

## 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/](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](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](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](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](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/](http://www.who.int/water_sanitation_health/publications/en/)

*Evaluation of the H<sub>2</sub>S method for detection of faecal 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<sub>2</sub>S tests” as measures or indicators of faecal contamination in drinking-water.

[http://www.who.int/entity/water\\_sanitation\\_health/dwq/WSH02.08.pdf](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](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](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](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](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](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](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](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/](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/](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](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](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](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](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](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](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](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/toxycyanobacteria.pdf](http://www.who.int/entity/water_sanitation_health/resourcesquality/toxycyanobacteria.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/](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](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](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](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](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](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](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](http://www.who.int/entity/water_sanitation_health/diseases/zoonoses.pdf)

## ANNEX 2

# References cited<sup>1,2</sup>

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<sup>1</sup> 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.

<sup>2</sup> The web links given in this annex were current as of January 2011.

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## 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 <sup>a</sup>	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

<sup>a</sup> 4-(4-chloro-*o*-tolylloxy)butyric acid.

## ANNEX 3. CHEMICAL SUMMARY TABLES

**Table A3.2 Chemicals for which guideline values have not been established**

<b>Chemical</b>	<b>Reason for not establishing a guideline value</b>
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
<i>Bacillus thuringiensis israelensis</i> (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 <sup>a</sup>
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)**

<b>Chemical</b>	<b>Reason for not establishing a guideline value</b>
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 <sup>b</sup>	Occur in drinking-water at concentrations well below those of health concern
Hardness	Not of health concern at levels found in drinking-water <sup>a</sup>
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 <sup>a</sup>
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 <sup>a</sup>
Malathion	Occurs in drinking-water at concentrations well below those of health concern

## ANNEX 3. CHEMICAL SUMMARY TABLES

**Table A3.2 (continued)**

<b>Chemical</b>	<b>Reason for not establishing a guideline value</b>
Manganese	Not of health concern at levels causing acceptability problems in drinking-water <sup>a</sup>
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 <i>tertiary</i> -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 <sup>c</sup>
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 <sup>a</sup>

**Table A3.2 (continued)**

<b>Chemical</b>	<b>Reason for not establishing a guideline value</b>
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 <sup>a</sup>
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 <sup>a</sup>
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 <sup>a</sup>

<sup>a</sup> May affect acceptability of drinking-water (see chapter 10).

<sup>b</sup> Aminomethylphosphonic acid.

<sup>c</sup> An important operational water quality parameter.

**Table A3.3 Guideline values for chemicals that are of health significance in drinking-water**

<b>Chemical</b>	<b>Guideline value</b>		<b>Remarks</b>
	<b>mg/l</b>	<b>µg/l</b>	
Acrylamide	0.000 5 <sup>a</sup>	0.5 <sup>a</sup>	
Alachlor	0.02 <sup>a</sup>	20 <sup>a</sup>	
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- <i>s</i> -triazine metabolites	0.1	100	
Barium	0.7	700	
Benzene	0.01 <sup>a</sup>	10 <sup>a</sup>	
Benzo[ <i>a</i> ]pyrene	0.000 7 <sup>a</sup>	0.7 <sup>a</sup>	
Boron	2.4	2 400	
Bromate	0.01 <sup>a</sup> (A, T)	10 <sup>a</sup> (A, T)	
Bromodichloromethane	0.06 <sup>a</sup>	60 <sup>a</sup>	
Bromoform	0.1	100	
Cadmium	0.003	3	
Carbofuran	0.007	7	
Carbon tetrachloride	0.004	4	

## ANNEX 3. CHEMICAL SUMMARY TABLES

Table A3.3 (continued)

Chemical	Guideline value		Remarks
	mg/l	µg/l	
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 $\geq 0.5$ 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-DB <sup>b</sup>	0.03	30	Applies to free acid
2,4-DB <sup>c</sup>	0.09	90	
DDT <sup>d</sup> and metabolites	0.001	1	
Dibromoacetonitrile	0.07	70	
Dibromochloromethane	0.1	100	
1,2-Dibromo-3-chloropropane	0.001 <sup>a</sup>	1 <sup>a</sup>	
1,2-Dibromoethane	0.000 4 <sup>a</sup> (P)	0.4 <sup>a</sup> (P)	
Dichloroacetate	0.05 <sup>a</sup> (D)	50 <sup>a</sup> (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 <sup>a</sup>	30 <sup>a</sup>	
1,2-Dichloroethene	0.05	50	
Dichloromethane	0.02	20	
1,2-Dichloropropane	0.04 (P)	40 (P)	
1,3-Dichloropropene	0.02 <sup>a</sup>	20 <sup>a</sup>	
Dichlorprop	0.1	100	
Di(2-ethylhexyl)phthalate	0.008	8	
Dimethoate	0.006	6	
1,4-Dioxane	0.05 <sup>a</sup>	50 <sup>a</sup>	Derived using tolerable daily intake approach as well as linearized multistage modelling

Table A3.3 (continued)

Chemical	Guideline value		Remarks
	mg/l	µg/l	
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 <sup>e</sup>	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 <sub>3</sub> <sup>-</sup> )	50	50 000	Short-term exposure
Nitrilotriacetic acid	0.2	200	
Nitrite (as NO <sub>2</sub> <sup>-</sup> )	3	3 000	Short-term exposure
N-Nitrosodimethylamine	0.000 1	0.1	
Pendimethalin	0.02	20	
Pentachlorophenol	0.009 <sup>a</sup> (P)	9 <sup>a</sup> (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 <sup>f</sup>	0.009	9	
Terbutylazine	0.007	7	
Tetrachloroethene	0.04	40	

Table A3.3 (continued)

Chemical	Guideline value		Remarks
	mg/l	µg/l	
Toluene	0.7 (C)	700 (C)	
Trichloroacetate	0.2	200	
Trichloroethene	0.02 (P)	20 (P)	
2,4,6-Trichlorophenol	0.2* (C)	200* (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	0.000 3 <sup>a</sup>	0.3 <sup>a</sup>	
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.

<sