Standard ISO 5667-11: Water quality—Sampling—Part 11: Guidance on sampling of groundwaters.* Geneva, International Organization for Standardization.

ISO (2009b) *Standard ISO 10704: Water quality—Measurement of gross alpha and gross beta activity in non-saline water—Thin source deposit method.* Geneva, International Organization for Standardization.

Nair RR et al. (2009) Background radiation and cancer incidence in Kerala, India—Karanagappally cohort study. *Health Physics*, 96(1):55–66.

NAS (1999) *Report on risk assessment of radon in drinking water*. Washington, DC, National Research Council, National Academy Press.

Picano E (2008) Informed consent and communication of risk from radiological and nuclear medicine examinations: How to escape from a communication inferno. *British Medical Journal*, 329:849–851.

Standards Australia, Standards New Zealand (1998) *Water quality—Sampling—Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples*. Homebush, Australia, and Wellington, New Zealand, Joint Australian/New Zealand Standards (AS/NZS 5667.1.1998).

Tao Z (2000) Cancer mortality in the high background radiation areas of Yangjiang, China during the period between 1979 and 1995. *Journal of Radiation Research (Tokyo)*, 41(Suppl.):31–41.

UNSCEAR (2000) *Report: Sources, effects and risks of ionizing radiation*. New York, NY, United Nations, United Nations Scientific Committee on the Effects of Atomic Radiation (http://www.unscear.org/unscear/en/publications/2000_1.html).

UNSCEAR (2008) *Report: Sources and effects of ionizing radiation. Vol. I. Sources.* New York, NY, United Nations, United Nations Scientific Committee on the Effects of Atomic Radiation (http://www.unscear.org/unscear/en/publications/2008_1.html).

USEPA (2007) *Communicating radiation risks.* Washington, DC, Environmental Protection Agency (EPA Publication 402-F-07-008).

WHO (2002) *Establishing a dialogue on risks from electromagnetic fields.* Geneva, World Health Organization.

WHO (2009) *WHO handbook on indoor radon: A public health perspective*. Geneva, World Health Organization.

Ye W et al. (1998) Mortality and cancer incidence in Misasa, Japan, a spa area with elevated radon levels. *Japanese Journal of Cancer Research*, 89(8):789–796.

Chapter 11[1]

WHO (2003) *Emerging issues in water and infectious disease*. Geneva, World Health Organization (http://www.who.int/water_sanitation_health/emerging/emerging.pdf).

[1] Selected bibliographical references are included at the end of each microbial fact sheet in chapter 11.

Chapter 12[1]

Background documents for preparation of WHO Guidelines for drinking-water quality[2]

WHO (2003) *1,1-Dichloroethane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/19).

WHO (2003) *1,1,1-Trichloroethane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/65).

WHO (2003) *1,2-Dibromo-3-chloropropane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/34).

WHO (2003) *1,2-Dibromoethane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/66).

WHO (2003) *1,2-Dichloroethane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/67).

WHO (2003) *1,2-Dichloroethene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/72).

WHO (2003) *1,2-Dichloropropane (1,2-DCP) in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/61).

WHO (2003) *1,3-Dichloropropane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/35).

WHO (2003) *1,3-Dichloropropene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/36).

WHO (2003) *2,4-D in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/70).

WHO (2003) *2-Phenylphenol and its sodium salt in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/69).

WHO (2003) *Alachlor in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/31).

WHO (2003) *Aldicarb in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/72).

WHO (2003) *Aldrin and dieldrin in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/73).

[1] References cited using the same author and date in chapter 12 are alphabetized by title here.

[2] All background documents may be found at http://www.who.int/water_sanitation_health/dwq/chemicals/en/index.html.

WHO (2003) *Ammonia in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/1).

WHO (2003) *Antimony in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/74).

WHO (2003) *Asbestos in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/2).

WHO (2003) *Barium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/76).

WHO (2003) *Bentazone in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/77).

WHO (2003) *Benzene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/24).

WHO (2003) *Bromate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/78).

WHO (2003) *Brominated acetic acids in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/79).

WHO (2003) *Carbofuran in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/81).

WHO (2003) *Carbon tetrachloride in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/82).

WHO (2003) *Chlordane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/84).

WHO (2003) *Chloride in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/3).

WHO (2003) *Chlorine in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/45).

WHO (2003) *Chloroacetones in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/50).

WHO (2003) *Chlorophenols in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/47).

WHO (2003) *Chlorophenoxy herbicides (excluding 2,4-D and MCPA) in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/44).

WHO (2003) *Chloropicrin in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/52).

WHO (2003) *Chlorotoluron in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/33).

WHO (2003) *Chlorpyrifos in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/87).

WHO (2003) *Chromium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/4).

WHO (2003) *Copper in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/88).

WHO (2003) *Cyanazine in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/60).

WHO (2003) *Cyanobacterial toxins: Microcystin-LR in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/57).

WHO (2003) *DDT and its derivatives in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/89).

WHO (2003) *Dialkyltins in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/109).

WHO (2003) *Dichlorobenzenes in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/28).

WHO (2003) *Dichloromethane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/18).

WHO (2003) *Di(2-ethylhexyl)adipate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/68).

WHO (2003) *Di(2-ethylhexyl)phthalate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/29).

WHO (2003) *Dimethoate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04).

WHO (2003) *Diquat in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/91).

WHO (2003) *Edetic acid (EDTA) in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/58).

WHO (2003) *Endosulfan in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/92).

WHO (2003) *Endrin in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/93).

WHO (2003) *Epichlorohydrin in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/94).

WHO (2003) *Ethylbenzene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/26).

WHO (2003) *Fenitrothion in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/95).

WHO (2003) *Fluoride in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/96).

WHO (2003) *Glyphosate and AMPA in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/97).

WHO (2003) *Halogenated acetonitriles in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/98).

WHO (2003) *Heptachlor and heptachlor epoxide in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/99).

WHO (2003) *Hexachlorobenzene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/100).

WHO (2003) *Hexachlorobutadiene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/101).

WHO (2003) *Hydrogen sulfide in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/7).

WHO (2003) *Inorganic tin in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/115).

WHO (2003) *Iodine in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/46).

WHO (2003) *Iron in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/08).

WHO (2003) *Isoproturon in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/37).

WHO (2003) *Lindane in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/102).

WHO (2003) *Malathion in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/103).

WHO (2003) *MCPA in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/38).

WHO (2003) *Methoxychlor in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/105).

WHO (2003) *Methyl parathion in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/106).

WHO (2003) *Metolachlor in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/39).

WHO (2003) *Molinate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/40).

WHO (2003) *Monochloramine in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/83).

WHO (2003) *Monochloroacetic acid in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/85).

WHO (2003) *Monochlorobenzene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/107).

WHO (2003) *MX in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/108).

WHO (2003) *Nitrilotriacetic acid in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/30).

WHO (2003) *Parathion in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/110).

WHO (2003) *Pendimethalin in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/41).

WHO (2003) *Pentachlorophenol in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/62).

WHO (2003) *Polynuclear aromatic hydrocarbons in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/59).

WHO (2003) *Propanil in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/112).

WHO (2003) *Silver in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/14).

WHO (2003) *Simazine in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/42).

WHO (2003) *Sodium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/15).

WHO (2003) *Styrene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/27).

WHO (2003) *Sulfate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/114).

WHO (2003) *Terbuthylazine in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/63).

WHO (2003) *Tetrachloroethene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/23).

WHO (2003) *Toluene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/116).

WHO (2003) *Total dissolved solids in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/16).

WHO (2003) *Trichloroacetic acid in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/120).

WHO (2003) *Trichlorobenzenes in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/117).

WHO (2003) *Trifluralin in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/43).

WHO (2003) *Vinyl chloride in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/119).

WHO (2003) *Xylenes in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/25).

WHO (2003) *Zinc in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/17).

WHO (2005) *1,1-Dichloroethene in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/20).

WHO (2005) *1,4-Dioxane in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/120).

WHO (2005) *Chloral hydrate in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/49).

WHO (2005) *Chlorite and chlorate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/86).

WHO (2005) *Dichloroacetic acid in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/121).

WHO (2005) *Formaldehyde in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/48).

WHO (2005) *Mercury in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/10).

WHO (2005) *Methyl tertiary-butyl ether (MTBE) in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/122).

WHO (2005) *Nickel in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/55).

WHO (2005) *Petroleum products in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/123).

WHO (2005) *Trichloroethene in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/22).

WHO (2005) *Trihalomethanes in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/64).

WHO (2007) *pH in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/07.01/1).

WHO (2008) *Carbaryl in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality.* Geneva, World Health Organization (WHO/HSE/AMR/08.03/5).

WHO (2008) *Diflubenzuron in drinking-water: Use for vector control in drinking-water sources and containers. Background document for preparation of WHO Guidelines for drinking-water quality.* Geneva, World Health Organization (WHO/HSE/AMR/08.03/6).

WHO (2008) *Methoprene in drinking-water: Use for vector control in drinking-water sources and containers. Background document for preparation of WHO Guidelines for drinking-water quality.* Geneva, World Health Organization (WHO/HSE/AMR/08.03/14).

WHO (2008) *N-Nitrosodimethylamine in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/AMR/08.03/8).

WHO (2008) *Novaluron in drinking-water: Use for vector control in drinking-water sources and containers. Background document for preparation of WHO Guidelines for drinking-water quality.* Geneva, World Health Organization (WHO/HSE/AMR/08.03/11).

WHO (2008) *Pirimiphos-methyl in drinking-water: Use for vector control in drinking-water sources and containers. Background document for preparation of WHO Guidelines for drinking-water quality.* Geneva, World Health Organization (WHO/HSE/AMR/08.03/15).

WHO (2008) *Sodium dichloroisocyanurate in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/AMR/08.03/3).

WHO (2009) *Bacillus thuringiensis israelensis (Bti) in drinking-water: Use for vector control in drinking-water sources and containers. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/09.01/8).

WHO (2009) *Beryllium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/09.01/5).

WHO (2009) *Boron in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality.* Geneva, World Health Organization (WHO/HSE/WSH/09.01/2).

WHO (2009) *Bromide in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/09.01/6).

WHO (2009) *Cyanide in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/09.01/3).

WHO (2009) *Cyanogen chloride in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/09.01/9).

WHO (2009) *Nitrobenzene in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality.* Geneva, World Health Organization (WHO/HSE/WSH/09.01/4).

WHO (2009) *Potassium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/09.01/7).

WHO (2009) *Temephos in drinking-water: Use for vector control in drinking-water sources and containers. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/AMR/09.01/1).

WHO (2010) *Aluminium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/53).

WHO (2010) *Pyriproxyfen in drinking-water: Use for vector control in drinking-water sources and containers. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/AMR/08.03/9).

WHO (2010) *Spinosad in drinking-water: Use for vector control in drinking-water sources and containers. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/10.01.12).

WHO (2011) *Acrylamide in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/71/Rev/1).

WHO (2011) *Arsenic in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/75/Rev/1).

WHO (2011) *Atrazine and its metabolites in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/10.01/11/Rev/1).

WHO (2011) *Cadmium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/80/Rev/1).

WHO (2011) *Hardness in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/WSH/10.01/10/Rev/1).

WHO (2011) *Lead in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/9/Rev/1).

WHO (2011) *Manganese in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/104/Rev/1).

WHO (2011) *Molybdenum in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/11/Rev/1).

WHO (2011) *Nitrate and nitrite in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/HSE/AMR/07.01/16/Rev/1).

WHO (2011) *Permethrin in drinking-water. Background document for development of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/05.08/111/Rev/1).

WHO (2011) *Selenium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/13/Rev/1).

WHO (2011) *Uranium in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality*. Geneva, World Health Organization (WHO/SDE/WSH/03.04/118/Rev/1).

Other references cited

Chorus I, Bartram J, eds (1999) *Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management*. Published by E & FN Spon, London, on behalf of the World Health Organization (http://www.who.int/entity/water_sanitation_health/resourcesquality/toxcyanobacteria.pdf).

FAO/WHO (1992) *Pesticide residues in food—1991 evaluations. Part II—Toxicology*. Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/92.52).

FAO/WHO (1993) *Pesticide residues in food—1992 evaluations. Part II—Toxicology.* Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/93.34).

FAO/WHO (1994) *Pesticide residues in food—1993 evaluations. Part II—Toxicology.* Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/94.4).

FAO/WHO (1995) *Pesticide residues in food—1994 evaluations. Part II—Toxicology.* Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/95.2).

FAO/WHO (1996) *Pesticide residues in food—1995 evaluations. Part II—Toxicological and environmental*. Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/96.48).

FAO/WHO (1997) *Pesticide residues in food—1996 evaluations. Part II—Toxicological.* Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/97.1).

FAO/WHO (1998) *Pesticide residues in food—1997 evaluations. Part II—Toxicological and environmental*. Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/98.6).

FAO/WHO (1999) *Pesticide residues in food—1998 evaluations. Part II—Toxicological*. Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/99.18).

FAO/WHO (2000) *Pesticide residues in food—1999 evaluations. Part II—Toxicological*. Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/00.4).

FAO/WHO (2001) *Evaluation of certain food additives and contaminants. Fifty-fifth report of the Joint FAO/WHO Expert Committee on Food Additives.* Geneva, World Health Organization (WHO Technical Report Series, No. 901).

FAO/WHO (2001) *Pesticide residues in food—2000 evaluations. Part II—Toxicological*. Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/01.3).

FAO/WHO (2002) *Evaluation of certain food additives. Fifty-ninth report of the Joint FAO/WHO Expert Committee on Food Additives.* Geneva, World Health Organization (WHO Technical Report Series, No. 913).

FAO/WHO (2002) *Pesticide residues in food—2001 evaluations. Part II—Toxicological*. Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/02.1).

FAO/WHO (2003) Nitrate (and potential endogenous formation of *N*-nitroso compounds). In: *Safety evaluation of certain food additives and contaminants.* Geneva, World Health Organization, Joint FAO/WHO Expert Committee on Food Additives (WHO Food Additives Series, No. 50).

FAO/WHO (2003) *Pesticide residues in food—2002 evaluations. Part II—Toxicological.* Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues (WHO/PCS/03.1).

FAO/WHO (2004) *Evaluation of certain food additives and contaminants*. Sixty-first report of the Joint FAO/WHO Committee on Food Additives. Geneva, World Health Organization (WHO Technical Report Series No. 922).

FAO/WHO (2004) *Vitamin and mineral requirements in human nutrition*, 2nd ed. Report of a Joint FAO/WHO Expert Consultation, Bangkok, Thailand, 21–30 September 1998. Geneva, World Health Organization (http://whqlibdoc.who.int/publications/2004/9241546123.pdf).

FAO/WHO (2006) *Pesticide residues in food—2005 evaluations. Part II—Toxicological.* Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues.

FAO/WHO (2007) Aluminium (from all sources, including food additives). In: *Evaluation of certain food additives and contaminants. Sixty-seventh report of the Joint FAO/WHO Expert Committee on Food Additives.* Geneva, World Health Organization, pp. 33–44 (WHO Technical Report Series, No. 940).

FAO/WHO (2008) *Pesticide residues in food—2006 evaluations. Part II—Toxicological.* Geneva, World Health Organization, Joint FAO/WHO Meeting on Pesticide Residues.

FAO/WHO (2009) *Pesticide residues in food—2007 evaluations. Part II—Toxicological*. Geneva, World Health Organization.

FAO/WHO (2011) *Evaluation of certain contaminants in food. Seventy-second report of the Joint FAO/WHO Expert Committee on Food Additives*. Geneva, World Health Organization (WHO Technical Report Series, No. 959).

FAO/WHO (2011) *Evaluation of certain food additives and contaminants. Seventy-third report of the Joint FAO/WHO Expert Committee on Food Additives*. Geneva, World Health Organization (WHO Technical Report Series, No. 960).

Fawell J et al. (2006) *Fluoride in drinking-water*. London, IWA Publishing on behalf of the World Health Organization (WHO Drinking-water Quality Series; http://www.who.int/entity/water_sanitation_health/publications/fluoride_drinking_water_full.pdf).

IARC (1987) *Overall evaluations of carcinogenicity: An updating of IARC Monographs volumes 1–42*. Lyon, International Agency for Research on Cancer, pp. 100–106 (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Supplement 7).

IPCS (1992) *Endrin*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 130; http://www.inchem.org/documents/ehc/ehc/ehc130.htm).

IPCS (1992) *Methyl parathion*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 145; http://www.inchem.org/documents/ehc/ehc/ehc145.htm).

IPCS (1994) *Glyphosate*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 159; http://www.inchem.org/documents/ehc/ehc/ehc159.htm).

IPCS (1994) *Hexachlorobutadiene*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 156; http://www.inchem.org/documents/ehc/ehc/ehc156.htm).

IPCS (1995) *1,2-Dichloroethane*, 2nd ed. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 176; http://www.inchem.org/documents/ehc/ehc/ehc176.htm).

IPCS (1995) *Report of the 1994 meeting of the Core Assessment Group*. Geneva, World Health Organization, International Programme on Chemical Safety, Joint Meeting on Pesticides (WHO/PCS/95.7).

IPCS (1996) *1,2-Dibromoethane*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 177; http://www.inchem.org/documents/ehc/ehc/ehc177.htm).

IPCS (1997) *Aluminium*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 194; http://www.inchem.org/documents/ehc/ehc/ehc194.htm).

IPCS (1997) *Hexachlorobenzene*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 195; http://www.inchem.org/documents/ehc/ehc/ehc195.htm).

IPCS (1998) *1,2-Dichloroethane*. Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 1; http://www.who.int/entity/ipcs/publications/cicad/en/cicad01.pdf).

IPCS (1998) *Copper*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 200; http://www.inchem.org/documents/ehc/ehc/ehc200.htm).

IPCS (1998) *Methyl tertiary-butyl ether*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 206; http://www.inchem.org/documents/ehc/ehc/ehc206.htm).

IPCS (1999) *Bacillus thuringiensis*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 217; http://www.inchem.org/documents/ehc/ehc/ehc217.htm).

IPCS (1999) *Carbon tetrachloride*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 208; http://www.who.int/entity/ipcs/publications/ehc/who_ehc_208.pdf).

IPCS (1999) *Manganese and its compounds*. Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 12; http://www.who.int/entity/ipcs/publications/cicad/en/cicad12.pdf).

IPCS (1999) *Vinyl chloride*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 215; http://www.inchem.org/documents/ehc/ehc/ehc215.htm).

IPCS (2000) *Chloral hydrate*. Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document No. 25; http://www.who.int/entity/ipcs/publications/cicad/en/cicad25.pdf).

IPCS (2000) *Disinfectants and disinfectant by-products*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 216; http://www.inchem.org/documents/ehc/ehc/ehc216.htm).

IPCS (2001) *Arsenic and arsenic compounds*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 224; http://www.inchem.org/documents/ehc/ehc/ehc224.htm).

IPCS (2001) *Barium and barium compounds*. Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 33; http://www.who.int/entity/ipcs/publications/cicad/en/cicad33.pdf).

IPCS (2001) *Beryllium and beryllium compounds*. Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 32; http://www.inchem.org/documents/cicads/cicads/cicad32.htm).

IPCS (2002) *Fluorides*. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 227; http://www.inchem.org/documents/ehc/ehc/ehc227.htm).

IPCS (2002) *Formaldehyde.* Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 40; http://www.who.int/entity/ipcs/publications/cicad/en/cicad40.pdf).

IPCS (2002) *N-Nitrosodimethylamine.* Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 38; http://www.who.int/entity/ipcs/publications/cicad/en/cicad38.pdf).

IPCS (2003) *1,1-Dichloroethene (vinylidene chloride).* Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 51; http://www.who.int/entity/ipcs/publications/cicad/en/cicad51.pdf).

IPCS (2003) *Elemental mercury and inorganic mercury compounds: Human health aspects*. Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 50; http://www.who.int/entity/ipcs/publications/cicad/en/cicad50.pdf).

IPCS (2004) *Chloroform*. Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 58; http://www.who.int/entity/ipcs/publications/cicad/en/cicad58.pdf).

IPCS (2004) *Hydrogen cyanide and cyanides: Human health aspects*. Geneva, World Health Organization, International Programme on Chemical Safety (Concise International Chemical Assessment Document 61; http://www.who.int/entity/ipcs/publications/cicad/en/cicad61.pdf).

ISO (1982) *Water quality—determination of total arsenic.* Geneva, International Organization for Standardization (ISO 6595-1982).

Schmoll O et al. (2006) *Protecting groundwater for health: Managing the quality of drinking-water sources*. London, IWA Publishing on behalf of the World Health Organization (http://www.who.int/water_sanitation_health/publications/protecting_groundwater/en/).

USNRC (2001) *Arsenic in drinking water, 2001 update.* Washington, DC, United States National Research Council, National Academy Press.

USNRC (2006) *Fluoride in drinking water: A scientific review of EPA's standards*. Washington, DC, United States National Research Council, National Academies Press.

WHO (2004) *Report of the seventh WHOPES working group meeting, 2–4 December 2003, Geneva.* Geneva, World Health Organization, WHO Pesticide Evaluation Scheme (WHO/CDS/WHOPES/2004.8; http://whqlibdoc.who.int/hq/2004/WHO_CDS_WHOPES_2004.8.pdf).

WHO (2006) *Report of the ninth WHOPES working group meeting, 5–9 December 2005, Geneva.* Geneva, World Health Organization, Control of Neglected Tropical Diseases, WHO Pesticide Evaluation Scheme (WHO/CDS/NTD/WHOPES/2006.2; http://whqlibdoc.who.int/hq/2006/WHO_CDS_NTD_WHOPES_2006.2_eng.pdf).

WHO (2007) *WHO specifications and evaluations for public health pesticides:* Bacillus thuringiensis *subspecies* israelensis *strain AM65-52*. Geneva, World Health Organization (http://www.who.int/whopes/quality/Bti_eval_spec_Jun_07.pdf).

ANNEX 3

Chemical summary tables

Table A3.1 Chemicals excluded from guideline value derivation

Chemical	Reason for exclusion
Amitraz	Degrades rapidly in the environment and is not expected to occur at measurable concentrations in drinking-water supplies
Chlorobenzilate	Unlikely to occur in drinking-water
Chlorothalonil	Unlikely to occur in drinking-water
Cypermethrin	Unlikely to occur in drinking-water
Deltamethrin	Unlikely to occur in drinking-water
Diazinon	Unlikely to occur in drinking-water
Dinoseb	Unlikely to occur in drinking-water
Ethylene thiourea	Unlikely to occur in drinking-water
Fenamiphos	Unlikely to occur in drinking-water
Formothion	Unlikely to occur in drinking-water
Hexachlorocyclohexanes (mixed isomers)	Unlikely to occur in drinking-water
MCPB[a]	Unlikely to occur in drinking-water
Methamidophos	Unlikely to occur in drinking-water
Methomyl	Unlikely to occur in drinking-water
Mirex	Unlikely to occur in drinking-water
Monocrotophos	Has been withdrawn from use in many countries and is unlikely to occur in drinking-water
Oxamyl	Unlikely to occur in drinking-water
Phorate	Unlikely to occur in drinking-water
Propoxur	Unlikely to occur in drinking-water
Pyridate	Not persistent and only rarely found in drinking-water
Quintozene	Unlikely to occur in drinking-water
Toxaphene	Unlikely to occur in drinking-water
Triazophos	Unlikely to occur in drinking-water
Tributyltin oxide	Unlikely to occur in drinking-water
Trichlorfon	Unlikely to occur in drinking-water

[a] 4-(4-chloro-*o*-tolyloxy)butyric acid.

Table A3.2 Chemicals for which guideline values have not been established

Chemical	Reason for not establishing a guideline value
Aluminium	A health-based value of 0.9 mg/l could be derived, but this value exceeds practicable levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants: 0.1 mg/l or less in large water treatment facilities and 0.2 mg/l or less in small facilities
Ammonia	Occurs in drinking-water at concentrations well below those of health concern
Asbestos	No consistent evidence that ingested asbestos is hazardous to health
Bentazone	Occurs in drinking-water at concentrations well below those of health concern
Beryllium	Rarely found in drinking-water at concentrations of health concern
Bromide	Occurs in drinking-water at concentrations well below those of health concern
Bromochloroacetate	Available data inadequate to permit derivation of health-based guideline value
Bromochloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Bacillus thuringiensis israelensis (Bti)	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Carbaryl	Occurs in drinking-water at concentrations well below those of health concern
Chloral hydrate	Occurs in drinking-water at concentrations well below those of health concern
Chloride	Not of health concern at levels found in drinking-water[a]
Chlorine dioxide	Rapidly breaks down to chlorite, and chlorite provisional guideline value is adequately protective for potential toxicity from chlorine dioxide
Chloroacetones	Available data inadequate to permit derivation of health-based guideline values for any of the chloroacetones
2-Chlorophenol	Available data inadequate to permit derivation of health-based guideline value
Chloropicrin	Available data inadequate to permit derivation of health-based guideline value
Cyanide	Occurs in drinking-water at concentrations well below those of health concern, except in emergency situations following a spill to a water source
Cyanogen chloride	Occurs in drinking-water at concentrations well below those of health concern
Dialkyltins	Available data inadequate to permit derivation of health-based guideline values for any of the dialkyltins
Dibromoacetate	Available data inadequate to permit derivation of health-based guideline value

Table A3.2 (continued)

Chemical	Reason for not establishing a guideline value
Dichloramine	Available data inadequate to permit derivation of health-based guideline value
1,3-Dichlorobenzene	Available data inadequate to permit derivation of health-based guideline value
1,1-Dichloroethane	Available data inadequate to permit derivation of health-based guideline value
1,1-Dichloroethene	Occurs in drinking-water at concentrations well below those of health concern
2,4-Dichlorophenol	Available data inadequate to permit derivation of health-based guideline value
1,3-Dichloropropane	Available data inadequate to permit derivation of health-based guideline value
Di(2-ethylhexyl)adipate	Occurs in drinking-water at concentrations well below those of health concern
Diflubenzuron	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Diquat	May be used as an aquatic herbicide for the control of free-floating and submerged aquatic weeds in ponds, lakes and irrigation ditches, but rarely found in drinking-water
Endosulfan	Occurs in drinking-water at concentrations well below those of health concern
Fenitrothion	Occurs in drinking-water at concentrations well below those of health concern
Fluoranthene	Occurs in drinking-water at concentrations well below those of health concern
Formaldehyde	Occurs in drinking-water at concentrations well below those of health concern
Glyphosate and AMPA[b]	Occur in drinking-water at concentrations well below those of health concern
Hardness	Not of health concern at levels found in drinking-water[a]
Heptachlor and heptachlor epoxide	Occur in drinking-water at concentrations well below those of health concern
Hexachlorobenzene	Occurs in drinking-water at concentrations well below those of health concern
Hydrogen sulfide	Not of health concern at levels found in drinking-water[a]
Inorganic tin	Occurs in drinking-water at concentrations well below those of health concern
Iodine	Available data inadequate to permit derivation of health-based guideline value, and lifetime exposure to iodine through water disinfection is unlikely
Iron	Not of health concern at levels causing acceptability problems in drinking-water[a]
Malathion	Occurs in drinking-water at concentrations well below those of health concern

Table A3.2 (continued)

Chemical	Reason for not establishing a guideline value
Manganese	Not of health concern at levels causing acceptability problems in drinking-water[a]
Methoprene	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Methyl parathion	Occurs in drinking-water at concentrations well below those of health concern
Methyl *tertiary*-butyl ether (MTBE)	Any guideline that would be derived would be significantly higher than concentrations at which MTBE would be detected by odour
Molybdenum	Occurs in drinking-water at concentrations well below those of health concern
Monobromoacetate	Available data inadequate to permit derivation of health-based guideline value
Monochlorobenzene	Occurs in drinking-water at concentrations well below those of health concern, and health-based value would far exceed lowest reported taste and odour threshold
MX	Occurs in drinking-water at concentrations well below those of health concern
Nitrobenzene	Rarely found in drinking-water at concentrations of health concern
Novaluron	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Parathion	Occurs in drinking-water at concentrations well below those of health concern
Permethrin	Not recommended for direct addition to drinking-water as part of WHO's policy to exclude the use of any pyrethroids for larviciding of mosquito vectors of human disease
Petroleum products	Taste and odour will in most cases be detectable at concentrations below those of health concern, particularly with short-term exposure
pH	Not of health concern at levels found in drinking-water[c]
2-Phenylphenol and its sodium salt	Occurs in drinking-water at concentrations well below those of health concern
Pirimiphos-methyl	Not recommended for direct application to drinking-water unless no other effective and safe treatments are available
Potassium	Occurs in drinking-water at concentrations well below those of health concern
Propanil	Readily transformed into metabolites that are more toxic; a guideline value for the parent compound is considered inappropriate, and there are inadequate data to enable the derivation of guideline values for the metabolites
Pyriproxyfen	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Silver	Available data inadequate to permit derivation of health-based guideline value
Sodium	Not of health concern at levels found in drinking-water[a]

Table A3.2 (continued)

Chemical	Reason for not establishing a guideline value
Spinosad	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Sulfate	Not of health concern at levels found in drinking-water[a]
Temephos	Not considered appropriate to set guideline values for pesticides used for vector control in drinking-water
Total dissolved solids	Not of health concern at levels found in drinking-water[a]
Trichloramine	Available data inadequate to permit derivation of health-based guideline value
Trichloroacetonitrile	Available data inadequate to permit derivation of health-based guideline value
Trichlorobenzenes (total)	Occur in drinking-water at concentrations well below those of health concern, and health-based value would exceed lowest reported odour threshold
1,1,1-Trichloroethane	Occurs in drinking-water at concentrations well below those of health concern
Zinc	Not of health concern at levels found in drinking-water[a]

[a] May affect acceptability of drinking-water (see chapter 10).
[b] Aminomethylphosphonic acid.
[c] An important operational water quality parameter.

Table A3.3 Guideline values for chemicals that are of health significance in drinking-water

	Guideline value		
Chemical	**mg/l**	**µg/l**	**Remarks**
Acrylamide	0.000 5[a]	0.5[a]	
Alachlor	0.02[a]	20[a]	
Aldicarb	0.01	10	Applies to aldicarb sulfoxide and aldicarb sulfone
Aldrin and dieldrin	0.000 03	0.03	For combined aldrin plus dieldrin
Antimony	0.02	20	
Arsenic	0.01 (A,T)	10 (A,T)	
Atrazine and its chloro-*s*-triazine metabolites	0.1	100	
Barium	0.7	700	
Benzene	0.01[a]	10[a]	
Benzo[*a*]pyrene	0.000 7[a]	0.7[a]	
Boron	2.4	2 400	
Bromate	0.01[a] (A,T)	10[a] (A,T)	
Bromodichloromethane	0.06[a]	60[a]	
Bromoform	0.1	100	
Cadmium	0.003	3	
Carbofuran	0.007	7	
Carbon tetrachloride	0.004	4	

Table A3.3 (continued)

Chemical	Guideline value mg/l	Guideline value µg/l	Remarks
Chlorate	0.7 (D)	700 (D)	
Chlordane	0.000 2	0.2	
Chlorine	5 (C)	5 000 (C)	For effective disinfection, there should be a residual concentration of free chlorine of ≥ 0.5 mg/l after at least 30 min contact time at pH < 8.0. A chlorine residual should be maintained throughout the distribution system. At the point of delivery, the minimum residual concentration of free chlorine should be 0.2 mg/l.
Chlorite	0.7 (D)	700 (D)	
Chloroform	0.3	300	
Chlorotoluron	0.03	30	
Chlorpyrifos	0.03	30	
Chromium	0.05 (P)	50 (P)	For total chromium
Copper	2	2 000	Staining of laundry and sanitary ware may occur below guideline value
Cyanazine	0.000 6	0.6	
2,4-D[b]	0.03	30	Applies to free acid
2,4-DB[c]	0.09	90	
DDT[d] and metabolites	0.001	1	
Dibromoacetonitrile	0.07	70	
Dibromochloromethane	0.1	100	
1,2-Dibromo-3-chloropropane	0.001[a]	1[a]	
1,2-Dibromoethane	0.000 4[a] (P)	0.4[a] (P)	
Dichloroacetate	0.05[a] (D)	50[a] (D)	
Dichloroacetonitrile	0.02 (P)	20 (P)	
1,2-Dichlorobenzene	1 (C)	1 000 (C)	
1,4-Dichlorobenzene	0.3 (C)	300 (C)	
1,2-Dichloroethane	0.03[a]	30[a]	
1,2-Dichloroethene	0.05	50	
Dichloromethane	0.02	20	
1,2-Dichloropropane	0.04 (P)	40 (P)	
1,3-Dichloropropene	0.02[a]	20[a]	
Dichlorprop	0.1	100	
Di(2-ethylhexyl)phthalate	0.008	8	
Dimethoate	0.006	6	
1,4-Dioxane	0.05[a]	50[a]	Derived using tolerable daily intake approach as well as linearized multistage modelling

Table A3.3 (continued)

Chemical	Guideline value mg/l	Guideline value µg/l	Remarks
Edetic acid	0.6	600	Applies to the free acid
Endrin	0.000 6	0.6	
Epichlorohydrin	0.000 4 (P)	0.4 (P)	
Ethylbenzene	0.3 (C)	300 (C)	
Fenoprop	0.009	9	
Fluoride	1.5	1 500	Volume of water consumed and intake from other sources should be considered when setting national standards
Hexachlorobutadiene	0.000 6	0.6	
Hydroxyatrazine	0.2	200	Atrazine metabolite
Isoproturon	0.009	9	
Lead	0.01 (A,T)	10 (A,T)	
Lindane	0.002	2	
MCPA[e]	0.002	2	
Mecoprop	0.01	10	
Mercury	0.006	6	For inorganic mercury
Methoxychlor	0.02	20	
Metolachlor	0.01	10	
Microcystin-LR	0.001 (P)	1 (P)	For total microcystin-LR (free plus cell-bound)
Molinate	0.006	6	
Monochloramine	3	3 000	
Monochloroacetate	0.02	20	
Nickel	0.07	70	
Nitrate (as NO_3^-)	50	50 000	Short-term exposure
Nitrilotriacetic acid	0.2	200	
Nitrite (as NO_2^-)	3	3 000	Short-term exposure
N-Nitrosodimethylamine	0.000 1	0.1	
Pendimethalin	0.02	20	
Pentachlorophenol	0.009[a] (P)	9[a] (P)	
Selenium	0.04 (P)	40 (P)	
Simazine	0.002	2	
Sodium dichloroisocyanurate	50	50 000	As sodium dichloroisocyanurate
	40	40 000	As cyanuric acid
Styrene	0.02 (C)	20 (C)	
2,4,5-T[f]	0.009	9	
Terbuthylazine	0.007	7	
Tetrachloroethene	0.04	40	

Chemical	Guideline value mg/l	Guideline value µg/l	Remarks
Simazine	0.002	2	
Sodium dichloroisocyanurate	50	50 000	As sodium dichloroisocyanurate
	40	40 000	As cyanuric acid
Styrene	0.02 (C)	20 (C)	
2,4,5-T[f]	0.009	9	
Terbuthylazine	0.007	7	
Tetrachloroethene	0.04	40	
Toluene	0.7 (C)	700 (C)	
Trichloroacetate	0.2	200	
Trichloroethene	0.02 (P)	20 (P)	
2,4,6-Trichlorophenol	0.2[a] (C)	200[a] (C)	
Trifluralin	0.02	20	
Trihalomethanes			The sum of the ratio of the concentration of each to its respective guideline value should not exceed 1
Uranium	0.03 (P)	30 (P)	Only chemical aspects of uranium addressed
Vinyl chloride	0.0003[a]	0.3[a]	
Xylenes	0.5 (C)	500 (C)	

A, provisional guideline value because calculated guideline value is below the achievable quantification level; C, concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints; D, provisional guideline value because disinfection is likely to result in the guideline value being exceeded; P, provisional guideline value because of uncertainties in the health database; T, provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

[a] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an upper-bound excess lifetime cancer risk of 10^{-5} (one additional case of cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with upper-bound estimated excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

[b] 2,4-Dichlorophenoxyacetic acid.

[c] 2,4-Dichlorophenoxybutyric acid.

[d] Dichlorodiphenyltrichlorethane.

[e] 4-(2-Methyl-4-chlorophenoxy)acetic acid.

ANNEX 4

Analytical methods and achievability

A4.1 Analytical methods

In *volumetric titration*, chemicals are analysed by titration with a standardized titrant. The titration end-point is identified by the development of colour resulting from the reaction with an indicator, by the change of electrical potential or by the change of pH value.

Colorimetric methods are based on measuring the intensity of colour of a coloured target chemical or reaction product. The optical absorbance is measured using light of a suitable wavelength. The concentration is determined by means of a calibration curve obtained using known concentrations of the determinant. The ultraviolet (UV) method is similar to this method except that UV light is used. For ionic materials, the ion concentration can be measured using an *ion selective electrode*. The measured potential is proportional to the logarithm of the ion concentration. Some organic compounds absorb UV light (wavelength 190–380 nm) in proportion to their concentration. *UV absorption* is useful for qualitative estimation of organic substances, because a strong correlation may exist between UV absorption and organic carbon content.

Atomic absorption spectrometry (AAS) is used for the determination of metals. It is based on the phenomenon that the atom in the ground state absorbs the light of wavelengths that are characteristic to each element when light is passed through the atoms in the vapour state. Because this absorption of light depends on the concentration of atoms in the vapour, the concentration of the target element in the water sample is determined from the measured absorbance. The Beer-Lambert law describes the relationship between concentration and absorbance.

In *flame atomic absorption spectrometry (FAAS)*, a sample is aspirated into a flame and atomized. A light beam from a hollow cathode lamp of the same element as the target metal is radiated through the flame, and the amount of absorbed light is measured by the detector. This method is much more sensitive than other methods and free from spectral or radiation interference by co-existing elements. Pretreatment is either unnecessary or straightforward. However, it is not suitable for simultaneous analysis of many elements, because the light source is different for each target element.

Electrothermal atomic absorption spectrometry (EAAS) is based on the same principle as FAAS, but an electrically heated atomizer or graphite furnace replaces the standard burner head for determination of metals. In comparison with FAAS, EAAS gives higher sensitivities and lower detection limits, and a smaller sample volume is required. EAAS suffers from more interference through light scattering by co-existing elements and requires a longer analysis time than FAAS.

The principle of *inductively coupled plasma atomic emission spectrometry (ICP-AES)* for determination of metals is as follows. An ICP source consists of a flowing stream of argon gas ionized by an applied radio frequency. A sample aerosol is generated in a nebulizer and spray chamber and then carried into the plasma through an injector tube. A sample is heated and excited in the high-temperature plasma. The high temperature of the plasma causes the atoms to become excited. On returning to the ground state, the excited atoms produce ionic emission spectra. A monochromator is used to separate specific wavelengths corresponding to different elements, and a detector measures the intensity of radiation of each wavelength. A significant reduction in chemical interference is achieved. In the case of water with low pollution, simultaneous or sequential analysis is possible without special pretreatment to achieve low detection limits for many elements. This, coupled with the extended dynamic range from three digits to five digits, means that multielement determination of metals can be achieved. ICP-AES has similar sensitivity to FAAS or EAAS.

In *inductively coupled plasma mass spectrometry* (ICP-MS), elements are atomized and excited as in ICP-AES, then passed to a mass spectrometer. Once inside the mass spectrometer, the ions are accelerated by high voltage and passed through a series of ion optics, an electrostatic analyser and, finally, a magnet. By varying the strength of the magnet, ions are separated according to mass/charge ratio and passed through a slit into the detector, which records only a very small atomic mass range at a given time. By varying the magnet and electrostatic analyser settings, the entire mass range can be scanned within a relatively short period of time. In the case of water with low pollution, simultaneous or sequential analysis is possible without special pretreatment to achieve low detection limits for many elements. This, coupled with the extended dynamic range from three digits to five digits, means that multielement determination of metals can be achieved.

Chromatography is a separation method based on the affinity difference between two phases, the stationary and mobile phases. A sample is injected into a column, either packed or coated with the stationary phase, and separated by the mobile phase based on the difference in interaction (distribution or adsorption) between compounds and the stationary phase. Compounds with a low affinity for the stationary phase move more quickly through the column and elute earlier. The compounds that elute from the end of the column are determined by a suitable detector.

In *ion chromatography*, an ion exchanger is used as the stationary phase, and the eluant for determination of anions is typically a dilute solution of sodium hydrogen carbonate and sodium carbonate. Colorimetric, electrometric or titrimetric detectors can be used for determining individual anions. In suppressed ion chromatography, anions are converted to their highly conductive acid forms; in the carbonate–bicarbonate

eluant, anions are converted to weakly conductive carbonic acid. The separated acid forms are measured by conductivity and identified on the basis of retention time as compared with their standards.

High-performance liquid chromatography (HPLC) is an analytical technique using a liquid mobile phase and a column containing a liquid stationary phase. Detection of the separated compounds is achieved through the use of absorbance detectors for organic compounds and through conductivity or electrochemical detectors for metallic and inorganic compounds.

Gas chromatography (GC) permits the identification and quantification of trace organic compounds. In GC, gas is used as the mobile phase, and the stationary phase is a liquid that is coated either on an inert granular solid or on the walls of a capillary column. When the sample is injected into the column, the organic compounds are vaporized and moved through the column by the carrier gas at different rates depending on differences in partition coefficients between the mobile and stationary phases. The gas exiting the column is passed to a suitable detector. A variety of detectors can be used, including flame ionization (FID), electron capture (ECD) and nitrogen–phosphorus. As separation ability is good in this method, mixtures of substances with similar structure are systematically separated, identified and determined quantitatively in a single operation.

The *gas chromatography/mass spectrometry (GC-MS)* method is based on the same principle as the GC method, using a mass spectrometer as the detector. As the gas emerges from the end of the GC column opening, it flows through a capillary column interface into the MS. The sample then enters the ionization chamber, where a collimated beam of electrons impacts the sample molecules, causing ionization and fragmentation. The next component is a mass analyser, which uses a magnetic field to separate the positively charged particles according to their mass. Several types of separating techniques exist; the most common are quadrupoles and ion traps. After the ions are separated according to their masses, they enter a detector.

The *purge-and-trap packed column GC-MS* method or *purge-and-trap packed column GC* method is applicable to the determination of various purgeable organic compounds that are transferred from the aqueous to the vapour phase by bubbling purge gas through a water sample at ambient temperature. The vapour is trapped with a cooled trap. The trap is heated and backflushed with the same purge gas to desorb the compounds onto a GC column. The principles of GC or GC-MS are as referred to above.

The principle of *enzyme-linked immunosorbent assay (ELISA)* is as follows. The protein (antibody) against the chemical of interest (antigen) is coated onto the solid material. The target chemical in the water sample binds to the antibody, and a second antibody with an enzyme attached is also added that will attach to the chemical of interest. After washing to remove any of the free reagents, a chromogen is added that will give a colour reaction due to cleavage by the enzyme that is proportional to the quantity of the chemical of interest. The ELISA method can be used to determine microcystin and synthetic surfactants.

A4.2 Analytical achievability for chemicals for which guideline values have been established

Analytical achievability for chemicals for which guideline values have been established is given in Tables A4.1–A4.6.

Table A4.1 Analytical achievability for inorganic chemicals for which guideline values have been established, by source category[a]

	Field methods		Laboratory methods				
	Col	Absor	IC	FAAS	EAAS	ICP	ICP-MS
Naturally occurring chemicals							
Arsenic	+++	#		++(H)	+	++(H)	+++
Barium				++	+++	+++	+++
Boron		++				+++	+++
Chromium		#			++	++	+++
Fluoride	#	+	+++				
Selenium		#		++(H)	++	++(H)	+++
Uranium							+++
Chemicals from industrial sources and human dwellings							
Cadmium		#			++	++	+++
Mercury				+++			
Chemicals from agricultural activities							
Nitrate/nitrite	+++	+++	+++				
Chemicals used in water treatment or materials in contact with drinking-water							
Antimony				+++(H)		++(H)	+++
Copper	#	+++		+++	+++	+++	+++
Lead		#			+	+	+++
Nickel		+		+	++	++	+++

[a] For definitions and notes to Table A4.1, see below Table A4.6.

Table A4.2 Analytical achievability for organic chemicals from industrial sources and human dwellings for which guideline values have been established[a]

	Col	GC	(PT-) GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC-FD
Benzene			+++						+++					
Carbon tetrachloride				+++					+++					
1,2-Dichlorobenzene			+++	+++				+++	+++					
1,4-Dichlorobenzene			+++	+++				+++	+++					
1,2-Dichloroethane				+++					+++					
1,2-Dichloroethene			+++	+++					+++					
Dichloromethane				+++					+++					
Di(2-ethylhexyl)phthalate								++						
1,4-Dioxane								+++						
Edetic acid								+++						
Ethylbenzene			+++						+++					
Hexachlorobutadiene			++	++					++					
Nitrilotriacetic acid		+++						+++						
Pentachlorophenol				+++				+			+			
Styrene			+++						+++					
Tetrachloroethene			+++	+++				+++	+++					
Toluene			+++						+++					
Trichloroethene			+++	+++				+++	+++					
Xylenes			+++						+++					

[a] For definitions and notes to Table A4.2, see below Table A4.6.

Table A4.3 Analytical achievability for organic chemicals from agricultural activities for which guideline values have been established[a,b]

	CoI	GC	(PT-) GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC-FD
Alachlor				+++				+++						
Aldicarb											+++			
Aldrin and dieldrin				++				++						
Atrazine and its chloro-*s*-triazine metabolites				+++				+++				+++		
Carbofuran		++												
Chlordane				+++				+++						
Chlorotoluron								+++				+++		
Cyanazine				+++				+++				+		
2,4-D				+++				+++				++		
2,4-DB				+++				++				++		
1,2-Dibromo-3-chloro-propane				+++				+++	+++					
1,2-Dibromoethane				++				++	+++					
1,2-Dichloropropane				+++					+++					
1,3-Dichloropropene				+++					+++					
Dichlorprop				+++				+++						
Dimethoate								+++						
Endrin				+++				+++						
Fenoprop				+++								+		
Hydroxyatrazine							+++					+++		
Isoproturon								+++				+++		
Lindane				+++				+++						
MCPA				+++				+++				+		

Table A4.3 (continued)

	Col	GC	(PT-) GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC-FD
Mecoprop				+++				+++						
Methoxychlor								+++						
Metolachlor				+++				+++						
Molinate		+++						+++						
Pendimethalin								+++						
Simazine				+++				+++						
2,4,5-T				+++								+		
Terbuthylazine								+++				++		
Trifluralin		+++		+++				+++						

[a] For definitions and notes to Table A4.3, see below Table A4.6.
[b] LC-MS is also applicable for many of these agricultural chemicals.

Table A4.4 Analytical achievability for chemicals used in water treatment or from materials in contact with water for which guideline values have been established[a]

	Col	GC	(PT-) GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC
Disinfectants														
Monochloramine	+++													
Chlorine	+++													
Sodium dichloroisocyanurate							+++	+++				+++		
Disinfection by-products														
Bromate														++
Bromodichloromethane				+++				+++	+++					
Bromoform				+++				+++	+++					
Chlorate														+++

Table A4.4 (continued)

	Col	GC	(PT-) GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC
Chlorite														+++
Chloroform				+++				+++	+++					
Dibromoacetonitrile				+++				+++						
Dibromochloromethane				+++				+++	+++					
Dichloroacetic acid				+++				+++						
Dichloroacetonitrile				+++				+++						
Monochloroacetic acid				+++				++						
N-Nitrosodimethylamine								+++						
Trichloroacetic acid				+++				+++						
2,4,6-Trichlorophenol				+++				+++						
Trihalomethanes[b]				+++				+++	+++					
Organic contaminants from treatment chemicals														
Acrylamide								+				+		
Epichlorohydrin				+++	+++				+					
Organic contaminants from pipes and fittings														
Benzo[*a*]pyrene								++			++			
Vinyl chloride			++	++					+					

[a] For definitions and notes to Table A4.4, see below Table A4.6.
[b] See also individual trihalomethanes.

Table A4.5 Analytical achievability for pesticides used in water for public health purposes for which guideline values have been established[a]

	Col	GC	GC-PD	GC-EC	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC/FD
Chlorpyrifos				+++		++	++	+++						
DDT (and metabolites)				++				++						

[a] For definitions and notes to Table A4.5, see below Table A4.6.

Table A4.6 Analytical achievability for cyanobacterial toxins for which guideline values have been established

	PPA	ELISA	GC-MS	HPLC-UVPAD	LC-MS
Microcystin-LR	+	++	+	++	++

Definitions to Tables A4.1–A4.6

Absor	Absorptiometry	HPLC	High-performance liquid chromatography
Col	Colorimetry	HPLC-FD	High-performance liquid chromatography–fluorescence detector
EAAS	Electrothermal atomic absorption spectrometry	HPLC-UVPAD	High-performance liquid chromatography–ultraviolet photodiode array detector
ELISA	Enzyme-linked immunosorbent assay	IC	Ion chromatography
FAAS	Flame atomic absorption spectrometry	IC-FAAS	Ion chromatography–flame atomic absorption spectrometry
GC	Gas chromatography	IC-FD	Ion chromatography–fluorescence detector
GC-ECD	Gas chromatography–electron capture detector	ICP	Inductively coupled plasma
GC-FID	Gas chromatography–flame ionization detector	ICP-MS	Inductively coupled plasma mass spectrometry
GC-FPD	Gas chromatography–flame photodiode detector	LC-MS	Liquid chromatography–mass spectrometry
GC-MS	Gas chromatography–mass spectrometry	PPA	Protein phosphatase assay
GC-PD	Gas chromatography–photoionization detector	PT-GC-MS	Purge-and-trap gas chromatography–mass spectrometry
GC-TID	Gas chromatography–thermal ionization detector		

Notes to Tables A4.1–A4.6

+	The detection limit is between the guideline value and 1/10th of its value.
++	The detection limit is between 1/10th and 1/50th of the guideline value.
+++	The detection limit is less than 1/100th of the guideline value.
#	The analytical method is available for detection of the guideline value concentration, but it is difficult to detect the concentration of 1/10 of the guideline value.
(H)	This method is applicable to the determination by conversion to their hydrides by hydride generator.

ANNEX 5

Treatment methods and performance

A5.1 Treatment methods

A5.1.1 Chlorination

Chlorination can be achieved by using liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules and on-site chlorine generators. Liquefied chlorine gas is supplied in pressurized containers. The gas is withdrawn from the cylinder and dosed into water by a chlorinator, which both controls and measures the gas flow rate. Sodium hypochlorite solution is dosed using a positive-displacement electric dosing pump or gravity feed system. Calcium hypochlorite has to be dissolved in water, then mixed with the main supply. Chlorine, whether in the form of chlorine gas from a cylinder, sodium hypochlorite or calcium hypochlorite, dissolves in water to form hypochlorous acid (HOCl) and hypochlorite ion (OCl^-).

Different techniques of chlorination can be used, including breakpoint chlorination, marginal chlorination and superchlorination/dechlorination. Breakpoint chlorination is a method in which the chlorine dose is sufficient to rapidly oxidize all the ammonia nitrogen in the water and to leave a suitable free residual chlorine available to protect the water against reinfection from the point of chlorination to the point of use. Superchlorination/dechlorination is the addition of a large dose of chlorine to effect rapid disinfection and chemical reaction, followed by reduction of excess free chlorine residual. Removing excess chlorine is important to prevent taste problems. It is used mainly when the bacterial load is variable or the detention time in a tank is not enough. Marginal chlorination is used where water supplies are of high quality and is the simple dosing of chlorine to produce a desired level of free residual chlorine. The chlorine demand in these supplies is very low, and a breakpoint might not even occur.

Chlorination is employed primarily for microbial disinfection. However, chlorine also acts as an oxidant and can remove or assist in the removal or chemical conversion of some chemicals—for example, decomposition of easily oxidized pesticides, such as aldicarb; oxidation of dissolved species (e.g. manganese(II)) to form insoluble products that can be removed by subsequent filtration; and oxidation of dissolved species to more easily removable forms (e.g. arsenite to arsenate).

A disadvantage of chlorine is its ability to react with natural organic matter to produce trihalomethanes and other halogenated disinfection by-products. However, by-product formation may be controlled by optimization of the treatment system.

A5.1.2 Ozonation

Ozone is a powerful oxidant and has many uses in water treatment, including oxidation of organic chemicals. Ozone can be used as a primary disinfectant. Ozone gas (O_3) is formed by passing dry air or oxygen through a high-voltage electric field. The resultant ozone-enriched air is dosed directly into the water by means of porous diffusers at the base of baffled contactor tanks. The contactor tanks, typically about 5 m deep, provide 10–20 minutes of contact time. Dissolution of at least 80% of the applied ozone should be possible, with the remainder contained in the off-gas, which is passed through an ozone destructor and vented to the atmosphere.

The performance of ozonation relies on achieving the desired concentration after a given contact period. For oxidation of organic chemicals, such as some oxidizable pesticides, a residual of about 0.5 mg/l after a contact time of up to 20 minutes is typically used. The doses required to achieve this vary with the type of water but are typically in the range 2–5 mg/l. Higher doses are needed for untreated waters, because of the ozone demand of the natural background organics.

Ozone reacts with natural organics to increase their biodegradability, measured as assimilable organic carbon. To avoid undesirable bacterial growth in distribution, ozonation is normally used with subsequent treatment, such as biological filtration or granular activated carbon (GAC), to remove biodegradable organics, followed by a chlorine residual, as ozone does not provide a disinfectant residual. Ozone is effective for the degradation of a wide range of pesticides and other organic chemicals.

A5.1.3 Other disinfection processes

Other disinfection methods include chloramination, the use of chlorine dioxide and UV radiation, as well as alternative disinfection techniques that may be used in smaller-scale applications, such as for household water.

Chloramines (monochloramine, dichloramine and trichloramine, or nitrogen trichloride) are produced by the reaction of aqueous chlorine with ammonia. Monochloramine is the only useful chloramine disinfectant, and conditions employed for chloramination are designed to produce only monochloramine. Monochloramine is a less effective disinfectant than free chlorine, but it is persistent, and it is therefore an attractive secondary disinfectant for the maintenance of a stable distribution system residual.

Chlorine dioxide has been used in recent years because of concerns about disinfection by-product production associated with chlorine disinfection. Typically, chlorine dioxide is generated immediately prior to application by the addition of chlorine gas or an aqueous chlorine solution to aqueous sodium chlorite. Chlorine dioxide decomposes in water to form chlorite and chlorate.

UV radiation, emitted by a low-pressure or medium-pressure mercury arc lamp, is biocidal between wavelengths of 180 and 320 nm. It can be used to inactivate protozoa, bacteria, bacteriophage, yeast, viruses, fungi and algae. Turbidity can inhibit UV

disinfection. UV radiation can act as a catalyst in oxidation reactions when used in conjunction with ozone or hydrogen peroxide.

Numerous possible disinfection techniques are being developed and are typically used in smaller-scale applications, such as household point-of-use and point-of-entry water treatment systems. Some of these, including bromine and iodine, show promise for expanded use. Bromine and iodine are halogens, like chlorine, and they are well-known biocides. Iodine is commonly used for short-term applications, such as by travellers in areas where water quality is questionable. Some forms of silver may have applications as bacteriostats or possibly as slow-acting disinfectants for some microorganisms; however, there are not good peer-reviewed published data to quantify the latter. It will be necessary to develop a more thorough analysis of the biocidal efficacy, potential disinfection by-products and risks from long-term exposures and application conditions for these lesser-used treatment chemicals to provide appropriate guidance as to their potential for wider applications.

A5.1.4 Filtration

Particulate matter can be removed from raw waters by rapid gravity, horizontal, pressure or slow sand filters. Slow sand filtration is essentially a biological process, whereas the others are physical treatment processes.

Rapid gravity, horizontal and pressure filters can be used for filtration of raw water, without pretreatment. Rapid gravity and pressure filters are commonly used to filter water that has been pretreated by coagulation and sedimentation. An alternative process is direct filtration, in which coagulation is added to the water, which then passes directly onto the filter where the precipitated floc (with contaminants) is removed; the application of direct filtration is limited by the available storage within the filter to accommodate solids.

Rapid gravity filters

Rapid gravity sand filters usually consist of open rectangular tanks (usually < 100 m^2) containing silica sand (size range 0.5–1.0 mm) to a depth of between 0.6 and 2.0 m. The water flows downwards, and solids become concentrated in the upper layers of the bed. The flow rate is generally in the range 4–20 $m^3/m^2 \cdot h$. Treated water is collected via nozzles in the floor of the filter. The accumulated solids are removed periodically by backwashing with treated water, sometimes preceded by scouring of the sand with air. A dilute sludge that requires disposal is produced.

In addition to single-medium sand filters, dual-media or multimedia filters are used. Such filters incorporate different materials, such that the structure is from coarse to fine as the water passes through the filter. Materials of suitable density are used in order to maintain the segregation of the different layers following backwashing. A common example of a dual-media filter is the anthracite–sand filter, which typically consists of a 0.2 m deep layer of 1.5 mm anthracite over a 0.6 m deep layer of silica sand. Anthracite, sand and garnet can be used in multimedia filters. The advantage of dual-media and multimedia filters is that there is more efficient use of the whole bed depth for particle retention—the rate of headloss development can be half that of

single-medium filters, which can allow higher flow rates without increasing headloss development.

Rapid gravity filters are most commonly used to remove floc from coagulated waters (see section A5.1.6). They may also be used to reduce turbidity (including adsorbed chemicals) and oxidized iron and manganese from raw waters.

Roughing filters

Roughing filters can be applied as pre-filters prior to other processes such as slow sand filters. Roughing filters with coarse gravel or crushed stones as the filter medium can successfully treat water of high turbidity (> 50 nephelometric turbidity units). The main advantage of roughing filtration is that as the water passes through the filter, particles are removed by both filtration and gravity settling. Horizontal filters can be up to 10 m long and are operated at filtration rates of 0.3–1.0 $m^3/m^2 \cdot h$.

Pressure filters

Pressure filters are sometimes used where it is necessary to maintain head in order to eliminate the need for pumping into supply. The filter bed is enclosed in a cylindrical shell. Small pressure filters, capable of treating up to about 15 m^3/h, can be manufactured in glass-reinforced plastics. Larger pressure filters, up to 4 m in diameter, are manufactured in specially coated steel. Operation and performance are generally as described for the rapid gravity filter, and similar facilities are required for backwashing and disposal of the dilute sludge.

Slow sand filters

Slow sand filters usually consist of tanks containing sand (effective size range 0.15–0.3 mm) to a depth of between 0.5 and 1.5 m. The raw water flows downwards, and turbidity and microorganisms are removed primarily in the top few centimetres of the sand. A biological layer, known as the "schmutzdecke", develops on the surface of the filter and can be effective in removing microorganisms. Treated water is collected in underdrains or pipework at the bottom of the filter. The top few centimetres of sand containing the accumulated solids are removed and replaced periodically. Slow sand filters are operated at a water flow rate of between 0.1 and 0.3 $m^3/m^2 \cdot h$.

Slow sand filters are more suitable for low-turbidity water or water that has been pre-filtered. They are used to remove algae and microorganisms, including protozoa, and, if preceded by microstraining or coarse filtration, to reduce turbidity (including adsorbed chemicals). Slow sand filtration is effective for the removal of some organics, including certain pesticides and also ammonia.

Bank filtration

Bank filtration is a process that produces an influx of surface water through the groundwater, via the bed and banks of the surface water body. This is commonly achieved through abstraction from boreholes adjacent to the surface water source. It is a relatively simple and low-cost means for removing particulates and microorganisms from surface water by placing pumping wells in alluvial sediments of the river or stream banks. The sediments act as both a filter and biofilter, trapping and reducing the concentrations of microorganisms and many organic pollutants. Bank filtration wells can

be either horizontal or vertical, depending upon the hydrogeological circumstances and required production rate. Horizontal wells are often used where alluvial deposits are shallow or where high pumping rates are required.

Bank filtration can remove particles, bacteria, viruses, parasites, heavy metals and easily biodegradable compounds. Bank filtration attenuates concentration peaks, providing uniform quality of raw water feed to downstream treatment. The performance of bank filtration can be highly dependent upon several factors, including soil and geological conditions as well as the quality of the source water. Bank filters can become clogged, resulting in pressure drops. Site-specific testing is needed to determine whether the appropriate geology is present as well as the effectiveness and operational parameters.

A5.1.5 Aeration

Aeration processes are designed to achieve removal of gases and volatile compounds by air stripping. Transfer can usually be achieved using a simple cascade or diffusion of air into water, without the need for elaborate equipment. Stripping of gases or volatile compounds, however, may require a specialized plant that provides a high degree of mass transfer from the liquid phase to the gas phase.

Cascade or step aerators are designed so that water flows in a thin film to achieve efficient mass transfer. Cascade aeration may introduce a significant headloss; design requirements are between 1 and 3 m to provide a loading of 10–30 $m^3/m^2 \cdot h$. Alternatively, compressed air can be diffused through a system of submerged perforated pipes. These types of aerator are used for oxidation and precipitation of iron and manganese.

Air stripping can be used for removal of volatile organics (e.g. solvents), some taste- and odour-causing compounds and radon. Aeration processes to achieve air stripping need to be much more elaborate to provide the necessary contact between the air and water. The most common technique is cascade aeration, usually in packed towers in which water is allowed to flow in thin films over plastic media with air blown counter-current. The required tower height and diameter are functions of the volatility and concentration of the compounds to be removed and the flow rate. Increasing the dissolved oxygen content of a water can increase its corrosivity towards some metallic materials used in distribution pipes and plumbing, and this should be taken into account when considering aeration as a treatment process.

A5.1.6 Chemical coagulation

Chemical coagulation-based treatment is the most common approach for treatment of surface waters and is almost always based on the following unit processes.

Chemical coagulants, usually salts of aluminium or iron, are dosed to the raw water under controlled conditions to form a solid flocculent metal hydroxide. Typical coagulant doses are 2–5 mg/l as aluminium or 4–10 mg/l as iron. The precipitated floc removes suspended and dissolved contaminants by mechanisms of charge neutralization, adsorption and entrapment. The efficiency of the coagulation process depends on raw water quality, the coagulant or coagulant aids used and operational factors, including mixing conditions, coagulation dose and pH. The floc is removed from the

treated water by subsequent solid–liquid separation processes such as sedimentation or flotation and/or rapid or pressure gravity filtration.

Effective operation of the coagulation process depends on selection of the optimum coagulant dose and also the pH value. The required dose and pH can be determined by using small-scale batch coagulation tests, often termed "jar tests". Increasing doses of coagulant are applied to raw water samples that are stirred and allowed to settle. The optimum dose is selected as that which achieves adequate removal of colour and turbidity; the optimum pH can be selected in a similar manner. These tests have to be conducted at a sufficient frequency to keep pace with changes in raw water quality and hence coagulant demand.

Powdered activated carbon (PAC) may be dosed during coagulation to adsorb organic chemicals, such as some hydrophobic pesticides. The PAC will be removed as an integral fraction of the floc and disposed of with the waterworks sludge.

The floc may be removed by sedimentation to reduce the solids loading to the subsequent rapid gravity filters. Sedimentation is most commonly achieved in horizontal flow or floc blanket clarifiers. Alternatively, floc may be removed by dissolved air flotation, in which solids are contacted with fine bubbles of air that attach to the floc, causing them to float to the surface of the tank, where they are removed periodically as a layer of sludge. The treated water from either process is passed to rapid gravity filters (see section A5.1.4), where remaining solids are removed. Filtered water may be passed to a further stage of treatment, such as additional oxidation and filtration (for removal of manganese), ozonation and/or GAC adsorption (for removal of pesticides and other trace organics), prior to final disinfection before the treated water enters the supply.

Coagulation is suitable for removal of particulates and bound microorganisms, certain heavy metals and low-solubility organic chemicals, such as certain organochlorine pesticides. For other organic chemicals, coagulation is generally ineffective, except where the chemical is bound to humic material or adsorbed onto particulates.

A5.1.7 Activated carbon adsorption

Activated carbon is produced by the controlled thermalization of carbonaceous material, normally wood, coal, coconut shells or peat. This activation produces a porous material with a large surface area (500–1500 m^2/g) and a high affinity for organic compounds. It is normally used in either powdered (PAC) or granular (GAC) form. When the adsorption capacity of the carbon is exhausted, it can be reactivated by burning off the organics in a controlled manner. However, PAC (and some GAC) is normally used only once before disposal. Different types of activated carbon have different affinities for types of contaminants.

The choice between PAC and GAC will depend upon the relative cost-effectiveness, frequency and dose required. PAC would generally be preferred in the case of seasonal or intermittent contamination or where low dosage rates are required.

PAC is dosed as a slurry into the water and removed by subsequent treatment processes, together with the waterworks sludge. Its use is therefore restricted to surface water treatment works with existing filters. GAC in fixed-bed adsorbers is used much more efficiently than PAC dosed into the water, and the effective carbon use per water

volume treated would be much lower than the dose of PAC required to achieve the same removal.

GAC is used for taste and odour control. It is normally used in fixed beds, either in purpose-built adsorbers for chemicals or in existing filter shells by replacement of sand with GAC of a similar particle size. Although at most treatment works it would be cheaper to convert existing filters rather than build separate adsorbers, use of existing filters usually allows only short contact times, and they are not capable of facile reactivation. It is therefore common practice to install additional GAC adsorbers (in some cases preceded by ozonation) between the rapid gravity filters and final disinfection. Most groundwater sources do not have existing filters, and separate adsorbers would need to be installed.

The service life of a GAC bed is dependent on the capacity of the carbon used and the contact time between the water and the carbon, the empty bed contact time, controlled by the flow rate of the water. Empty bed contact times are usually in the range 5–30 minutes. GACs vary considerably in their capacity for specific organic compounds, which can have a significant effect upon their service life. A guide to capacity can be obtained from published isotherm data. Carbon capacity is strongly dependent on the water source and is greatly reduced by the presence of background organic compounds. The properties of a chemical that influence its adsorption onto activated carbon include the water solubility and octanol–water partition coefficient. As a general rule, chemicals with low solubilities and high log octanol–water partition coefficients are well adsorbed.

Activated carbon is used for the removal of pesticides and other organic chemicals, taste and odour compounds, cyanobacterial toxins and total organic carbon.

A5.1.8 Ion exchange

Ion exchange is a process in which ions of like charge are exchanged between the water phase and the solid resin phase. Water softening is achieved by cation exchange. Water is passed through a bed of cationic resin, and the calcium ions and magnesium ions in the water are replaced by sodium ions. When the ion exchange resin is exhausted (i.e. the sodium ions are depleted), it is regenerated using a solution of sodium chloride. The process of "dealkalization" can also soften water. Water is passed through a bed of weakly acidic resin, and the calcium and magnesium ions are replaced by hydrogen ions. The hydrogen ions react with the carbonate and bicarbonate ions to produce carbon dioxide. The hardness of the water is thus reduced without any increase in sodium levels. Anion exchange can be used to remove contaminants such as nitrate, fluoride, arsenate and uranium (as the uranyl anion), which are exchanged for chloride. Several appropriate resins are available for this purpose.

An ion exchange plant normally consists of two or more resin beds contained in pressure shells with appropriate pumps, pipework and ancillary equipment for regeneration. The pressure shells are typically up to 4 m in diameter, containing 0.6–1.5 m depth of resin.

Cation exchange can be used for removal of certain heavy metals. Potential applications of anionic resins, in addition to nitrate removal, are for removal of arsenic and selenium species.

A5.1.9 Membrane processes

The membrane processes of most significance in water treatment are reverse osmosis, ultrafiltration, microfiltration and nanofiltration. These processes have traditionally been applied to the production of water for industrial or pharmaceutical applications, but are now being applied to the treatment of drinking-water.

High-pressure processes

If two solutions are separated by a semipermeable membrane (i.e. a membrane that allows the passage of the solvent but not of the solute), the solvent will naturally pass from the lower-concentration solution to the higher-concentration solution. This process is known as osmosis. It is possible, however, to force the flow of solvent in the opposite direction, from the higher to the lower concentration, by increasing the pressure on the higher-concentration solution. The required pressure differential is known as the osmotic pressure, and the process is known as reverse osmosis.

Reverse osmosis results in the production of a treated water stream and a relatively concentrated waste stream. Typical operating pressures are in the range 15–50 bar, depending on the application. Reverse osmosis rejects monovalent ions and organics of molecular weight greater than about 50 daltons (membrane pore sizes are less than 0.002 μm). The most common application of reverse osmosis is desalination of brackish water and seawater.

Nanofiltration uses a membrane with properties between those of reverse osmosis and ultrafiltration membranes; pore sizes are typically 0.001–0.01 μm. Nanofiltration membranes allow monovalent ions such as sodium or potassium to pass but reject a high proportion of divalent ions such as calcium and magnesium and some higher molecular weight organics. Operating pressures are typically about 5 bar. Nanofiltration may be effective for the removal of colour-forming organic compounds.

Lower-pressure processes

Ultrafiltration is similar in principle to reverse osmosis, but the membranes have much larger pore sizes (typically 0.002–0.03 μm) and operate at lower pressures. Ultrafiltration membranes reject organic molecules of molecular weight above about 800 daltons and usually operate at pressures less than 5 bar.

Microfiltration is a direct extension of conventional filtration into the submicrometre range. Microfiltration membranes have pore sizes typically in the range 0.01–12 μm and do not separate molecules but reject colloidal and suspended material at operating pressures of 1–2 bar. Microfiltration is capable of sieving out particles greater than 0.05 μm. It has been used for water treatment in combination with coagulation or PAC to remove particulates and some dissolved organic carbon prior to reverse osmosis membranes and to improve permeate flux.

A5.1.10 Other treatment processes

Processes aimed at generating hydroxyl radicals are known collectively as advanced oxidation processes and can be effective for the destruction of chemicals that are difficult to treat using other methods, such as ozone alone. Hydrogen peroxide with UV is also a source of hydroxyl radicals. Chemicals can react either directly with molecular

ozone or with the hydroxyl radical (HO·), which is a product of the decomposition of ozone in water and is an exceedingly powerful indiscriminate oxidant that reacts readily with a wide range of organic chemicals. The formation of hydroxyl radicals can be encouraged by using ozone at high pH. One advanced oxidation process using ozone or UV plus hydrogen peroxide involves dosing hydrogen peroxide simultaneously with ozone at a rate of approximately 0.4 mg of hydrogen peroxide per litre per milligram of ozone dosed per litre (the theoretical optimum ratio for hydroxyl radical production) and bicarbonate.

Other treatment processes that can be used in certain applications include:

- precipitation softening (addition of lime, lime plus sodium carbonate or sodium hydroxide to precipitate hardness at high pH);
- ion exchange softening;
- biological denitrification for removal of nitrate from surface waters;
- biological nitrification for removal of ammonia from surface waters;
- activated alumina (or other adsorbents) for specialized applications, such as removal of fluoride and arsenic.

A5.2 Treatment performance for chemicals for which guideline values have been established

Treatment performance for chemicals for which guideline values have been established is given in Tables A5.1–A5.5.

A5.3 Corrosion of metals used in water treatment and distribution

A5.3.1 Brass

The main corrosion problem with brasses is dezincification, which is the selective dissolution of zinc from duplex brass, leaving behind copper as a porous mass of low mechanical strength. Meringue dezincification, in which a voluminous corrosion product of basic zinc carbonate forms on the brass surface, largely depends on the ratio of chloride to alkalinity. Meringue dezincification can be controlled by maintaining a low zinc to copper ratio (1:3 or lower) and by keeping pH below 8.3.

General dissolution of brass can also occur, releasing metals, including lead, into the water. Impingement attack can occur under conditions of high water velocity with waters that form poorly protective corrosion product layers and that contain large amounts of dissolved or entrained air.

A5.3.2 Concrete and cement

Concrete is a composite material consisting of a cement binder in which an inert aggregate is embedded. Cement is primarily a mixture of calcium silicates and aluminates together with some free lime. Cement mortar, in which the aggregate is fine sand, is used as a protective lining in iron and steel water pipes. In asbestos–cement pipe, the aggregate is asbestos fibres, which are not of concern in drinking-water (see also asbestos fact sheet in chapter 12). Cement is subject to deterioration on prolonged exposure to aggressive water, due either to the dissolution of lime and other soluble compounds

Table A5.1 Treatment performance for naturally occurring chemicals for which guideline values have been established[a,b]

	Chlorination	Coagulation	Ion exchange	Precipitation softening	Activated alumina	Activated carbon	Ozonation	Membranes
Arsenic[c]		++	+++	++	+++			+++[d]
		<0.005	<0.005	<0.005	<0.005			<0.005
Fluoride		++			+++			+++
					<1			<1
Selenium		++	+++		+++			+++
			<0.01		<0.01			<0.01
Uranium		++	+++	++	+++			
			<0.001		<0.001			

[a] Symbols are as follows:
++ Approximately 50% or more removal
+++ Approximately 80% or more removal

[b] The table includes chemicals for which some treatment data are available. A blank entry in the table indicates either that the process is completely ineffective or that there are no data on the effectiveness of the process. For the most effective processes, the table estimates the concentration of the chemical (in mg/l) that could be achievable in an ideal water.

[c] Iron oxide–based and iron hydroxide–based media have been shown to be very effective for both arsenate and arsenite forms.

[d] Reverse osmosis membranes are more effective for removal of arsenate than arsenite. However, arsenite is readily oxidized to arsenate by disinfectants (e.g. chlorine).

Table A5.2 Treatment performance for chemicals from industrial sources and human dwellings for which guideline values have been established[a,b]

	Air stripping	Coagulation	Ion exchange	Precipitation softening	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment[c]	UV irradiation
Cadmium		+++	+++	+++				+++		
		<0.002	<0.002	<0.002				<0.002		
Mercury		+++		+++	+++			+++		
		<0.0001		<0.0001	<0.0001			<0.0001		
Benzene	+++				+++	+++				
	<0.01				<0.01	<0.01	Yes[d]			
Carbon tetrachloride	+++				+++			+		
	<0.001				<0.001					
1,2-Dichlorobenzene	+++				+++	+++		Yes[d]		
	<0.01				<0.01	<0.01				
1,4-Dichlorobenzene	+++				+++	+++		Yes[d]		
	<0.01				<0.01	<0.01				
1,2-Dichloroethane	+++				+++		+			
					<0.01					
1,2-Dichloroethene	+++				+++	+++				
	<0.01				<0.01	<0.01				
1,4-Dioxane					+		+++			
							0.05			
Edetic acid					+++					
					<0.01					
Ethylbenzene	++	+			+++	+++	++	+	++	
	<0.001				<0.001	<0.001				
Hexachlorobutadiene					+++			+		
					<0.001					

Table A5.2 (continued)

	Air stripping	Coagulation	Ion exchange	Precipitation softening	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment[c]	UV irradiation
Nitrilotriacetic acid					++				++	
N-Nitrosodimethylamine					+		++			+
Pentachlorophenol					+++			++		
					<0.0004					
Styrene	+++				+++	++		+	+	
	<0.02				<0.002					
Tetrachloroethene	+++				+++			+		
	<0.001				<0.001					
Toluene	+++				+++	+++	+++[e]		++	
	<0.001				<0.001	<0.001	<0.001		<0.001	
Trichloroethene	+++				+++	+++	+++[e]			
	<0.02				<0.02	<0.02	<0.02			
Xylenes	+++				+++		+++[e]		++	
	<0.005				<0.005		<0.005			

[a] Symbols are as follows:
+ Limited removal
++ Approximately 50% or more removal
+++ Approximately 80% or more removal

[b] The table includes only those chemicals for which some treatment data are available. A blank entry in the table indicates either that the process is completely ineffective or that there are no data on the effectiveness of the process. For the most effective processes, where data are available, the table indicates the concentration of the chemical (in mg/l) that should be achievable.

[c] Biological treatment includes slow sand filtration and bank filtration.

[d] Yes means known or likely to be effective, but performance was not quantified.

[e] Might be effective, but other techniques would be more likely to be applied due to cost.

Table A5.3 Treatment performance for chemicals from agricultural activities for which guideline values have been established[a,b]

	Chlorination	Air stripping	Coagulation	Ion exchange	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment[c]
Nitrate				+++				+++	+++
				<5				<5	<5
Nitrite	+++							+	+++
	<0.1								
Alachlor					+++	++	+++	+++	
					<0.001		<0.001	<0.001	
Aldicarb					+++	+++		+++	
					<0.001	<0.001		<0.001	
Aldrin/dieldrin			+		+++	++		+++	
					<0.000 02	<0.000 02		<0.000 02	
Atrazine and its chloro-*s*-triazine metabolites			+		+++	Yes[d]	+++	+++	+++[e]
					<0.0001		<0.0001	<0.0001	<0.0001
Carbofuran	+				+++	Yes[d]		+++	
					<0.001			<0.001	
Chlordane					+++	++		Yes[d]	
					<0.0001	<0.0001			
Chlorotoluron					+++	+++			
					<0.0001	<0.0001			
Cyanazine					+++	+		+++	
					<0.0001			<0.0001	
2,4-D					+++	+++		Yes[d]	
					<0.001	<0.001			
1,2-Dibromo-3-chloropropane		++			+++				
		<0.001			<0.0001				

Table A5.3 (continued)

	Chlorination	Air stripping	Coagulation	Ion exchange	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment[c]
1,2-Dibromoethane		+++ <0.0001			+++ <0.0001				
1,2-Dichloropropane		Yes			+++ <0.001	+			
Dimethoate	+++ <0.001				++	++			
Endrin			+		+++ <0.0002			Yes[d]	
Hydroxyatrazine							+++ <0.001	Yes[d]	
Isoproturon	++				+++ <0.0001	+++ <0.0001	+++ <0.0001	+++ <0.0001	+
Lindane					+++ <0.0001	++		Yes[d]	++
MCPA					+++ <0.0001	+++ <0.0001		Yes[d]	
Mecoprop					+++ <0.0001	+++ <0.0001			+++ <0.0001
Methoxychlor			++		+++ <0.0001	+++ <0.0001		Yes[d]	
Metalochlor					+++ <0.0001	++		Yes[d]	++
Simazine					+++ <0.0001	++	+++ <0.0001	+++ <0.0001	

Table A5.3 (continued)

	Chlorination	Air stripping	Coagulation	Ion exchange	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment[c]
2,4,5-T					+++			Yes[d]	
					<0.001				
Terbuthylazine			+		+++	++			
					<0.0001				
Trifluralin					+++			+++[f]	
					<0.0001			<0.0001	

[a] Symbols are as follows:
+ Limited removal
++ Approximately 50% or more removal
+++ Approximately 80% or more removal

[b] The table includes only those chemicals for which some treatment data are available. A blank entry in the table indicates either that the process is completely ineffective or that there are no data on the effectiveness of the process. For the most effective processes, the table indicates the concentration of the chemical (in mg/l) that should be achievable.

[c] Biological treatment includes slow sand filtration, bank filtration and biological denitrification (for nitrate removal).

[d] Yes means known or likely to be effective, but performance was not quantified.

[e] For bank filtration; slow sand filtration is not effective.

[f] Might be effective, but other techniques would be more likely to be applied due to cost.

Table A5.4 Treatment performance for pesticides used in water for public health for which guideline values have been established[a,b]

	Chlorination	Coagulation	Activated carbon	Ozonation	Advanced oxidation	Membranes
DDT and metabolites		+	+++	+	+++[c]	+++[c]
			<0.0001		<0.0001	<0.0001

[a] Symbols are as follows:
+ Limited removal
+++ Approximately 80% or more removal
[b] For the most effective processes, the table indicates the concentration of the chemical (in mg/l) that should be achievable.
[c] Might be effective, but other techniques would be more likely to be applied due to cost.

Table A5.5 Treatment performance for cyanobacterial cells and cyanotoxins for which guideline values have been established[a,b,c]

	Chlorination	Coagulation	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment[d]
Cyanobacterial cells		+++				+++	
Cyanotoxins	+++		+++	+++	+++		+++

[a] Chlorination or ozonation may release cyanotoxins.
[b] +++ = 80% or more removal.
[c] The table includes only those chemicals for which some treatment data are available. A blank entry in the table indicates either that the process is completely ineffective or that there are no data on the effectiveness of the process.
[d] Biological treatment includes slow sand filtration and bank filtration.

or to chemical attack by aggressive ions such as chloride or sulfate, and this may result in structural failure. Newly installed cement materials will leach lime, with consequent increases in pH, alkalinity and hardness. Cement contains a variety of metals that can be leached into the water. Aggressiveness to cement is related to the "aggressivity index", which has been used specifically to assess the potential for the dissolution of concrete. A pH of 8.5 or higher may be necessary to control cement corrosion.

A5.3.3 Copper

The corrosion of copper pipework and hot water cylinders can cause blue water, blue or green staining of bathroom fittings and, occasionally, taste problems. Copper tubing may be subject to general corrosion, impingement attack and pitting corrosion.

General corrosion is most often associated with soft, acidic waters; waters with pH below 6.5 and hardness of less than 60 mg of calcium carbonate per litre are very aggressive to copper. Copper, like lead, can enter water by dissolution of the corrosion product, basic copper carbonate. The solubility is mainly a function of pH and total inorganic carbon. Solubility decreases with increase in pH, but increases with increase in concentrations of carbonate species. Raising the pH to between 8 and 8.5 is the usual procedure to overcome these difficulties.

Impingement attack is the result of excessive flow velocities and is aggravated in soft water at high temperature and low pH.

The pitting of copper is commonly associated with hard groundwaters having a carbon dioxide concentration above 5 mg/l and high dissolved oxygen. Phosphates have been used to suppress copper corrosion in those cases. Surface waters with organic colour may also be associated with pitting corrosion. Copper pipes can fail by pitting corrosion, which involves highly localized attacks leading to perforations with negligible loss of metal. Two main types of attack are recognized. Type I pitting affects cold water systems (below 40 °C) and is associated, particularly, with hard borehole waters and the presence of a carbon film in the bore of the pipe, derived from the manufacturing process. Tubes that have had the carbon removed by cleaning are immune from Type I pitting. Type II pitting occurs in hot water systems (above 60 °C) and is associated with soft waters. A high proportion of general and pitting corrosion problems are associated with new pipe in which a protective oxide layer has not yet formed. Calcium carbonate precipitation indices such as Langelier and Ryznar are not good predictors of corrosion for copper systems.

A5.3.4 Iron

Iron (either cast or ductile) is frequently used in water distribution systems, and its corrosion is of concern. While structural failure as a result of iron corrosion is rare, water quality problems (e.g. "red water") can arise as a result of excessive corrosion of iron pipes. The corrosion of iron is a complex process that involves the oxidation of the metal, normally by dissolved oxygen, ultimately to form a precipitate of iron(III). This leads to the formation of tubercules on the pipe surface. The major water quality factors that determine whether the precipitate forms a protective scale are pH and alkalinity. The concentrations of calcium, chloride and sulfate also influence iron corrosion. Successful control of iron corrosion has been achieved by adjusting the pH to

the range 6.8–7.3, hardness and alkalinity to at least 40 mg/l (as calcium carbonate), oversaturation with calcium carbonate of 4–10 mg/l and a ratio of alkalinity to chloride plus sulfate of at least 5 (when both are expressed as calcium carbonate).

Silicates and polyphosphates are often described as "corrosion inhibitors", but there is no guarantee that they will inhibit corrosion in water distribution systems. However, they can complex dissolved iron (in the iron(II) state) and prevent its precipitation as visibly obvious red "rust". These compounds may act by masking the effects of corrosion rather than by preventing it. Orthophosphate is a possible corrosion inhibitor and, like polyphosphates, is used to prevent "red water".

A5.3.5 Lead

Lead corrosion (plumbosolvency) is of particular concern. Lead piping is still common in old houses in some countries, lead solders have been used widely for jointing copper tubing and brass fittings can contain substantial amounts of lead. Galvanized iron pipe plumbing can accumulate incoming lead and release it at a later time as particulates. The solubility of lead is governed by the formation of lead carbonates as pipe deposits. Wherever practicable, lead pipework should be replaced. Lead can also leach from lead-based solders and brass and bronze fittings.

The solubility of corrosion-related lead salts increases markedly as the pH increases above or decreases below 8.3 because of the substantial decrease in the equilibrium carbonate concentration. Thus, plumbosolvency tends to be at a maximum in waters with a low pH and low alkalinity, and a useful interim control procedure, pending pipe replacement, is to increase the pH to 8.0–8.5 after chlorination prior to distribution. Orthophosphate and other phosphates are effective in suppressing dissolution of lead.

Lead concentrations increase with increasing standing time of water in lead pipe. Flushing the pipework before drawing water for consumption can be used as an interim measure to reduce exposure to lead. Showering, bathing and flushing the toilet can be used to flush out the system.

Lead can corrode more rapidly when it is coupled to copper. The rate of such galvanic corrosion is faster than that of simple oxidative corrosion, and lead concentrations are not limited by the solubility of the corrosion products. The rate of galvanic corrosion is affected principally by chloride concentration. Galvanic corrosion is less easily controlled but can be reduced by dosing zinc in conjunction with orthophosphate and by adjustment of pH.

Treatment to reduce plumbosolvency usually involves pH adjustment. When the water is very soft (calcium carbonate concentration less than 50 mg/l), the optimum pH is about 8.0–8.5. Alternatively, dosing with orthophosphoric acid or sodium orthophosphate might be more effective, particularly when plumbosolvency occurs in non-acidic waters. Calcium carbonate precipitation indices such as Langelier and Ryznar are not considered to be necessarily good predictors of corrosion for lead.

A5.3.6 Nickel

Nickel in water may arise due to the leaching of nickel from new nickel/chromium-plated taps. Low concentrations may also arise from stainless steel pipes and fittings.

Nickel leaching falls off over time. An increase of pH to control corrosion of other materials should also reduce leaching of nickel.

A5.3.7 Zinc

Galvanized pipes will release zinc (from the galvanizing layer) and can also leach cadmium and lead. Corrosion can be a particular problem where galvanized steel or iron piping is connected to dissimilar materials, such as brass, in taps and fittings.

The solubility of zinc in water is a function of pH and total inorganic carbon concentrations; the solubility of basic zinc carbonate decreases with increase in pH and concentrations of carbonate species. For low-alkalinity waters, an increase of pH to 8.5 should be sufficient to control the dissolution of zinc.

With galvanized iron, the zinc layer initially protects the steel by corroding preferentially. In the long term, a protective deposit of basic zinc carbonate forms; however, galvanized pipe is also prone to uncontrolled deposition and clogging. Recent findings have shown that lead can accumulate on galvanized pipe particulates and become resuspended by physical disruption, such as water hammer. Protective deposits do not form in soft waters where the alkalinity is less than 50 mg/l as calcium carbonate or waters containing high carbon dioxide concentrations (> 25 mg/l), and galvanized steel is unsuitable for these waters. Electrolytic corrosion can occur where galvanized steel or iron pipes or fittings are connected with copper tube or brass fittings.

ANNEX 6

Supporting information on radionuclides

A6.1 Guidance levels for radionuclides in drinking-water

Table A6.1 Guidance levels for radionuclides in drinking-water

Radio-nuclide	Guidance level (Bq/l)[a]	Radio-nuclide	Guidance level (Bq/l)[a]	Radio-nuclide	Guidance level (Bq/l)[a]	Radio-nuclide	Guidance level (Bq/l)[a]
^{3}H	10 000	^{71}Ge	10 000	^{105}Rh	1 000	^{129}Cs	1 000
^{7}Be	10 000	^{73}As	1 000	^{103}Pd	1 000	^{131}Cs	1 000
^{14}C	100	^{74}As	100	^{105}Ag	100	^{132}Cs	100
^{22}Na	100	^{76}As	100	^{110m}Ag	100	^{134}Cs	10
^{32}P	100	^{77}As	1 000	^{111}Ag	100	^{135}Cs	100
^{33}P	1 000	^{75}Se	100	^{109}Cd	100	^{136}Cs	100
^{35}S	100	^{82}Br	100	^{115}Cd	100	^{137}Cs	10
^{36}Cl	100	^{86}Rb	100	^{115m}Cd	100	^{131}Ba	1 000
^{45}Ca	100	^{85}Sr	100	^{111}In	1 000	^{140}Ba	100
^{47}Ca	100	^{89}Sr	100	^{114m}In	100	^{140}La	100
^{46}Sc	100	^{90}Sr	10	^{113}Sn	100	^{139}Ce	1 000
^{47}Sc	100	^{90}Y	100	^{125}Sn	100	^{141}Ce	100
^{48}Sc	100	^{91}Y	100	^{122}Sb	100	^{143}Ce	100
^{48}V	100	^{93}Zr	100	^{124}Sb	100	^{144}Ce	10
^{51}Cr	10 000	^{95}Zr	100	^{125}Sb	100	^{143}Pr	100
^{52}Mn	100	^{93m}Nb	1 000	^{123m}Te	100	^{147}Nd	100
^{53}Mn	10 000	^{94}Nb	100	^{127}Te	1 000	^{147}Pm	1 000
^{54}Mn	100	^{95}Nb	100	^{127m}Te	100	^{149}Pm	100
^{55}Fe	1 000	^{93}Mo	100	^{129}Te	1 000	^{151}Sm	1 000
^{59}Fe	100	^{99}Mo	100	^{129m}Te	100	^{153}Sm	100
^{56}Co	100	^{96}Tc	100	^{131}Te	1 000	^{152}Eu	100
^{57}Co	1 000	^{97}Tc	1 000	^{131m}Te	100	^{154}Eu	100
^{58}Co	100	^{97m}Tc	100	^{132}Te	100	^{155}Eu	1 000
^{60}Co	100	^{99}Tc	100	^{125}I	10	^{153}Gd	1 000
^{59}Ni	1 000	^{97}Ru	1 000	^{126}I	10	^{160}Tb	100
^{63}Ni	1 000	^{103}Ru	100	^{129}I	1	^{169}Er	1 000
^{65}Zn	100	^{106}Ru	10	^{131}I	10	^{171}Tm	1 000

Table A6.1 (continued)

Radio-nuclide	Guidance level (Bq/l)[a]	Radio-nuclide	Guidance level (Bq/l)[a]	Radio-nuclide	Guidance level (Bq/l)[a]	Radio-nuclide	Guidance level (Bq/l)[a]
^{175}Yb	1 000	^{210}Pb[b]	0.1	^{231}U	1 000	^{243}Am	1
^{182}Ta	100	^{206}Bi	100	^{232}U	1	^{242}Cm	10
^{181}W	1 000	^{207}Bi	100	^{233}U	1	^{243}Cm	1
^{185}W	1 000	^{210}Bi[b]	100	^{234}U[b]	1	^{244}Cm	1
^{186}Re	100	^{210}Po[b]	0.1	^{235}U[b]	1	^{245}Cm	1
^{185}Os	100	^{223}Ra[b]	1	^{236}U[b]	1	^{246}Cm	1
^{191}Os	100	^{224}Ra[b]	1	^{237}U	100	^{247}Cm	1
^{193}Os	100	^{225}Ra	1	^{238}U[b,c]	10	^{248}Cm	0.1
^{190}Ir	100	^{226}Ra[b]	1	^{237}Np	1	^{249}Bk	100
^{192}Ir	100	^{228}Ra[b]	0.1	^{239}Np	100	^{246}Cf	100
^{191}Pt	1 000	^{227}Th[b]	10	^{236}Pu	1	^{248}Cf	10
^{193m}Pt	1 000	^{228}Th[b]	1	^{237}Pu	1 000	^{249}Cf	1
^{198}Au	100	^{229}Th	0.1	^{238}Pu	1	^{250}Cf	1
^{199}Au	1 000	^{230}Th[b]	1	^{239}Pu	1	^{251}Cf	1
^{197}Hg	1 000	^{231}Th[b]	1 000	^{240}Pu	1	^{252}Cf	1
^{203}Hg	100	^{232}Th[b]	1	^{241}Pu	10	^{253}Cf	100
^{200}Tl	1 000	^{234}Th[b]	100	^{242}Pu	1	^{254}Cf	1
^{201}Tl	1 000	^{230}Pa	100	^{244}Pu	1	^{253}Es	10
^{202}Tl	1 000	^{231}Pa[b]	0.1	^{241}Am	1	^{254}Es	10
^{204}Tl	100	^{233}Pa	100	^{242}Am	1 000	^{254m}Es	100
^{203}Pb	1 000	^{230}U	1	^{242m}Am	1		

[a] Guidance levels are rounded according to averaging the log scale values (to 10^n if the calculated value was below 3×10^n and above $3 \times 10^{n-1}$).

[b] Natural radionuclides.

[c] The provisional guideline value for uranium in drinking-water is 30 µg/l based on its chemical toxicity for the kidney (see section 8.5).

A6.2 References for further information about radionuclides

ICRP (1989) Individual monitoring for intakes of radionuclides by workers. ICRP Publication 54. *Annals of the ICRP*, 19(1–3).

ICRP (2006) Human alimentary tract model for radiological protection. ICRP Publication 100. *Annals of the ICRP*, 36(2).

ICRP (2008) Nuclear decay data for dosimetric calculations. ICRP Publication 107. *Annals of the ICRP*, 38(3).

A6.3 References for further information about analytical methods and treatment technologies for radionuclides

Annanmäki M, ed. (2000) *Treatment techniques for removing natural radionuclides from drinking water. Final report of the TENAWA Project.* Helsinki, Radiation and Nuclear Safety Authority (STUK-A169).

APHA, AWWA, WEF (2005) *Standard methods for the examination of water and wastewater*, 21st ed. Washington, DC, American Public Health Association, American Water Works Association and Water Environment Federation, pp. 7–15.

ASTM (1998) *ASTM annual book of standards. Vol. 11.02.* Philadelphia, PA, American Society for Testing and Materials.

Bring R, Miller AG (1992) Direct detection of trace levels of uranium by laser induced kinetic phosphorimetry. *Analytical Chemistry*, 64:1413–1418.

Chiu NW, Dean JR (1986) *Radioanalytical methods manual*. Ottawa, Ontario, Canadian Government Publishing Centre, Canadian Centre for Mineral and Energy Technology, National Uranium Tailings Program (CANMET Report 78-22).

Crawford-Brown DJ (1989) The biokinetics and dosimetry of radon-222 in the human body following ingestion of groundwater. *Environmental Geochemistry and Health*, 11:10–17.

Department of National Health and Welfare (1977) *Chemical procedures for the determination of ^{89}Sr, ^{90}Sr, and ^{137}Cs in surface waters, fresh-water algae and fresh-water fish.* Ottawa, Ontario, Department of National Health and Welfare (Report 77-EHD-14).

Health Canada (2000) *Environmental radioactivity in Canada 1989–1996*. Available from Environmental Radiation Hazards Division, Radiation Protection Bureau, Health Canada, Ottawa, Ontario [see also earlier editions of *Environmental radioactivity in Canada*].

Health Canada (2004) *Point-of-use and point-of-entry treatment technologies for the removal of lead-210 and uranium from drinking water.* Richmond Hill, Ontario, Senes Consultants Ltd.

Igarashi Y, Kawamura H, Shiraishi K (1989) Determination of thorium and uranium in biological samples by inductively coupled plasma mass spectrometry using internal standardization. *Journal of Analytical Atomic Spectrometry*, 4:571–576.

ISO (2003) *Standard ISO 5667-3: Water quality—Sampling—Part 3: Guidance on the preservation and handling of water samples*. Geneva, International Organization for Standardization.

ISO (2006) *Standard ISO 5667-1: Water quality—Sampling—Part 1: Guidance on the design of sampling programmes and sampling techniques*. Geneva, International Organization for Standardization.

ISO (2006) *Standard ISO 5667-5: Water quality—Sampling—Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems.* Geneva, International Organization for Standardization.

ISO (2007) *Standard ISO 9696: Water quality—Measurement of gross alpha activity in non-saline water—Thick source method.* Geneva, International Organization for Standardization.

ISO (2007) *Standard ISO 10703: Water quality—Determination of the activity concentration of radionuclides—Method by high resolution gamma-ray spectrometry.* Geneva, International Organization for Standardization.

ISO (2008) *Standard ISO 9697: Water quality—Measurement of gross beta activity in non-saline water—Thick source method.* Geneva, International Organization for Standardization.

ISO (2009) *Standard ISO 5667-11: Water quality—Sampling—Part 11: Guidance on sampling of groundwaters.* Geneva, International Organization for Standardization.

ISO (2009) *Standard ISO 10704: Water quality—Measurement of gross alpha and gross beta activity in non-saline water—Thin source deposit method.* Geneva, International Organization for Standardization.

ISO (2010) *ISO 969: Water quality—Determination of tritium activity concentration—Liquid scintillation counting method.* Geneva, International Organization for Standardization.

ISO (2010) *Standard ISO 11704: Water quality—Measurement of gross alpha and beta activity concentration in non-saline water—Liquid scintillation counting method.* Geneva, International Organization for Standardization.

ISO (in preparation) *Standard ISO 13160: Water quality—Measurement of strontium 90 and strontium 89.* Geneva, International Organization for Standardization.

ISO (in preparation) *Standard ISO 13161: Water quality—Measurement of polonium 210 activity concentration in water by alpha spectrometry.* Geneva, International Organization for Standardization.

ISO (in preparation) *Standard ISO 13162: Water quality—Determination of carbon 14 activity—Liquid scintillation counting method.* Geneva, International Organization for Standardization.

ISO (in preparation) *Standard ISO 13163-1: Water quality—Measurement of lead 210 activity concentration—Part 1: Liquid scintillation counting method.* Geneva, International Organization for Standardization.

ISO (in preparation) *Standard ISO 13164-1: Water quality—Measurement of the activity concentration of radon-222 and its short-lived decay products—Part 1: Radon origins and measurement methods.* Geneva, International Organization for Standardization.

ISO (in preparation) *Standard ISO 13164-2: Water quality—Measurement of the activity concentration of radon-222 and its short-lived decay products—Part 2: Direct measurement by gamma spectrometry.* Geneva, International Organization for Standardization.

ISO (in preparation) *Standard ISO 13164-3: Water quality—Measurement of the activity concentration of radon-222 and its short-lived decay products—Part 3: Indirect measurement with degassing.* Geneva, International Organization for Standardization.

ISO (in preparation) *Standard ISO 13165-1: Water quality—Measurement of radium 226 activity concentration—Part 1: Liquid scintillation counting method.* Geneva, International Organization for Standardization.

Lariviere D et al. (2009) Rapid and automated analytical technologies for radiological nuclear emergency preparedness. In: Koskinen AN, ed. *Nuclear chemistry: New research*. Nova Science Publishers, Inc., pp. 99–154.

NSF International (2005) *Contaminant guide*. Ann Arbor, MI, NSF International (http://www.nsf.org/consumer/drinking_water/dw_contaminant_guide.asp?program=WaterTre).

NSF International (2005) *Contaminant testing protocols*. Ann Arbor, MI, NSF International (http://www.nsf.org/consumer/drinking_water/dw_contaminant_protocols.asp).

Prichard HM, Gesell TF (1977) Rapid measurements of ^{222}Rn concentrations in water with a commercial liquid scintillations counter. *Health Physics*, 33:577–581.

Prichard HM, Venso EA, Dodson CL (1991) Liquid scintillation analysis of ^{222}Rn in water by alpha/beta discrimination. *Radioactivity and Radiochemistry*, 3:28–26.

USEPA (1980) *Prescribed procedures for measurement of radioactivity in drinking water*. Washington, DC, United States Environmental Protection Agency (EPA 600/4-80-032).

USEPA (1987) *Two test procedures for radon in drinking water. Appendix D. Analytical test procedure.* Washington, DC, United States Environmental Protection Agency, p. 22 (EPA/600/2-87/082).

USEPA (1999) National primary drinking water regulations; radon-222. Washington, DC, United States Environmental Protection Agency. *Federal Register*, 64(211).

USEPA (2000) *National primary drinking water regulations; radionuclides; final rule.* Washington, DC, United States Environmental Protection Agency (40 Code of Federal Regulations Parts 9, 141 and 142).

USEPA (2000) *Radionuclides notice of data availability technical support document*. Prepared by Office of Groundwater and Drinking Water, United States Environmental Protection Agency, in collaboration with Office of Indoor Air and Radiation, USEPA, and United States Geological Survey.

USEPA (2008) *Approved methods for radionuclides*. Washington, DC, United States Environmental Protection Agency (http://www.epa.gov/ogwdw/methods/pdfs/methods/methods_radionuclides.pdf).

Vitz E (1991) Toward a standard method for determining waterborne radon. *Health Physics*, 60:817–829.

Volchok HL, de Planque G, eds (1983) *EML procedures manual*, 26th ed. New York, NY, United States Department of Energy, Environmental Measurements Laboratory (HASL-300).

WHO (2002) *Establishing a dialogue on risks from electromagnetic fields*. Geneva, World Health Organization.

WHO (2009) *WHO handbook on indoor radon: A public health perspective.* Geneva, World Health Organization.

ANNEX 7

Contributors to the development of the fourth edition of the *Guidelines for drinking-water quality*

This annex lists the names of those who have contributed to the development of the fourth edition of the *Guidelines for drinking-water quality*, through participation at relevant meetings, through authorship or peer review of text in the Guidelines themselves or its supporting documents or through provision of intellectual advice. The list of contributors begins with the first meeting at which the fourth edition was discussed, held in Berlin, Germany, in 2007. All those who contributed to the third edition of the Guidelines as well as the first and second addenda to the third edition, which constitute a major portion of this fourth edition, are listed in Annex 2 of the third edition incorporating the first and second addenda, available on the WHO web site at http://www.who.int/entity/water_sanitation_health/dwq/GDWAN2rev1and2.pdf. Sincere apologies are extended to any contributors whose names have inadvertently been omitted from these lists.

C. Abbot, United Utilities, Warrington, England
H. Abouzaid, World Health Organization, Cairo, Egypt
L. Achene, Istituto Superiore di Sanità, Rome, Italy
J. Adams, Liverpool School of Tropical Medicine, Liverpool, England
A. Adin, Hebrew University of Jerusalem, Jerusalem, Israel
S. Adrian, Environmental Protection Agency, Washington, DC, USA
R. Aertgeerts, World Health Organization European Centre for Environment and Health, Rome, Italy
F. Ahmed, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
A. Aitio, World Health Organization, Geneva, Switzerland
H. Al-Hasni, Public Authority for Electricity and Water, Muscat, Oman
N. Al-Hmoud, Princess Sumaya University for Technology, Amman, Jordan
G. Allgood, The Procter & Gamble Company, Cincinnati, USA
B.M. Altura, New York Downstate Medical Center, New York, USA
B.T. Altura, New York Downstate Medical Center, New York, USA

L. Alves Campos, National Sanitary Control Agency (ANVISA), Brasília, Brazil
S. Al-Wahaibi, Ministry of Health, Muscat, Oman
M. Amazonas, The Coca-Cola Company, Atlanta, USA
R. Anderson, World Health Organization, Geneva, Switzerland
K.B. Andrus, Air Transport Association of America, Inc., Washington, DC, USA
G. Ardon, Ministry of Housing, Spatial Planning and Environment, the Netherlands
M. Asami, National Institute of Public Health, Saitama, Japan
N. Ashbolt, Environmental Protection Agency, Cincinnati, USA
S. Atkinson, McMaster University, Hamilton, Canada
H. Bakir, WHO Regional Centre for Environmental Health Activities, Amman, Jordan
L. Barrott, MWH, High Wycombe, England
J. Barrow, Centers for Disease Control and Prevention, Atlanta, USA
J. Bartram, University of North Carolina, Chapel Hill, USA
R. Bastos, University of Viçosa, Viçosa, Brazil
H.K. Bates, Research Association, Durham, USA
A. Bathija, Environmental Protection Agency, Washington, DC, USA
J. Baumgartner, University of Wisconsin, Madison, USA
A.S. Baweja, Health Canada, Ottawa, Canada
P. A. Bawono, Ministry of Health, Jakarta, Indonesia
D. Bennitz, Health Canada, Ottawa, Canada
M. Berglund, Karolinska Institute of Environmental Medicine, Stockholm, Sweden
S. Bish, United Nations Children's Fund, New York, USA
M. Blokker, Kiwa Water Research, Nieuwegein, the Netherlands
L. Bonadonna, Istituto Superiore di Sanità, Rome, Italy
R. Bos, World Health Organization, Geneva, Switzerland
M. Bowman, Water Corporation, California, USA
E. Briand, Ministère du Travail, de l'Emploi et de la Santé, Paris, France
T. Brooks, Health Canada, Ottawa, Canada
J. Brown, London School of Hygiene & Tropical Medicine, London, England
C. Browne, Ministry of Health, St Michael, Barbados, West Indies
G. Brundrett, Brundett Associates, Kingsley, England
T. Bruursema, NSF International, Ann Arbor, USA
P. Byleveld, New South Wales Department of Health, Sydney, Australia
E. Calderon, Agua y Saneamientos Argentinos, Buenos Aires, Argentina
R. Calderon, Environmental Protection Agency, Durham, USA
P. Callan, National Health and Medical Research Council, Canberra, Australia
D. Calmet, International Organization for Standardization and Nuclear Advisor of the Permanent Mission of France at United Nations, Vienna, Austria
D. Campbell-Lendrum, World Health Organization, Geneva, Switzerland
Z. Carr, World Health Organization, Geneva, Switzerland
V. Casey, WaterAid, London, England
C. Castell-Exner, German Technical and Scientific Association for Gas and Water, Bonn, Germany

P. Charles, Centre International de Recherche Sur l'eau et l'Environnement – Suez Environnement, Le Pecq, France
R. Charron, Health Canada, Ottawa, Canada
Y. Chartier, World Health Organization, Geneva, Switzerland
J. Chen, Health Canada, Ottawa, Canada
C.K. Chew, World Health Organization, Geneva, Switzerland
M.L. Chong, World Health Organization, Manila, Philippines
I. Chorus, Federal Environment Agency, Berlin, Germany
D. Chuckman, International Flight Services Association, Mississauga, Canada
G. Cissé, Swiss Tropical and Public Health Institute, Basel, Switzerland
T. Clasen, London School of Hygiene and Tropical Medicine, London, England
L. Coccagna, consultant, Italy
J. Colbourne, Drinking Water Inspectorate, London, England
A. Colgan, International Atomic Energy Agency, Vienna, Australia
G. Combs, United States Department of Agriculture, Grand Forks, USA
L. Corrales, Centers for Disease Control and Prevention, Atlanta, USA
R. Costello, National Institutes of Health, Bethesda, USA
P. Costrop, Syngenta Crop Protection, Basel, Switzerland
J. Cotruvo, Joseph Cotruvo & Associates/NSF International Collaborating Centre, Washington, DC, USA
M. Couper, World Health Organization, Geneva, Switzerland
D. Cunliffe, Department of Health, Adelaide, Australia
T. Darlow, MWH, Edinburgh, Scotland
D. Davidson, Center for Food Safety and Applied Nutrition, Food and Drug Administration, College Park, USA
A. Davison, Water Futures Pty Ltd, Dundas Valley, Australia
D. Deere, Cooperative Research Centre for Water Quality and Treatment, Salisbury, Australia
J. De France, NSF International, Zaventem, Belgium
M. Del Rosario Perez, World Health Organization, Geneva, Switzerland
J. Dennis, Thames Water Utilities, England
A.M. de Roda Husman, National Institute of Public Health and the Environment, Bilthoven, the Netherlands
H. Dieter, Federal Environment Agency, Dessau, Germany
P. Donlon, Water Services Association, Victoria, Australia
J. Donohue, Environmental Protection Agency, Washington, DC, USA
T. Dooley, United Nations Children's Fund, New York, USA
F. Douchin, DASS de Seine Maritime, Rouen, France
N. Dowdall, British Airways, Harmondsworth, England
P. Drechsel, International Water Management Institute, Colombo, Sri Lanka
D. Drury, Independent Consultant, London, United Kingdom
I. Dublineau, Institut de Radioprotection et de Sûreté Nucléaire, Fontenay-aux-Roses, France
C. Edgar, Cranfield University, Bedford, England
P. Edmondson, Medentech Ltd, Wexford, England

R. Elin, University of Louisville, Louisville, USA
T. Endo, Ministry of Health, Labour and Welfare, Tokyo, Japan
J. Escamilla, World Health Organization, Panama
A. Evans, International Civil Aviation Organization, Montreal, Canada
M. Exner, Institute for Hygiene and Public Health, University of Bonn, Bonn, Germany
A. Eyring, Philadelphia Water Department, Philadelphia, USA
Z. Fang, Department of Health Quarantine, General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Beijing, China
J. Fawell, Independent Consultant, Buckingham, England
D. Fayzieva, Uzbekistan Academy of Science, Uzbekistan
E. Ferretti, Istituto Superiore di Sanità, Rome, Italy
I. Feuerpfeil, Federal Environment Agency, Germany
L. Fewtrell, Aberystwyth University, Aberystwyth, Wales
K. Ford, Rio Tinto, London, England
P. Fosselard, European Federation of Bottled Water, Brussels, Belgium
D. Frost, Aqua Focus Ltd, Newport, England
D. Gamper, Airports Council International, Geneva, Switzerland
D. Gatel, EUREAU, Brussels, Belgium
R.J. Gelting, Centers for Disease Control and Prevention, Atlanta, USA
M. Giddings, Health Canada, Ottawa, Canada
S. Godfrey, United Nations Children's Fund, Bhopal, India
C. Gollnisch, Akkreditierte Hygieneinspektionsstelle für Trinkwassersysteme, Germany
R. Goossens, Compagnie Intercommunale Bruxelloise des Eaux, Belgium
B. Gordon, World Health Organization, Geneva, Switzerland
F. Gore, World Health Organization, Geneva, Switzerland
W. Grabow, retired (formerly of University of Pretoria, Pretoria, South Africa)
J. Grace, Air Safety, Health and Security Department, Association of Flight Attendants-CWA, Washington, DC, USA
A.C. Grandjean, Center for Human Nutrition, Omaha, USA
C. Güler, Hacettepe University, Turkey
C. Hadjichristodoulou, University of Thessaly, Larissa, Greece
S. Harris, International Life Sciences Institute, Washington, DC, USA
P. Hartemann, Faculté de Médicine de Nancy, France
T. Hasan, Pacific Islands Applied Geoscience Commission, Suva, Fiji Islands
S. Hauswirth, Public Health Service, North Rhine–Westphalia, Germany
R.P. Heaney, Creighton University, Omaha, USA
H. Heijnen, World Health Organization, Kathmandu, Nepal
S. Herbst, Institute for Hygiene and Public Health, University of Bonn, Germany
A. Hirose, National Institute of Health Sciences, Tokyo, Japan
E.J. Hoekstra, Institute for Health and Consumer Protection, Ispra, Italy
C. Hollister, Air Transport Association of Canada, Mississauga, Canada
L. Hope, World Health Organization, Geneva, Switzerland

G. Howard, Department for International Development, East Kilbride, Scotland
S. Hrudey, University of Alberta, Edmonton, Canada
L.C. Hsiang, National Environment Agency, Singapore, Singapore
J. Huff, National Institute of Environmental Health Sciences, Research Triangle Park, USA
P. Hunter, University of East Anglia, Norwich, England
F. Husson, Solar Solutions LLC, San Diego, USA
P. Illig, Centers for Disease Control and Prevention, Anchorage, USA
T. Inoue, Japan Water Forum, Tokyo, Japan
M. Itoh, National Institute of Public Health, Japan
S. Itoh, Kyoto University, Kyoto, Japan
D. Jackson, MWH, Melbourne, Australia
P. Jackson, WRc-NSF Ltd, Reading, England
E. Jesuthasan, World Health Organization, Geneva, Switzerland
H.E. Jianzhong, National University of Singapore, Singapore
B. Jiménez Cisneros, Institute of Engineering, Mexico City, Mexico
R. Johnston, Eawag, Duebendorf, Switzerland
H. Jones, Loughborough University, Leicestershire, England
P.S. Joshi, National Environment Agency, Singapore
T. Jung, German Federal Office for Radiation Protection, Oberschleissheim, Germany
M. Kanazawa, Ministry of Health, Labour and Welfare, Tokyo, Japan
P. Karani, African Development Bank, Tunis, Tunisia
G.Y.-H. Karina, National University of Singapore, Singapore
H. Kasan, Rand Water, Johannesburg, South Africa
A. Kasuya, Ministry of Health Labour and Welfare, Tokyo, Japan
H. Katayama, University of Tokyo, Tokyo, Japan
D. Kay, University of Wales, Ceredigion, Wales
N.R. Khatri, World Health Organization, Kathmandu, Nepal
T. Kistemann, University of Bonn, Germany
K. Komatsu, National Institute for Environmental Studies, Ibaraki, Japan
K. Kosaka, National Institute of Public Health, Saitama, Japan
N.O. Kotei, Public Utilities Regulatory Commission, Accra, Ghana
P. Kozarsky, Centers for Disease Control and Prevention, Atlanta, USA
F. Kozisek, National Institute of Public Health, Prague, Czech Republic
R. Kryschi, Germany
Y. Kubo, Ministry of Health, Labour and Welfare, Tokyo, Japan
P. Kubon, Federal Environment Agency, Germany
Y. Kudo, Japan Water Works Association, Tokyo, Japan
S. Kumar, University of Malaya, Kuala Lumpur, Malaysia
S. Kunikane, University of Shizuoka, Shizuoka, Japan
S. Kurebayashi, Ministry of the Environment, Tokyo, Japan
H. Lahav, Makhshim Chemical Works Ltd, New York, USA
H.K. Lee, National University of Singapore, Singapore
J. Lee, Health Protection Agency, London, England

P. Lennon, PATH, Seattle, USA
K. Levy, Rollins School of Public Health, Atlanta, USA
M.H. Lim, Public Utilities Board, Singapore
J.-F. Loret, Centre International de Recherche Sur l'eau et l'Environnement – Suez Environnement, Le Pecq, France
P. Lotz, MINTEK, Randburg, South Africa
A. Lovell, Water Services Association of Australia, Sydney, Australia
S. Luby, International Centre for Diarrhoeal Disease Research, Dhaka, Bangladesh
L. Lucentini, Istituto Superiore di Sanità, Rome, Italy
Y. Magara, Hokkaido University, Sapporo, Japan
B. Magtibay, Department of Health, Manila, Philippines
S.G. Mahmud, World Health Organization, Dhaka, Bangladesh
D. Maison, World Health Organization, Geneva, Switzerland
D. Mara, University of Leeds, Leeds, England
K.J. Marienau, Centers for Disease Control and Prevention, Minneapolis, USA
P. Marsden, Department for Environment, Food and Rural Affairs, London, England
T. Matsuda, Ministry of Health, Labour and Welfare, Tokyo, Japan
Y. Matsui, Hokkaido University, Sapporo, Japan
K. Matsumoto, Ministry of Health, Labour and Welfare, Tokyo, Japan
A. May, Drinking Water Inspectorate, London, England
S. McFadyen, Health Canada, Ottawa, Canada
C. McLaren, Drinking Water Quality Regulator for Scotland, Edinburgh, Scotland
D. Medeiros, Health Canada, Ottawa, Canada
G. Medema, Kiwa Water Research, Nieuwegein, the Netherlands
R. Meierhofer, Eawag, Duebendorf, Switzerland
K. Meme, Lifewater International, San Luis Obispo, USA
J. Mercer, Health Canada, Ottawa, Canada
D.L. Menucci, World Health Organization, Lyon, France
R. Meyerhoff, Lilly Research Laboratories, Eli Lilly and Company, Greenfield, USA
F. Miranda da Rocha, National Sanitary Control Agency, Brasília, Brazil
H.G.H. Mohammad, Ministry of Health, Rumaithiya, Kuwait
D. Mokadam, Association of Flight Attendants-CWA, Washington, DC, USA
D. Moir, Health Canada, Ottawa, Canada
M. Mons, Kiwa Water Research, Nieuwegein, the Netherlands
M. Montgomery, World Health Organization, Geneva, Switzerland
A. Mooijman, Independent Consultant, Meerssen, the Netherlands
H. Morii, Osaka City University, Osaka, Japan
V. Morisset, Health Canada, Ottawa, Canada
T. Morita, Japan Water Forum, Tokyo, Japan
N. Moritani, Ministry of Health, Labour and Welfare, Tokyo, Japan
R. Morris, University College London, London, England
B. Mouchtouri, University of Thessal, Larissa, Greece
M. Moussif, Mohamed V Airport, Casablanca, Morocco
J. Nadeau, Health Canada, Ottawa, Canada
K.J. Nath, Institution of Public Health Engineers, India

R. Neipp, Ministry of Health and Social Policy, Madrid, Spain
A.V.F. Ngowi, Muhimbili University of Health and Allied Sciences, Dar-Es-Salaam, United Republic of Tanzania
C. Nicholson, Sydney Water, Sydney, Australia
F.H. Nielsen, United States Department of Agriculture, Grand Forks, USA
J.W. Nieves, Columbia University, New York, USA
C. Nokes, Environmental Science and Research Ltd, Christchurch, New Zealand
O. Odediran, United Nations Children's Fund, New York, USA
M. Ogoshi, National Institute for Land and Infrastructure Management, Ibaraki, Japan
E. Ohanian, Environmental Protection Agency, Washington, DC, USA
S. Okamoto, Public Works Research Institute, Ibaraki, Japan
C.N. Ong, National University of Singapore, Singapore
S.L. Ong, National University of Singapore, Singapore
L. Onyon, World Health Organization, Geneva, Switzerland
P. Osborn, 300in6 initiative, Uithoorn, the Netherlands
W. Oswald, Rollins School of Public Health, Atlanta, USA
A. Paoli, Atkins Limited, Epsom, England
T. Paux, Ministère de la santé, de la jeunesse et des sports, Paris, France
G.L. Peralta, World Health Organization, Manila, Philippines
S. Perry, State of Washington Office of Drinking Water, Tumwater, USA
S. Petterson, Water & Health Pty Ltd, Parramatta, Australia
B. Pilon, International Air Transport Association, Geneva, Switzerland
M. Plemp, Centre for Infectious Disease Control, Amsterdam, the Netherlands
B. Plotkin, World Health Organization, Geneva, Switzerland
T. Pohle, Air Transport Association, Washington, DC, USA
K. Pond, University of Surrey, Guildford, England
K. Porter, Environmental Protection Agency, Washington, DC, USA
F. Properzi, World Health Organization, Geneva, Switzerland
T. Pule, World Health Organization, Brazzaville, Republic of Congo
W. Qu, Fudan University, Shanghai, China
H. Quiñones, Scientific and Technical Translator, Madrid, Spain
V. Ramnath, National Environment Agency, Singapore, Singapore
T. Rapp, Federal Environment Agency, Germany
S. Regli, Environmental Protection Agency, Washington, DC, USA
P. Regunathan, Regunathan & Associates Inc., Wheaton, USA
A. Rinehold, Centers for Disease Control and Prevention, Atlanta, USA
J. Ringo, Bio-Cide International, Inc., Norman, USA
S. Risica, National Institute of Health, Rome, Italy
W. Robertson, retired (formerly Health Canada, Ottawa, Canada)
G. Rodier, World Health Organization, Geneva, Switzerland
J.W. Rosenboom, Water and Sanitation Program of the World Bank (WSP), Phnom Penh, Cambodia
K. Rotert, Environmental Protection Agency, Washington, DC, USA

H. Sanderson, Danish National Environmental Research Institute, Roskilde, Denmark
B. Schaefer, Federal Environment Agency, Bad Elster, Germany
S. Schaub, Environmental Protection Agency, Washington, DC, USA
O. Schmoll, Federal Environment Agency, Bad Elster, Germany
S. Seki, Ministry of the Environment, Tokyo, Japan
C. Sevenich, Hamburg Port Health Center, Hamburg, Germany
G. Shaghaghi, Ministry of Health, Tehran, Islamic Republic of Iran
N. Shah, Unilever R & D Laboratory, Bangalore, India
F. Shannoun, World Health Organization, Geneva, Switzerland
N. Shaw, International Shipping Federation, London, England
D. Sheehan, Department of Human Services, Adelaide, Australia
M. Sheffer, Editor, Ottawa, Canada
E. Sheward, University of Central Lancashire, West Sussex, England
D. Shrestha, United Nations High Commissioner for Refugees, Geneva, Switzerland
D. Simazaki, National Institute of Public Health, Saitama, Japan
J. Simmonds, Health Protection Agency, Didcot, England
J. Sims, retired (formerly World Health Organization, Geneva, Switzerland)
M. Sinclair, Monash University, Melbourne, Australia
C. Skak, Danish Toxicology Centre, Denmark
D. Smith, Melbourne Water, Melbourne, Australia
S. Smith, Wessex Water, Bath, England
M. Sobsey, University of North Carolina, Chapel Hill, USA
J. Soller, Soller Environmental, LLC, Berkeley, USA
B. Sontia, University of Ottawa, Ottawa, Canada
T.-A. Stenstrom, Swedish Institute for Infectious Disease Control, Stockholm, Sweden
M. Stevens, Melbourne Water Corporation, Melbourne, Australia
N. Stewart, Carnival UK, London, England
K. Sudo, Japan International Cooperation Agency, Tokyo, Japan
S. Surman-Lee, Health Protection Agency, London, England
D. Sutherland, Independent Consultant, Epsom, England
A. Suzuki, Ministry of the Environment, Tokyo, Japan
M. Takahashi, Hokkaido University, Hokkaido, Japan
H. Tanaka, Kyoto University, Shiga, Japan
R. Tanner, consultant, Belgium
M. Taylor, Ministry of Health, Wellington, New Zealand
P. Teixeira, World Health Organization, Washington, DC, USA
P. Teunis, National Institute for Public Health and the Environment, Bilthoven, the Netherlands
C. Thibeault, International Air Transport Association, Montreal, Canada
T. Thompson, World Health Organization, Manila, Philippines
S.M. Tibatemwa, International Water Association, Nairobi, Kenya
D. Till, consultant, New Zealand
R. Tomisaka, Ministry of the Environment, Tokyo, Japan
R.M. Touyz, University of Ottawa, Ottawa, Canada
B. Tracy, Health Canada, Ottawa, Canada

A. Trevett, World Health Organization, Kathmandu, Nepal
D.M. Trindade, Centre for Disease Control and Prevention, Macao Special Administrative Region, China
A. Tritscher, World Health Organization, Geneva, Switzerland
S. Tuite, Health Canada, Ottawa, Canada
T. Udagawa, Japan Water Works Association, Tokyo, Japan
P. Undesser, Water Quality Association, Lisle, USA
S. Vajpeyee, Government Medical College and New Civil Hospital, Surat, India
J.P. van der Hoek, Amsterdam Water Supply, Amsterdam, the Netherlands
P. Van Maanen, United Nations Children's Fund, New York, USA
L. Vázquez-Coriano, Environmental Protection Agency, Washington, DC, USA
G. Velo, University of Verona,Verona, Italy
F. Venter, University of Pretoria, Pretoria, South Africa
E. Veschetti, Istituto Superiore di Sanità, Rome, Italy
C. Vickers, World Health Organization, Geneva, Switzerland
J.M.P. Vieira, University of Minho, Braga, Portugal
L. Vijselaar, Danish Committee for Aid to Afghan Refugees (DACAAR), Kabul, Afghanistan
C. Viljoen, Rand Water, Johannesburg, South Africa
G. Vivas, World Health Organization, Bridgetown, Barbados
N. Wang, World Health Organization, Lyon, France
C. Weaver, Purdue University, West Lafayette, USA
W. Weglicki, George Washington University Medical Center, Washington, DC, USA
S. Westacott, Southampton City Council, Southampton, England
I. Wienand, University of Bonn, Bonn, Germany
A. Wiklund, DG Energy, European Commission, Luxembourg
T. Williams, International Water Association, The Hague, the Netherlands
D. Wilusz, Department of State, Washington, DC, USA
C. Witkowski, Association of Flight Attendants-CWA, Washington, DC, USA
K.-M. Wollin, Niedersächsisches Landesgesundheitsampt, Hanover, Germany
J. Yap, National Environment Agency, Singapore
R. Yuen, International Water Association, Singapore
R. Zhang, National Center for Rural Water Supply Technical Guidance, Center for Disease Control and Prevention, Beijing, China
G. Ziglio, University of Trento, Trento, Italy

Index

Page numbers in **bold** indicate main discussions.

Acanthamoeba 119, 120, 123, 269–270
Acceptability **7–8, 219–230**
  biologically derived contaminants 221–222
  chemical contaminants 156, 222–230
  in emergencies and disasters 101, 199
  guideline values for chemicals affecting **167**
  setting standards 28
Acceptable daily intake (ADI) 161
  allocation to drinking-water 163–164, 195–196, 197
  derivation of guideline values 164
  uncertainty factors 162–163
Access to water (accessibility) 83, **85**
  definition of reasonable 85
  equitability 101
  policies 33
Acids, household water treatment 142
Acinetobacter 107, 120, 121, **232–234,** 298
Acrylamide **307–308**
  analysis 483
  guideline value 188, 308, 472
Actinomycetes 221
Activated alumina 493
Activated carbon
  adsorption **490–491**
  granular (GAC) 176, 490–491
  powdered (PAC) 490–491
Acute reference doses (ARfDs) 197
Additives 26, 182–185
Adenoviruses 119, **258–260,** 305, 306
Adequacy of supply, surveillance **83–86**
ADI *see* Acceptable daily intake
Advanced oxidation processes 492–493
Aeration **489**
  radon removal 217
Aeromonas 107, 120, 121, **234–235,** 298
Aerosols 120
Aesthetic acceptability *see* Acceptability
Affordability 83, **85–86**
Aggressivity index, cement 501
Agricultural activities, chemicals from 158, **179–182**
  analysis 481–482
  guideline values 183–184
  treatment performance 497–499
AIDS 120, 280
Air, radon in 215–216
Air stripping 489
Aircraft **109–112**
Airports **109–112**
Alachlor **308–309**
  analysis 481
  guideline value 183, 309, 472
  treatment performance 497
Aldicarb **309–310**
  analysis 481
  guideline value 183, 309, 472
  treatment performance 497
Aldrin **310–311**
  analysis 481
  guideline value 183, 310, 472
  treatment performance 497
Algae 221
Alkalinity

corrosion and 175, 501, 502, 503
see also pH
Alkyl benzenes 226, 409
Alkyl naphthalenes 409
Alpha radiation activity
measurement **213,** 214
screening levels 208, 209
Alumina, activated 493
Aluminium **311–313,** 469
acceptability 222–223, 311
coagulants 489
dialysis water 107
optimal values 186, 311, 312, 313
Alzheimer disease (AD) 311–312
Americium-241 211, 215
Aminomethylphosphonic acid (AMPA) 182, **374,** 470
Amitraz 181, 468
Ammonia 173, 182, **313,** 469
taste and odour 223
treatment to remove 230
Amoebae 57
Legionella ingestion 244
routes of transmission 120
see also Acanthamoeba; *Entamoeba histolytica*; *Naegleria fowleri*
Amoebiasis 276
Amoebic encephalitis, granulomatous 269, 270
Amoebic meningoencephalitis, primary (PAM) 282
AMPA 182, **374,** 470
Anabaena spp. 293, 344
Analytical achievability **479–484**
Analytical methods
chemicals 168–170, **476–478**
radionuclides **213–214**
Ancylostoma (duodenale) 120, 289, 290
Animals
in drinking-water **221–222**
rainwater collection systems 58–59
toxicological studies 159
Anion exchange 176
Anthracite–sand filters 487–488
Anthrax 236
Antimony **314–315**
analysis 479
guideline value 188, 314, 472
Aphanizomenon spp. 293
Aphelenchus 289
Appearance 7–8, **219–230**
biologically derived contaminants 221–222
chemical contaminants 222–230
treatments for improving **230**
see also Colour; Turbidity
Aquifers *see* Groundwaters
Argyria 415
Arsenic **315–318**
analysis 318, 479
guideline value 178, 315, 317–318, 472
household treatment 176
priority 29
treatment performance 494
Asbestos 187, **318,** 469
Asbestos–cement pipes 493
Ascaris 120, 290
Asellus aquaticus 222
Aspergillus 107
Astroviruses 119, **260–261,** 305
Atomic absorption spectrometry (AAS) 476–477
Atomic emission spectrometry (AES) 477
Atrazine **319–320**
analysis 481
guideline value 183, 319, 472
treatment performance 497
Audit
approach to surveillance **78–79**
water safety plans 69, 78, 87

Bacillus **235–236**
Bacillus cereus 235
Bacillus thuringiensis israelensis (Bti) 191, 193, **434–435,** 469
Backflow 105
prevention 99
Bacteria
pathogenic 119, 121, **232–258**
reference pathogens **127**
treatment efficacy 139–140, 145–146
Bacteriophages 148, 301–305
Bacteroides fragilis phages 148, **303–305**
Balantidium coli (balantidiasis) 120, 121, **270–271**
Bank filtration 488–489
Barium **320–321**
analysis 479
guideline value 178, 320, 472
BDCM *see* Bromodichloromethane

Becquerel (Bq) 205
Benchmark dose (BMD) **161–162**
lower confidence limit (BMDL) 160, 161–162
uncertainty factors 162
Bentazone 182, **321–322,** 469
Benzene **322**
analysis 480
guideline value 180, 322, 472
treatment performance 495
Benzo[*a*]pyrene 411, 412
analysis 483
guideline value 188, 411, 472
Beryllium 179, **322–323,** 469
Beta radiation activity
due to potassium-40 209–210, 213
measurement **213,** 214
screening levels 208, 209
β_2-microglobulin, urinary 327–328
Bilharzia *see* Schistosomiasis
Biofilms 57
atypical mycobacteria 247–248
desalinated water 99
Klebsiella 243
Legionella 244, 245
Biologically derived contaminants **221–222**
Blastocystis (hominis) 121, **271–273**
Bleach, household 110, 141
Blooms, cyanobacterial 221, 294, 345
Blue-baby syndrome *see* Methaemoglobinaemia
Blue-green algae *see* Cyanobacteria
Body weight, guideline value calculations 164
Boil water advisories 72, **151–153**
Boiling of water
households 143, 146
travellers 108, 110
Bone char 176
Borehole waters 96, 215
Boron **323–324**
analysis 479
guideline value 178, 323, 472
Bottle-fed infants 196, 398, 399, 400, 402–403
Bottled water 101, 108, 114–115
Brass corrosion **493**
Bromate 172, **324–325**
analysis 482
guideline value 187, 324, 472
strategies for reducing 173
in water treatment products 189, 324
Bromide 177, **325–326,** 469
Brominated acetic acids **326**
Bromine 487
Bromochloroacetate 186, 326, 469
Bromochloroacetonitrile 186, **375–376,** 469
Bromodichloromethane (BDCM) **427–430**
analysis 482
guideline value 187, 427, 472
Bromoform **427–430**
analysis 482
guideline value 187, 427, 472
Buildings
large **104–107,** 245
plumbing systems 16–17
Bulk water supply **97–98**
Burkholderia pseudomallei 119, **236–237**

Cadmium **327–328**
analysis 479
guideline value 180, 327, 472
treatment performance 495
Caesium 215
Caesium-134 211
Caesium-137 211
Calcium
hard water 377
taste threshold 225
Calcium carbonate
saturation status 175
scale 225
see also Hardness
Calcium hypochlorite 110, 141, 485
decomposition products 188
Calcium sulfate 227
Caliciviruses **261–263,** 305
Campylobacter **237–239**
in faeces, wastewater and raw water 136
health-based targets 134
as reference pathogen 127
risk assessment 130, 132
Campylobacter coli 119, 237
Campylobacter jejuni 119, 237–238
Cancer
arsenic-related 316–317
radiation-induced 207
radon-related risk 216
see also Carcinogens
Capacity-building networks 18

Carbaryl 182, **328,** 469
Carbofuran **328–329**
analysis 481
guideline value 183, 329, 472
treatment performance 497
Carbon, activated *see* Activated carbon
Carbon-14 211
Carbon block technologies 176
Carbon filters 108, 109, 111
Carbon tetrachloride **329–330**
analysis 480
guideline value 180, 329, 472
treatment performance 495
Carcinogens
derivation of guideline values 159–160, 165
genotoxic 159, 165
guideline values 184
health effects of acute exposure 196
IARC classification 160
non-genotoxic 159
Cascade aeration 489
Catchments
control measures 54–55
hazard identification 53–54
management 53–55
new systems 50
performance targets 43
roles and responsibilities 11, 12–13
see also Source waters
Cation exchange 176, 491
Cement, corrosion **493–501**
Ceramic filters, porous 109, 111, 142, 145
Certification 15–16
agencies **15–16**
chemicals in water 42–43
household treatment and storage 146–147
Cheilobus 289
Chemical-specific adjustment factors (CSAF) 160, **163**
Chemicals **6–7, 155–201**
acceptability aspects **222–230**
acute reference doses 197
agricultural activities *see* Agricultural activities, chemicals from
analytical achievability **479–484**
analytical methods 168–170, **476–478**
carcinogenic risk categories 160
categorization by source 157–158
emergencies involving *see* Emergencies, chemical contamination
of emerging concern **189–190**
fact sheets **307–442**
guideline values *see* Guideline values
health-based targets 40, 42–43, 156
health-based values for use in emergencies **197–198**
health hazards 5, **156–158**
industrial sources and human dwellings *see* Industrial sources and human dwellings, chemicals from
information sources 30
mixtures **167–168**
spills involving 199–200
naturally occurring *see* Naturally occurring chemicals
non-threshold 159
derivation of guideline values **165**
not included in Guidelines **167**
piped distribution systems 56
priority setting **29–30**
"short-listing" 30
summary tables **468–475**
threshold 159, **160–165**
treatment to remove **170–176**
verification **26–27,** 65, **66–67**
Chemicals used in water treatment/materials in contact with water 158, **182–189**
analysis 479, 482–483
guideline values 187–188
with no guideline values 186–187
process control measures 171–174
see also Disinfection by-products
Children
guideline value calculations 164
radionuclide guidance levels 212–213
see also Infants
Chironomus larvae 222
Chloral hydrate (trichloroacetaldehyde) 186, **330–331,** 469
Chloramination 57, 486
by-products 185, 405
effects on acceptability 220
nitrite formation 399
Chloramines **331–332,** 486
taste and odour 223
see also Monochloramine

Chlorate 172, **335–336**
analysis 482
guideline value 187, 335, 473
in water treatment products 188, 189
Chlordane **333**
analysis 481
guideline value 183, 333, 473
treatment performance 333, 497
Chloride 177, **333–334,** 469
acceptability 223, 334
Chlorinated acetic acids 352–353, 395, 423–424
Chlorination **485–486**
alternatives to 174
breakpoint 485
by-products 172, 184, 185
indicators for monitoring 185–188
chemical contaminants 188–189
in emergencies 151
household use 141–142, 145
marginal 485
microbial reduction 140
for travellers 108, 110
Chlorine 6, **334–335**
acceptable levels 223
analysis 482
gas, liquefied 485
guideline value 187, 334, 473
residual, monitoring 62
treatment *see* Chlorination
Chlorine dioxide 186, 469, 486
by-products 172, 185, 335
see also Chlorate; Chlorite
chemical contaminants 189
health effects 336
household use 141
microbial reduction 140
water treatment 174
Chlorite 172, **335–336**
analysis 483
guideline value 187, 335, 473
in water treatment products 188, 189
3-Chloro-4-dichloromethyl-5-hydroxy-2-(5H)-furanone *see* MX
Chloroacetones 186, **337,** 469
Chlorobenzenes 223–224
Chlorobenzilate 181, 468
Chloroform **427–430**
analysis 483
guideline value 187, 427, 473
2-Chlorophenol 186, 224, **337–338,** 469
Chlorophenols 224, **337–338**
Chlorophenoxy herbicides 348–349, 360–361, 369–370, 387–389, 419–420
Chloropicrin 186, **338,** 469
Chlorothalonil 181, 468
Chlorotoluron **338–339**
analysis 481
guideline value 183, 338, 473
treatment performance 497
Chlorpyrifos **339–340**
analysis 483
guideline value 183, 339, 473
Cholera 255, 256
Chromatography 477–478
Chromium **340**
analysis 479
guideline value 178, 340, 473
Chydorus sphaericus 221
Citrobacter 295, 296
Citrus fruit juices 142
Clarification
microbial reduction 139
for travellers 108–109
Climate change 3–4, 94
Clostridium perfringens 148, **300–301**
Cloudiness 221, 228
Co-precipitation method, measuring radioactivity 213, 214
Coagulation (chemical) 55, **489–490**
household use 143
microbial reductions 139
Codex Alimentarius Commission (CAC) 115
Cold water systems 105
Coliform bacteria
in faeces, wastewater and raw water 136
thermotolerant *see* Thermotolerant coliforms
total **294–296**
use in monitoring 148
see also Escherichia coli
Coliphages **301–303**
F-RNA 301, 302–303
somatic 301, 302
use in monitoring 148
Collaborative multiagency approach 8
Colorimetric methods 476
Colour 221, **224**
Communication **25**

radiation risk **217–218**
surveillance information **89–92**
water safety plans 46, **76**
Community
communication with 25, 89–90
organizations 12, 90
participation 89–90
Community drinking-water systems **58–59**
control measures 58–59
grading schemes 90–91
hazard identification 58
management **74–75**
operation and maintenance 87
operational monitoring **63–64**
roles and responsibilities 11–12, **14–15**
surveillance 80, **81–82**
verification **68**
Composite filters 142, 145
Concrete, dissolution **493–501**
Conjunctivitis, adenovirus 259
Consumers
acceptability to *see* Acceptability
communication with 25
informing about chemical emergencies 195
interaction with **89–90**
radiation risk communication 217–218
roles and responsibilities **15**
Consumption of drinking-water, per capita 83
assessing exposure to pathogens 129
guideline value calculations 164
local variations 31, 168
performance target setting and 134, 135
Contact, transmission via 120, 123
Contact lenses 270
Containers, water
breeding of disease vectors 190
bulk supplies 97
in emergencies and disasters 101
household storage 146
packaged drinking-water 114
pesticide use *see* Pesticides, used in water for vector control
rainwater 95
vended water 96–97
Continuity of supply 83, **86**
emergencies and disasters 101
Control measures 23, 46
assessment and planning **52–53**
defined 52
determining **61–62**
monitoring performance *see* Operational monitoring
non-piped, community and household systems **58–59**
operational and critical limits 63
piped distribution systems **57–58**
resource and source protection **54–55**
treatment stage **55–56**
validation *see* Validation
Cooling towers 244, 245
Copper 184, **340–342**
acceptability **224–225,** 341
analysis 479
corrosion **501**
guideline value 188, 341, 473
health effects of acute exposure 196
impingement attack 501
pitting 501
Corrosion **174–175**
control strategies 175
desalinated water 98
galvanic 502
inhibitors 502
pH and 174–175, 226–227
pitting 501
potential, characterizing 175
treatment and distribution systems **493–503**
Cosmic radiation 204, 206
Costs
water supply 85–86
water treatment 171
Coxsackieviruses 263
Crangonyx pseudogracilis 221
Critical limits **63**
Crustaceans 221
Cryptosporidiosis 273
Cryptosporidium 119, **273–274**
in faeces, wastewater and raw water 136
performance targets 133–134
as reference pathogen 127–128
risk assessment 132
treatment efficacy 145–146, 174
Cryptosporidium hominis 273
Cryptosporidium parvum 273
Ct concept 56
Culex larvae 222
Cyanazine **342**

analysis 481
guideline value 183, 342, 473
treatment performance 497
Cyanide 179, **342–344,** 346–347, 469
Cyanobacteria 176, **293–294**
acceptability 221
blooms 221, 294, 345
toxins *see* Cyanotoxins
treatment performance 500
Cyanogen chloride 186, 343–344, **346–347,** 469
Cyanotoxins 176, 293–294, **344–346**
analysis 484
treatment 346, 500
see also Microcystin-LR
Cyanuric acid 417
Cyclops 221, 222, 286
Cyclospora cayetanensis 119, **274–276**
Cyclosporiasis 275
Cylindrospermum spp. 293
Cypermethrin 181, 468

2,4-D (2,4-dichlorophenoxyacetic acid) **347–348**
analysis 481
guideline value 183, 347, 473
treatment performance 497
DALYs *see* Disability-adjusted life years
Data
derivation of guideline values 165–166
fitness for purpose 68
regional use **90–92**
system assessment and design 51–53
2,4-DB 183, **348–349,** 473, 481
DBCP *see* 1,2-Dibromo-3-chloropropane
DBPs *see* Disinfection by-products
DCBs *see* Dichlorobenzenes
DDT and metabolites 191, **349–350**
analysis 483
guideline value 192, 349, 473
treatment performance 500
"Dealkalization" 491
Dechlorination 485
DEHA *see* Di(2-ethylhexyl)adipate
DEHP *see* Di(2-ethylhexyl)phthalate
Deltamethrin 181, 468
Demineralized water 115
Denitrification, biological 493
Dental surgeries 107
Desalination systems **98–99**
Detergents, synthetic 227
Developing countries
urban areas **81**
vended water 96
"Deviations" 71
Dezincification of brass 493
Di(2-ethylhexyl)adipate (DEHA) 179, **361,** 470
Dialkyltins 187, **350,** 469
Dialysis, renal 107
Diarrhoea
Campylobacter 238
Cryptosporidium 273
Escherichia coli 240
Isospora **279**
rotavirus 267
travellers' 107–108
see also Gastroenteritis
Diazinon 181, 468
1,2-Dibromo-3-chloropropane (DBCP) **350–351**
analysis 481
guideline value 183, 351, 473
treatment performance 497
Dibromoacetate 186, 326, 469
Dibromoacetonitrile 187, **375–376,** 473, 483
Dibromochloromethane (DCBM) **427–430**
analysis 483
guideline value 187, 427, 473
1,2-Dibromoethane **351–352**
analysis 481
guideline value 183, 351, 473
treatment performance 498
Dichloramine **331–332,** 486
acceptability 223
lack of guideline value 186, 332, 470
Dichloroacetic acid (dichloroacetate) 187, **352–353,** 473, 483
1,1-Dichloroacetone 337
Dichloroacetonitrile 187, **375–376,** 473, 483
3,4-Dichloroaniline 413
1,2-Dichlorobenzene **353–354**
acceptable levels 224
analysis 480
guideline value 180, 353, 473
treatment performance 495
1,3-Dichlorobenzene 179, **353–354,** 470
1,4-Dichlorobenzene 180, **353–354**
acceptable levels 224
analysis 480

guideline value 353, 473
treatment performance 495
Dichlorobenzenes (DCBs) **353–354**
Dichlorodiphenyltrichloroethane *see* DDT and metabolites
1,1-Dichloroethane 179, **354–355,** 470
1,2-Dichloroethane **355**
analysis 480
guideline value 180, 355, 473
treatment performance 495
1,1-Dichloroethene 179, **355–356,** 470
1,2-Dichloroethene **356–357**
analysis 480
guideline value 180, 356, 473
treatment performance 495
Dichloromethane 180, **357–358,** 473, 480
2,4-Dichlorophenol 186, 224, **337–338,** 470
2,4-Dichlorophenoxyacetic acid *see* 2,4-D
1,2-Dichloropropane (1,2-DCP) **358–359**
analysis 481
guideline value 183, 358, 473
treatment performance 498
1,3-Dichloropropane 182, **359,** 470
1,3-Dichloropropene 183, **359–360,** 473, 481
Dichlorprop (2,4-DP) 183, **360–361,** 473, 481
Dieldrin **310–311**
analysis 481
guideline value 183, 310, 472
treatment performance 497
Diflubenzuron 191, 193, **435–436,** 470
Dimethoate **362–363**
analysis 481
guideline value 183, 362, 473
treatment performance 498
Dinoseb 181, 468
1,4-Dioxane **363–364**
analysis 480
guideline value 180, 363, 473
treatment performance 495
Di(2-ethylhexyl)phthalate (DEHP) 180, **361–362,** 473, 480
Diplogaster 289
Diquat 182, **364,** 470
Disability-adjusted life years (DALYs) **37–38,** 39
microbial hazards 130–131
Disasters 57, **100–102**
see also Emergencies
Disease burden
reference pathogens 130–131, 132
tolerable **37–38**
Diseases, infectious *see* Infectious diseases
Disinfectants
analysis 482
changing 174
guideline values 187
with no guideline values 186
residual, piped distribution systems 57
see also specific disinfectants
Disinfection **5–6,** 56
desalinated water 98, 99
emergencies and disasters 101
household based 141–142, 145
limitations 6
methods **485–487**
microbial reduction 140
monitoring 62
non-chemical 174
packaged drinking-water 114
solar 143, 146
temporary water supplies 103
for travellers 108–109, 110–111
turbidity and 228
vended water 96
verification 65
Disinfection by-products (DBPs) 6, 155, 184, 185
analysis 482–483
control strategies 171–174
guideline values 187–188
indicators for monitoring 185–188
with no guideline values 186
removal prior to distribution 174
see also specific chemicals
Displaced populations 100–101
Dissolved air flotation 490
Distilled water 115
Documentation **24–25**
incidents and emergencies 25, 71
supporting **443–448**
water safety plans **75–76**
Domestic systems *see* Household drinking-water systems
Dose, infectious 130
Dose–response assessment, waterborne pathogens 130
Dracunculus Eradication Programme 285
Dracunculus medinensis (guinea worm) 119, 122, **285–287**

intermediate host 222
Dreissena polymorpha 222
Droughts 94
Dual piped water supply systems **99**
Dysentery
amoebic 276
bacillary 252

Echinococcus 120
Echoviruses 263
Edetic acid (EDTA) **364–365**
analysis 480
guideline value 180, 365, 474
treatment performance 495
EDTA *see* Edetic acid
Education programmes 12, 14, 63
building owners and managers 106
establishing 87
Electron capture detection (ECD) 478
Electrothermal atomic absorption spectrometry (EAAS) 477
ELISA (enzyme-linked immunosorbent assay) 478
Emergencies **72, 100–102**
chemical contamination **192–201**
consumer acceptability 199
determining appropriate action 198–199
evaluating health significance 195–198
health-based values 197–198
informing public 195
investigation 194
liaison with key authorities 194–195
mixtures 199–200
sensitive subpopulations 198
trigger for action 194
updating water safety plan 199
water avoidance advisories 200–201
documentation and reporting 25, 71
follow-up investigation 71
longer-term planning 101
microbial quality problems **150–153**
response plans 69–70, 72
verification testing 67
water safety plan review after 76
see also Incidents
Emerging diseases 122–123, 269
Encephalitis, granulomatous amoebic 269, 270
Encephalitozoon 280, 281
Endosulfan 182, **365–366,** 470
Endrin **366–367**
analysis 481
guideline value 183, 366, 474
treatment performance 498
Entamoeba histolytica 119, **276–277**
Enteric fever 250–251
Enteric viruses 258, **305–306**
coliphages as indicator 302
indicator organisms for 149
use in monitoring 148, 305
Enterobacter 295, 296
Enterobacter sakazakii 121, **239–240**
Enterococci, intestinal **298–300**
Enterococcus spp. 299
Enterocolitis, *Staphylococcus aureus* 253
Enterocytozoon 280
Enteroviruses 119, **263–264,** 305, 306
in faeces, wastewater and raw water 136
as reference pathogens 126–127
Enzyme-linked immunosorbent assay (ELISA) 478
Epichlorohydrin (ECH) 188, **367–368,** 474, 483
Epidemiological studies 11, 124–125
Equitability, access to water 101
Escherichia coli 43, 295
detection methods 150
diffusely adherent (DAEC) 240
enteroaggregative (EAEC) 240
enterohaemorrhagic (EHEC) 119, 127, 240, 241
enteroinvasive (EIEC) 240, 241
enteropathogenic (EPEC) 240, 241
enterotoxigenic (ETEC) 240
as indicator of faecal pollution 26, **296–297**
O157:H7 serotype 127, 240, 241
pathogenic 119, **240–241**
phages (coliphages) 148, 301–303
piped distribution systems 57
in source waters 136, 137–138
use in monitoring 148–149
verification of microbial quality 65, 149
see also Coliform bacteria
Ethylbenzene **368**
analysis 480
guideline value 180, 368, 474
odour and taste thresholds 225

treatment performance 495
Ethylene dibromide *see* 1,2-Dibromoethane
Ethylene thiourea 181, 468
Evaporation method, measuring radioactivity 213, 214
Exposure assessment, waterborne pathogens 129
Eye infections
Acanthamoeba 269, 270
adenovirus 259

Faecal contamination 4, 120
control measures 6, 54
in emergencies 100, 150–151
indicator organisms *see* Indicator organisms
on ships 113
temporary water supplies 103
Faecal–oral route of transmission 120
Faeces, numbers of microorganisms 136, 137
Fasciola 120, 122, **287–288**
Fascioliasis 287–288
Fasciolopsis 120
Fenamiphos 181, 468
Fenitrothion 182, **368–369,** 470
Fenoprop 183, **369–370,** 474, 481
Field test kits 170
Filtration 55–56, **487–489**
bank 488–489
household 142–143, 145
microbial reductions 139
pressure 488
rapid gravity 487–488
roughing 488
slow sand 488
for travellers 108–109, 111
turbid water 228
First-flush diverters 59, 95
Flame atomic absorption spectrometry (FAAS) 476
Flame ionization detection (FID) 478
Flavobacterium 120, 298
Floc removal 489–490
Flocculant-chlorine tablets/sachets 110
Flocculation 55, 489–490
microbial reduction 139
Floods 94
Flotation, dissolved air 490
Flow diagrams 50
Fluoranthene 187, 410, 412, 470
Fluoride **370–373**
analysis 373, 479
desalinated water 99
guideline value 178, 371, 474
health-based target 42
priority 29
treatment performance 494
treatment technologies 176, 373
Fluorosis 372–373
Food
intake of chemicals 163–164
production and processing **116**
safety, travellers 108
Food and Agriculture Organization of the United Nations (FAO) 161
Food poisoning
Bacillus cereus 235, 236
Campylobacter 238
Salmonella 251
Staphylococcus aureus 253–254
Formaldehyde 186, **373–374,** 470
Formothion 181, 468
Framework for safe drinking-water, conceptual 3–4, **19–33**
developing quality standards 30–31
identifying priority concerns 27–30
key components 19–25
regulations and supporting policies and programmes 31–33
verification of quality 25–27
Francisella tularensis 119
Fulvic acids 224
Fungi 221

β-Galactosidase 295
Galvanized iron 503
Gammarus pulex 221
Gas chromatography (GC) 478
Gas chromatography/mass spectrometry (GC-MS) 478
Gastroenteritis
adenovirus 259
astrovirus 260
calicivirus 262
rotavirus 267
Salmonella 250, 251
Yersinia 257
see also Diarrhoea
Geosmin 221

Geothermal waters 282
Giardia (intestinalis) 119, **277–278**
in faeces, wastewater and raw water 136
as reference pathogen 127–128
Giardiasis 277
β-Glucuronidase 296
Glyphosate 182, **374,** 470
Gnat larvae 222
Grading schemes, safety of drinking-water 25, 90–91
Granular activated carbon (GAC) 176, 490–491
Granular media filters 142–143, 145
Granulomatous amoebic encephalitis 269, 270
Groundwaters
control measures 54–55, 58
effects of climate change 94
hazard identification 53, 54
radon 215, 216
Guideline values 2, 7, 27
acceptability and 220
adaptation to local conditions **31, 168**
chemicals affecting acceptability **167**
chemicals by source category **176–190**
chemicals of health significance **472–475**
chemicals without established **469–472**
criteria for establishing 158
derivation **158–168**
approaches 159–160
assessment, in emergencies **195–196**
data quality 165–166
non-threshold chemicals (non-TDI-based) 165
relative source allocation 163–164
significant figures 164–165
sources of uncertainty 162–163
threshold chemicals (TDI-based) 160–165
see also Tolerable daily intake
deviations from 192–201
excluded chemicals 468
health-based targets based on 156
mixtures of chemicals **167–168**
provisional 158, **166**
radionuclides *see* Radionuclides, guidance levels
treatment performance 171–172
for use in emergencies **197–198**
as water quality targets 42
Guinea worm *see Dracunculus medinensis*

Haemolytic uraemic syndrome (HUS) 240
Hafnia 295
Haloacetic acids (HAAs) 155, 172, 173, 185
Halogenated acetonitriles **375–376**
Hardness 177, **376–377,** 470
acceptability **225**
corrosion and 175, 502
treatment to reduce 230
see also Softening
Hazard(s)
definition 50
non-piped, community and household systems **58**
piped distribution systems **56–57**
prioritizing, for control **51–52**
source waters **53–54**
treatment **55**
Hazardous events 50
Health-based targets **20–21, 35–44**
benefits 37
chemical hazards 40, 42–43, 156
identifying priorities 27–28
incremental improvement concept 3, 36, 37
microbial hazards 41, 43, **124–136**
selection 40–41
setting 36–37
short-term variations and 40
types 38–44
use of DALYs 38, 39
see also Health outcome targets; Performance targets; Specified technology targets; Water quality targets
Health-care facilities **107**
Health education 82
see also Education programmes
Health outcome targets 20–21, **41**
application 40, 41
infectious diseases **135–136**
Health promotion 82
Heat technologies
household water treatment 143, 146
see also Boiling of water
Helicobacter pylori 121, **241–242**
Helminths 119, 122, **285–292**
routes of transmission 120

Hepatitis A virus (HAV) 119, **264–265,** 305
Hepatitis E virus (HEV) 119, **265–267,** 305
Heptachlor 182, **377–378,** 470
Heptachlor epoxide 182, **377–378,** 470
Heterotrophic microorganisms 57, 62–63
Heterotrophic plate counts (HPC) 148, **297–298**
Hexachlorobenzene (HCB) 179, **378–379,** 470
Hexachlorobutadiene (HCBD) **379–380**
  analysis 480
  guideline value 180, 379, 474
  treatment performance 495
Hexachlorocyclohexanes 181, 468
High-income countries, performance targets 133, 134, 135
High-performance liquid chromatography (HPLC) 478
Holistic approach 3–4
Hookworms 289, 290
Hoses, transfer 96–97, 98
Hospital-acquired (nosocomial) infections
  Acinetobacter 232, 233
  Klebsiella 243
  Pseudomonas aeruginosa 249
Hospitals 107
Hot water systems 105, 244–245
Hotels 105
Household(s)
  disposal of chemicals 178
  quantity of water collected 83–84
Household drinking-water systems
  control measures 58–59
  hazard identification 58
  management **74–75**
  operational monitoring **63–64**
  roles and responsibilities 11–12, 15
  water safety plans **58–59**
Household treatment and storage 15, **140–147**
  certification 146–147
  microbial reductions 144, 145–146
  programmes to promote 87–88
  removal of chemicals **175–176**
  surveillance **82–83,** 146–147
  technologies 140, 141–144, 487
  use of data 91–92
  validation 146–147
Human activities, potentially polluting 12–13, 53
Human dwellings, chemicals originating from *see* Industrial sources and human dwellings, chemicals from
Humic acids 224
Hydrocarbons
  petroleum 226, 408–409
  polynuclear aromatic (PAHs) **410–412**
Hydrogen peroxide 173, 492–493
Hydrogen sulfide 177, **380,** 470
  acceptable levels 225–226
  treatment to remove 230
Hydroxyatrazine 319, 320
  analysis 481
  guideline value 183, 319, 474
  treatment performance 498
Hydroxyl radicals 492–493
Hygiene education programmes *see* Education programmes
Hypochlorite 141, 485
  by-products 185
  decomposition products 188
Hypochlorous acid 141, 485
  by-products 185

Ice 108, 115
IDC *see* individual dose criterion
Immunity, acquired 124, 131
Immunocompromised persons 107, 120–122
  Aeromonas infections 234
  atypical mycobacteria infections 247
  disease burden estimates 131
  isosporiasis 279
  Klebsiella infections 243
  Pseudomonas aeruginosa 249
  travellers 109
  Tsukamurella infections 254
Improved drinking-water sources 85
Improvement, drinking-water systems **60–61,** 87
Incidents 69–72
  actions following 153, 199
  chemical contamination *see* Emergencies, chemical contamination
  documentation and reporting 25, 71
  follow-up investigation 71
  predictable 71
  response plans 69–72
  unplanned events 71–72

verification testing 67
water safety plan review after 76
see also Emergencies
Incremental improvement concept 3, 36, 37
Indicator organisms **294–306**
criteria 147–148
detection methods **150**
grading water quality 90, 91
presence/absence testing 66
in source waters 136, 137–138
use in monitoring 24, 147–149
validation 60
verification 26, 65, 66, 67
see also specific organisms
Individual dose criterion (IDC) 206, 207
contribution of each radionuclide to 210
remedial measures 214
screening levels and 207–208
screening of supplies and 209
Inductively coupled plasma atomic emission spectrometry (ICP-AES) 477
Inductively coupled plasma mass spectrometry (ICP-MS) 477
Industrial sources and human dwellings, chemicals from 158, **177–179**
analysis 479, 480
guideline values 179, 180
treatment performance 495–496
Infants
bottle-fed 196, 398, 399, 400, 402–403
radionuclide guidance levels 212–213
see also Children
Infectious diseases 117, **118–123**
asymptomatic 124, 130
emerging issues 122–123
health outcome targets **135–136**
public health aspects 11, **124**
routes of transmission 5, 120, 123
vulnerable subpopulations 1–2, 120, 124
see also Microbial hazards; Pathogens
Infectious dose 130
Influenza viruses 121, 122
Information channels, establishing 87
Inhalation
adapting guideline values 31, 168
microbial pathogens 120, 123
radionuclides 206
radon 204, 215
Inorganic tin 187, **380–381,** 470
Insect vectors 190–191
Insecticides, aquatic *see* Pesticides, used in water for vector control
Intermittent water supply 57, 86
International Agency for Research on Cancer (IARC) 160, 166
International Commission on Radiological Protection (ICRP) 204, 207, 214
International Organization for Standardization (ISO) standards 69, 70, 150
International Programme on Chemical Safety (IPCS) 166
International standards 2
Interspecies variation 162
Invertebrate animals **221–222**
Iodine 186, **381,** 470
household use 142, 487
use by travellers 108, 111
Iodine-131 211, 215
Ion chromatography 477–478
Ion exchange **491,** 493
Ion selective electrode 476
Iron 177, **381–382,** 470
acceptable levels **226**
coagulants 489
coloration of water 224
corrosion **501–502**
galvanized 503
priority 29
Iron bacteria 222, 226
Isoproturon **382–383**
analysis 481
guideline value 183, 382, 474
treatment performance 498
Isospora belli 121, **279–280**
Isosporiasis 279

Jar tests 490
Joint FAO/WHO Expert Committee on Food Additives (JECFA) 161, 164, 166
Joint FAO/WHO Meeting on Pesticide Residues (JMPR) 161, 164, 166, 197

Katayama fever 291
Keratoconjunctivitis, epidemic 259
Klebsiella 121, **242–243**

as indicator organism 295, 296, 298
pathogenicity 120, 243

Laboratories
analysis of chemicals 169
in emergencies and disasters 102
Lactose fermentation 295, 296
Land use 12–13, 53
Langelier index 175
Larson ratio 175
Larvicides, aquatic 190–191, 193, 434–442
Latrines 178
Lead 184, **383–384**
analysis 479
corrosion **502**
guideline value 188, 383, 474
priority 29
sampling locations 67
Lead-210 211
Legionella spp. 57, 119, **244–245**
growth in water 123
health-care facilities 107
large building systems 105
route of transmission 120
Legionellosis 244
Legionnaires' disease 244
Leptospira 119, **245–247**
Leptospirosis 246, 247
Lindane **385–386**
analysis 481
guideline value 183, 385, 474
treatment performance 498
Liver flukes *see Fasciola*
LOAEL *see* Lowest-observed-adverse-effect level
Local authorities **11–12**
Low-income countries, performance targets 133, 134
Lowest-observed-adverse-effect level (LOAEL) 160, **161**
uncertainty factors 162
Lyngbya spp. 293

Magnesium 225, 377
Malathion 182, **386,** 470
Management
community and household supplies **74–75**
piped distribution systems **69–74**
plans **24,** 46, **69–75**
roles and responsibilities **8–17**
water resource **12–13**
Manganese 177, **386–387,** 471
acceptability 226
priority 29
treatment to remove 230
Mass spectrometry (MS) 477
MCPA (4-(2-methyl-4-chlorophenoxy) acetic acid) **387–388**
analysis 481
guideline value 183, 388, 474
treatment performance 498
MCPB 181, 468
MCPP *see* Mecoprop
Mecoprop **388–389**
analysis 482
guideline value 183, 388, 474
treatment performance 498
Melioidosis 236, 237
Membrane filters 109, 111, 142, 145
Membrane treatment processes **492**
Meningoencephalitis, primary amoebic (PAM) 282
Mercury **389–390**
analysis 479
guideline value 180, 389, 474
treatment performance 495
Meringue dezincification 493
Methaemoglobinaemia 176, 196, 399, 400, 405
Methamidophos 181, 468
Methomyl 181, 468
Methoprene 191, 193, **436–437,** 471
Methoxychlor **390–391**
analysis 482
guideline value 183, 390, 474
treatment performance 498
4-(2-Methyl-4-chlorophenoxy)acetic acid *see* MCPA
2-(2-Methyl-chlorophenoxy)propionic acid *see* Mecoprop
2-Methyl isoborneol 221
Methyl parathion 182, **391–392,** 471
Methyl *tertiary*-butyl ether (MTBE) 179, **392–393,** 471
Methylcyclopentadienyl manganese tricarbonyl (MMT) 386–387
Methylene chloride *see* Dichloromethane
Methylmercury 389
Metolachlor **393**

analysis 482
guideline value 183, 393
treatment performance 498
Microbial aspects **4–5, 117–153**
Microbial fact sheets **231–306**
Microbial growth **123**
desalinated water 99
piped distribution systems 105, 120
Microbial hazards **117–124**
health-based targets 41, 43, **124–136**
health outcome targets 135–136
identification 128
risk assessment *see* Quantitative microbial risk assessment
risk-based performance target setting 131–135
turbidity as indicator 228–229
Microbial monitoring **147–149**
Microbial pathogens *see* Pathogens
Microbial quality
assessing priorities **29**
community supplies 75
grading schemes based on 90–91
responses to problems and emergencies **150–153**
verification **26, 65–66,** 149
Microcystin-LR 176, **344–346**
analysis 484
guideline value 178, 344, 474
Microcystins 176, 344
Microcystis spp. 293, 344
Microfiltration 492
Microsporidia 121, **280–282**
Millennium Development Goals 33, 85
Mineral waters, natural 115
Mirex 181, 468
Molinate 184, **393–394,** 474, 482
Molluscs 222
Molybdenum 177, **394,** 471
Monitoring
dissolved radionuclides **208–212**
in emergencies and disasters 101–102
microbial **147–149**
operational *see* Operational monitoring
plans, preparing **73**
temporary water supplies 104
see also Sanitary inspection; Surveillance
Monobromoacetate 186, 326, 471
Monochloramine **331–332**
acceptability 223
analysis 482
by-products 172, 174
disinfectant activity 486
guideline value 187, 331, 474
Monochloroacetic acid (monochloroacetate) **395**
analysis 483
guideline value 188, 395, 474
Monochlorobenzene (MCB) 179, 223–224, **395–396,** 471
Monocrotophos 181, 468
Moraxella 298
Mosquitoes
breeding in containers 95, 190
pesticides for control 190–191, 193, 434–442
Multiagency approach, collaborative 8
Multiple-barrier principle 4, 52, 143–144
MX (3-chloro-4-dichloromethyl-5-hydroxy-2-(5H)-furanone) 186, **396,** 471
Mycobacterium (mycobacteria) **247–249**
atypical (non-tuberculous) 119, 120–122, 247–248
in free-living nematodes 289
health-care facilities 107
Mycobacterium avium complex 247, 248
Mycobacterium kansasii 248

Naegleria fowleri 119, 120, **282–283**
control measures 57
growth in water 123
Nais worms 222
Nanofiltration 492
National priorities, supply improvement 87
National standards and regulations **30–33**
chemical contaminants 156–157
developing 2–3, **30–31**
periodic review and revision 31
supporting policies and programmes 33
Natural disasters 57
Natural mineral waters 115
Naturally occurring chemicals 158, **176–177**
analysis 479
guideline values 177, 178
with no guideline values 177
treatment performance 494
Naturally occurring radionuclides 203–204, 205
Necator (americanus) 120, 289, 290
Nematodes

free-living 122, 222, **288–290**
parasitic 285, 289
see also Dracunculus medinensis
Nephelometric turbidity units (NTU) 229
Networks, capacity-building 18
New drinking-water supply systems **50–51**
Nickel **396–397**
analysis 479
guideline value 188, 397, 474
leaching **502–503**
Nitrate **398–403**
agricultural sources 179
analysis 399, 479
guideline value 183, 196, 398, 401, 474
health effects of acute exposure 196
priority 29
treatment performance 399, 497
treatment technologies 176, 403
Nitrification, biological 493
Nitrilotriacetic acid (NTA) **403–404**
analysis 480
guideline value 180, 403, 474
treatment performance 496
Nitrite **398–403**
analysis 399, 479
guideline value 183, 398, 402, 474
treatment performance 399, 497
treatment technologies 176, 403
Nitrobenzene 179, **404–405,** 471
Nitrogen trichloride *see* Trichloramine
N-Nitroso compounds 400–401
N-Nitrosodimethylamine (NDMA) **405–406**
analysis 483
guideline value 188, 428, 474
treatment performance 496
No-observed-adverse-effect level (NOAEL) 160, **161**
acute exposures 197
uncertainty factors 162
NOAEL *see* No-observed-adverse-effect level
Nocardia 289
Nodularia spp. 293
Non-piped water systems **58–59**
control measures 58–59
hazard identification 58
operational monitoring **63–64**
roles and responsibilities 15
Non-piped water treatment *see* Household treatment and storage
Non-potable piped supplies 99
Norms, drinking-water 10
Noroviruses 119, 261–262
as reference pathogens 127
Nosema 280
Nosocomial infections *see* Hospital-acquired infections
Nostoc spp. 293
Novaluron 191, 193, **437,** 471

Odour 7–8, 220–221
biologically derived contaminants 221–222
chemical contaminants 222–230
treatments for removing **230**
Operational limits **63**
Operational monitoring **23–24,** 46, 60, **61–64**
parameters 62–63, 64
plans, preparing 73
use of indicator organisms 148
Organolead compounds 383
Organotins 350
Orthoreoviruses **267–268,** 305, 306
Oscillatoria spp. 293
Osmosis 492
see also Reverse osmosis
Oxamyl 181, 468
Oxidation processes, advanced 492–493
Oxidation–reduction potential 62
Oxygen, dissolved 225
Ozonation **486**
advanced oxidation processes 492–493
alternatives to 174
by-products 172, 185
household use 142
microbial reduction 140
Ozone 486
chemical contaminants 189

Packaged drinking-water **114–115**
in emergencies and disasters 101
see also Bottled water
Parasites **268–292**
secondary hosts 222
see also Helminths; Protozoa
Parathion 182, **406–407,** 471
Parechoviruses 127
Particulate matter 221, 228
Pathogens 118–122, 231–232
bacterial 119, 121, **232–258**

detection methods 147
dose–response assessment 130
emerging 122–123, 269
exposure assessment 129
fact sheets **232–292**
health-care facilities 107
helminth **285–292**
monitoring 147
occurrence **136–137**
persistence and growth in water **123**
piped distribution systems 56–57
protozoan 119, 121, **268–285**
reference *see* Reference pathogens
routes of transmission 5, 120, 123
treatment **138–147**
viral 119, 121, **258–268**
zoonotic 122
see also Infectious diseases
Pendimethalin 184, **407,** 474, 482
Pentachlorophenol (PCP) **407–408**
analysis 480
guideline value 180, 408, 474
treatment performance 496
Performance targets 21, 40, **43**
adaptation to local conditions 134–135, 136
application 40, 41
pathogens in raw water 133–134
risk-based development **131–135**
Permethrin 191, **438,** 471
Pesticides
acute reference doses 197
used in agriculture 180
analysis 481–482
guideline values 183–184
with no guideline values 182
treatment performance 497–499
used in water for vector control 158, **190–191, 434–442**
analysis 483
formulations and doses 193
guideline values 192
with no guideline values 191
treatment performance 500
see also Agricultural activities, chemicals from; *specific compounds*
Petroleum products 179, **408–409,** 471
source contamination 178
taste and odour **226,** 409
pH 177, **409,** 471
corrosion and 174–175, 226–227, 501–502, 503
disinfection by-products and 173
optimum range 226–227
Phages *see* Bacteriophages
Pharmaceuticals **189–190**
Pharyngoconjunctival fever 259
2-Phenylphenol (and its sodium salt) 182, **409–410,** 471
Phorate 181, 468
Phosphates 501, 502
Piped distribution systems **56–58**
control measures 57–58
corrosion of metals used **493–503**
dual **99**
hazard identification 56–57
management procedures **69–74**
microbial hazards 120
operational monitoring 62–63
plumbing within buildings **16–17**
sampling locations 66–67
on ships 113
verification testing **67–68**
Pipes (and fittings) 17
bulk water supplies 97–98
cement linings 493–501
chemical contaminants from 184, 187, 188
corrosion **493–503**
galvanized 503
lead exposure 383, 384
vended water 96–97
Pirimiphos-methyl 191, 193, **438–439,** 471
Pitting corrosion 501
Planktothrix spp. 293, 344
Pleistophora 280
Plumatella 222
Plumbing **16–17**
lead exposure 383, 384
on ships 113
Plumbosolvency 502
Plutonium-239 (^{239}Pu) 211, 215
Point-of-use treatment *see* Household treatment and storage
Poisson distribution 130
Policy
development, wider 10
national **33**
water resource management 13
Poliovirus 127, 263

Polonium-210 (^{210}Po) 211
Polyacrylamides 307, 308
Polynuclear aromatic hydrocarbons (PAHs) **410–412**
Polyomaviruses 258
Polyphosphates 502
Polyvinylchloride (PVC) 431
Pontiac fever 244
Porous ceramic filters 109, 111, 142, 145
Port authority 113
Potassium 177, **412–413,** 471
Potassium-40 (^{40}K) 209–210, 213
Potassium bromate 324
Potassium chloride 412
Potassium permanganate 412
Powdered activated carbon (PAC) 490–491
Precipitation 143
  softening 493
  see also Coagulation
Presence/absence testing 66
Pressure, water 57, 58
  large buildings 105
  monitoring 63
Pressure filters 488
Pretreatment 55
  microbial reductions 139
Preventive integrated management approach 8
Priorities
  identifying **27–30**
  national 87
  setting 28, 51–52
  subnational/regional 87
Propanil 182, **413,** 471
Propoxur 181, 468
Protozoa
  cysts and oocysts, removal 56
  indicator organisms for 149
  pathogenic 119, 121, **268–285**
  reference pathogens **127–128**
  treatment efficacy 139–140, 145–146
Pseudomonas 298
Pseudomonas aeruginosa 107, 120, 121, **249–250**
Public awareness, establishing 87
Public health
  policy context 36–37
  surveillance 10–11, 78
  waterborne infections and **124**
Public health authorities
  chemical emergencies 194–195
  roles and responsibilities **10–11,** 13
Purge-and-trap packed-column GC method 478
Purge-and-trap packed-column GC-MS method 478
Pyridate 181, 468
Pyriproxyfen **439–440**
  as aquatic larvicide 193, 439, 440
  lack of guideline value 181, 191, 440, 471

QMRA *see* Quantitative microbial risk assessment
Quality, drinking-water 83
  assessment **28–29**
  climate change effects 94
  monitoring *see* Monitoring
  regulations **32–33**
  standards *see* Standards
  verification *see* Verification
  see also Guideline values
Quality assessment **28–29**
Quality assurance **68–69**
Quality control **8–10, 68–69**
Quantitative microbial risk assessment (QMRA) 118, 124, 125, **128–131**
  dose–response assessment 130
  exposure assessment 129
  hazard identification 128
  problem formulation 128
  risk characterization 130–131, 132
Quantitative service indicators 68
Quantity of supply
  assessing adequacy **83–84**
  climate change effects 94
  emergencies and disasters 101
Quintozene 181, 468

Radiation
  effective dose 205
  exposure situations 207
  exposure through drinking-water **205**
  health risks 206
  individual dose criterion *see* Individual dose criterion
  risk communication **217–218**
  sources **204–205,** 206
Radioactivity
  measurement **213,** 214

screening 42, 209–210
screening levels **207–208,** 209
assessment when levels exceed 210
units 205
Radiological aspects **7, 203–218**
Radionuclides 7, 203–218
analytical methods **213–214**
in drinking-water 205
effective half-life 205
guidance levels **207–208, 504–505**
assessment when levels exceed 210–212
calculation 213
common radionuclides 211, **212–213**
human-made 205
monitoring and assessment for dissolved **208–212**
naturally occurring 203–204, 205
remedial measures **214,** 215
sampling frequency 212
screening for 42, 209–210
sources 205
supporting information **504–508**
Radium 215
Radium-226 (^{226}Ra) 211
Radium-228 (^{228}Ra) 211
Radon (^{222}Rn) 204, **214–217**
in air and water 214–216
guidance and screening levels 216
health risks 216
measurement 217
reduction in drinking-water 217
Rainfall, heavy 26, 94
Rainwater harvesting systems **94–96**
contaminants 95
control measures 58–59
Raphidiopsis curvata 293
Records *see* Documentation
"Red water" 501, 502
Redox potential 62
Reference level of risk **37–38**
Reference pathogens **125–128**
bacteria 127
protozoa 127–128
quantitative microbial risk assessment 128
risk characterization 130–131, 132
selection 126
setting performance targets 133–135, 136
viruses 126–127
Regional level
establishing priorities 87
use of data for priority setting **90–92**
Regulations **32–33**
see also National standards and regulations
Reporting
incidents and emergencies 25, 71
radioactivity analysis **217**
surveillance information **89–92**
Reservoirs 54, 139
Resource protection **53–55**
control measures 54–55
hazard identification 53–54
Respiratory viruses 258, 259
Reverse osmosis 492
household use 176
use by travellers 109, 111
Rhabditis 289
Risk
characterization, infectious diseases 130–131, 132
communication, radiation 217–218
defined 50
reference level **37–38**
scoring and ranking 51–52, 53
Risk assessment
chemical emergencies 195–198
holistic approach 3–4
quantitative microbial *see* Quantitative microbial risk assessment
Stockholm Framework 3
Risk–benefit approach 2
Roles and responsibilities, management **8–17**
Roof materials, rainwater harvesting 95
Rotaviruses 119, **267–268,** 305
in faeces, wastewater and raw water 136
performance target setting 133, 134–135
as reference pathogens 126
risk assessment 131, 132
Roughing filters 488

Salmonella (salmonellae) 119, **250–251**
as reference pathogens 127
Salmonella Enteritidis 251
Salmonella Paratyphi 250–251
Salmonella Typhi 119, 127, 250–251

Salmonella Typhimurium 251
Sample numbers, minimum 67
Sampling
  community-managed supplies 82
  home-stored water 82–83
  ISO guidance 70
  locations 66–68
Sampling frequency
  radiological monitoring **212**
  for verification 65, 66, 68
Sand filters
  rapid gravity 487
  slow 488
Sanitary inspection 63, 80
  community-managed supplies 68, 82
  temporary water supplies 104
  use of data 91–92
Sanitary survey 49
Sapoviruses (Sapporo-like viruses) 119, 261
Scale, calcium carbonate 225
Scarcity, water 94
Schistosoma spp. 119, **290–292**
Schistosome cercarial dermatitis 292
Schistosomiasis 120, 291, 292
Schmutzdecke 142–143, 488
Schools 105
Scum, soap 225
Seasonal discontinuity of supply 86
Sedimentation 55, 490
  household use 143, 146
  microbial reduction 139
Selenium **413–415**
  analysis 479
  guideline value 178, 413, 474
  priority 29
  treatment performance 494
Septata 280
Septic tanks 178
Serratia 120, 295, 298
Service indicators, quantitative 68
Service level 84
Severe acute respiratory syndrome (SARS) coronavirus 121, 122
Shigella 119, 127, **252–253**
Shigellosis 252
Ships **112–114**
"Shipyard eye" 259
Sievert (Sv) 205
Signs, temporary water supplies 103
Silicates 502
Silver **415**
  disinfection 108, 487
  lack of guideline value 186, 415, 471
Simazine **415–416**
  analysis 482
  guideline value 184, 416, 474
  treatment performance 498
Single-hit principle 130
Snails 120, 222, 291
SODIS system 143
Sodium 177, **416,** 471
  taste threshold 227
Sodium bromate 324
Sodium cyanurate 418
Sodium dichloroisocyanurate 110, 141, **417–418**
  analysis 482
  by-products 185
  guideline value 187, 417, 474
Sodium hypochlorite 110, 141, 485
  bromate residue 189
  decomposition products 188
Sodium sulfate 227
Sodium trichloroisocyanurate 141
Softening 377
  household use 176
  methods 491, 493
  microbial reduction 139
  see also Hardness
Solar disinfection 143, 146
Solids, total dissolved *see* Total dissolved solids
Source protection **53–55,** 101
Source waters
  community and household systems 63, 75
  hazard identification 53–54
  microbial hazards 120
  naturally occurring chemicals 176–177
  new systems 50
  operational monitoring 62, 63
  pathogen occurrence 136–137
  performance targets 43
  radioactive contamination 214
  radon 214–215
  verification testing 66, **67**
  see also Catchments
Spas 244, 248, 282
Specified technology targets 21, 40, **43–44**
  application 40, 41

Spinosad 191, 193, **440–441,** 472
Spirometra 120
Standard operating procedures (SOPs) 72, 74
Standards 10
  bottled/packaged water 115
  certification 16
  developing **30–31**
  international 2
  periodic review and revision 31
  see also National standards and regulations
Standpipes 96–97
Staphylococcus aureus 121, **253–254**
Step aerators 489
Stockholm Framework 3
Storage
  after disinfection 56
  household *see* Household treatment and storage
  see also Containers, water
Streptococci, faecal 298–299
Strongyloides 120, 289, 290
Strontium-90 (^{90}Sr) 211, 215
Styrene **418–419**
  analysis 480
  guideline value 180, 418, 474
  odour threshold 227
  treatment performance 496
Sulfate 177, **419,** 472
  acceptable level 227, 419
Superchlorination/dechlorination 485
Supply, drinking-water
  adequacy **83–86**
  improved sources 85
  intermittent 57, 86
  planning and implementing improvement **87–89**
  unimproved sources 85
Supply agencies, drinking-water
  independent surveillance 8–10
  management plans *see* Water safety plans
  roles and responsibilities 8, **13–14**
Supporting programmes **73–74**
Surface waters
  control measures 54, 59
  hazard identification 53–54
  verification 66
Surveillance **8–10, 25, 77–92**
  adapted to specific circumstances 81–83
  adequacy of supply 83–86
  agencies 9–10, 78
  approaches 79–81
  audit approach 79–80
  community drinking-water supplies 80, 81–82
  definition 9, 77
  direct assessment approach 80–81
  household treatment and storage 82–83, 146–147
  planning and implementation 87–89
  public health 10–11
  reporting and communicating 89–92
  stages of development 88–89
  urban areas in developing countries 81
  use of indicator organisms 148
  see also Monitoring
Swimming pools 259, 270, 282
System assessment and design **22–23,** 46, **49–61**
  data collection and evaluation 51–53
  new systems 50–51
  team members 49
Systems, drinking-water
  description 50
  new **50–51**
  non-piped *see* Non-piped water systems
  operational monitoring *see* Operational monitoring
  piped *see* Piped distribution systems
  upgrade and improvement 60–61, 87
  validation *see* Validation
  verification *see* Verification

2,4,5-T (2,4,5-trichlorophenoxy acetic acid) **419–420**
  analysis 482
  guideline value 184, 420, 474
  treatment performance 499
Taenia solium 120
Tankers, water 96, 97
Targets *see* Health-based targets
Taste 7–8, 220–221
  biologically derived contaminants 221–222
  chemical contaminants 222–230
  treatments for removing **230**
TBA *see* Terbuthylazine
TDI *see* Tolerable daily intake

Temephos 191, 193, **441–442,** 472
Temperature, water
  acceptable levels 230
  Legionella growth/survival 105, 245
  Naegleria growth/survival 282
Temporary water supplies **102–104**
Terbuthylazine (TBA) **420–421**
  analysis 482
  guideline value 184, 420, 474
  treatment performance 499
3,3′,4,4′-Tetrachloroazobenzene 413
Tetrachloroethene **421–422**
  analysis 480
  guideline value 180, 421, 474
  treatment performance 496
Tetraethyl lead 383
Tetramethyl lead 383
Thermal technologies
  household water treatment 143, 146
  see also Boiling of water
Thermotolerant coliforms 295, **296–297**
  detection methods 150
  use in monitoring 148
  verification testing 149
THMs *see* Trihalomethanes
Thorium-228 211
Thorium-230 211
Thorium-232 211
Threadworms 289, 290
Tin, inorganic 187, **380–381,** 470
Titration, volumetric 476
Tobrilus 289
Tolerable daily intake (TDI) 160, **161**
  allocation to drinking-water 163–164, 195–196, 197
  calculation of guideline values 160
  chemical-specific adjustment factors 163
  uncertainty factors 162–163
Tolerable disease burden **37–38**
Toluene **422–423**
  acceptability 228
  analysis 480
  guideline value 180, 422, 475
  treatment performance 496
Total coliform bacteria **294–296**
Total dissolved solids (TDS) 177, 228, **423,** 472
Toxaphene 181, 468
Toxicological studies 159
Toxocara 120
Toxoplasma gondii 121, **283–285**
Toxoplasmosis 283–284
2,4,5-TP *see* Fenoprop
Trachipleistophora 280
Transport, vended water 96
Travellers **107–109,** 110–111
Treatment **55–56**
  central 138–140
  chemicals used in *see* Chemicals used in water treatment/materials in contact with water
  control measures 55–56
  for corrosion control **175**
  corrosion of metals used in **493–503**
  desalinated water 98, 99
  hazard identification 55
  household *see* Household treatment and storage
  membrane processes **492**
  methods **485–493**
    microbial reductions 139–140
    ranking of complexity/costs 171
    see also specific treatments
  microbial reduction **138–147**
  operational monitoring 62, 64
  performance 493, **494–500**
  performance targets 43, 132–135
  pharmaceuticals 190
  plants, design of new 50–51
  radioactive contamination 214, 215
  removal of chemicals **170–176**
    household use 175–176
    process performance 171–172
  stored rainwater 95–96
  taste, odour and appearance problems **230**
  for travellers 108–109, 110–111
  turbidity 228, 229
  validation 60
  water quality targets 42–43
  see also Disinfection
Triazophos 181, 468
Tributyltin oxide (TBTO) 181, 468
Tricaprylin 376
Trichloramine **331–332,** 486
  lack of guideline value 186, 332, 472
  taste and odour 223
Trichlorfon 181, 468
Trichloroacetaldehyde *see* Chloral hydrate

Trichloroacetic acid (trichloroacetate) **423–424**
analysis 483
guideline value 188, 423, 475
Trichloroacetonitrile 186, **375–376,** 472
Trichlorobenzenes (TCBs) 179, **424,** 472
acceptable levels 224
1,1,1-Trichloroethane 179, **424–425,** 472
Trichloroethene **425–426**
analysis 480
guideline value 180, 425, 475
treatment performance 496
Trichloronitromethane *see* Chloropicrin
2,4,6-Trichlorophenol **337–338**
acceptable level 224
analysis 483
guideline value 188, 337, 475
2,4,5-Trichlorophenoxy acetic acid *see* 2,4,5-T
2,4,5-Trichlorophenoxy propionic acid *see* Fenoprop
Trichuris 120, 290
Trifluralin **426–427**
analysis 482
guideline value 184, 426, 475
treatment performance 499
Trihalomethanes (THMs) 155, 171–172, **427–430**
analysis 483
guideline value 188, 475
monitoring 185
strategies for reducing 172, 173
Trimethylbenzene 226
Tritium (^{3}H) 211, 215
True colour units (TCU) 224
Tsukamurella 121, **254–255**
Turbidity **228–229**
measurement 229
monitoring 63
Turner diagram 175
Typhoid fever 250–251

Ultrafiltration 492
Ultraviolet (UV) absorption 476
Ultraviolet (UV) irradiation 140, 174, 486–487
household methods 143, 146
Umezakia natans 293
Uncertainty factors (UF) 160, **162–163**
data-derived *see* Chemical-specific adjustment factors
Unimproved drinking-water sources 85
United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 204–205
Unplanned events **71–72**
Upgrading, drinking-water systems **60–61,** 87
Uranium 215, **430–431**
analysis 479
guideline value 178, 430, 475
priority 29
treatment performance 494
Uranium-234 (^{234}U) 211
Uranium-238 (^{238}U) 211
Urban areas
in developing countries **81**
zoning 81

Validation 22, **59–60,** 138
household treatment and storage 146–147
use of indicator organisms 148
Vector control 190–191
see also Pesticides, used in water for vector control
Vended water **96–97**
Vendors, water **15,** 96
Verification 20, **25–26, 64–69**
chemical quality 26–27, 65, 66–67
community-managed supplies 68
microbial quality 26, 65–66, 149
piped distribution systems 67–68
plans, preparing 73
quality assurance and quality control 68–69
source waters 67
use of indicator organisms 148
water safety plans 69
Vibrio **255–256**
Vibrio cholerae 119, 123, **255–256**
in faeces, wastewater and raw water 136
point-of-use treatment 142
as reference pathogen 127
Vinyl chloride **431–432**
analysis 483
guideline value 188, 432, 475
Vinylidene chloride *see* 1,1-Dichloroethene
Viruses
enteric *see* Enteric viruses
pathogenic 119, 121, **258–268**
reference pathogens **126–127**

treatment efficacy 139–140, 145–146
Visible organisms 221
Vittaforma 280
Volatile substances, adapting guideline values 31, 168
Volumetric titration 476

Wastewater
chemicals in 178
pathogens and indicator organisms 136, 137–138
temporary water supplies and 103
Water avoidance advisories 72, **200–201**
Water quality *see* Quality, drinking-water
Water quality targets (WQTs) 21, 40, **42–43**
application 40, 41
see also Guideline values
Water resource management **12–13**
see also Resource protection
Water safety plans (WSPs) 20, **22–25, 45–76**
aircraft and airports 109, 112
approval and review 78–79
audit 69, 78, 87
benefits of using 47
buildings 104, 105
communication 25, 46, 76
documentation 24–25, 75–76
health-care facilities 107
key components 46
management plans 24, 46, 69–75
model 59
operational monitoring 23–24, 46, 61–64
planned review 76
post-incident actions 199
ships 113–114
in specific circumstances 93–94
steps in developing 48
supporting programmes 73–74
surveillance *see* Surveillance
system assessment and design 22–23, 46, 49–61
temporary water supplies 102, 104
vended water 97
verification *see* Verification
Water sources *see* Source waters
Water suppliers *see* Supply agencies, drinking-water
Water treatment *see* Treatment
Water vendors **15**
Waterborne infections *see* Infectious diseases
Weil disease 246
Wells 96, 215, 402
WHO Pesticide Evaluation Scheme (WHOPES) programme 158, 190
WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation 85
Winter vomiting disease 262
Worms, parasitic *see* Helminths
WQTs *see* Water quality targets
WSPs *see* Water safety plans

Xanthomonas 298
Xylenes **432–433**
analysis 480
guideline value 180, 433, 475
odour threshold 229
treatment performance 496

Yersinia **257–258**
Yersinia enterocolitica 121, 257
Yersinia pseudotuberculosis 257
Yersiniosis 257

Zebra mussel 222
Zinc 187, **433–434,** 472
acceptable level 229–230
corrosion **503**
dissolution from brass 493
Zoning, urban areas 81
Zoonotic pathogens 122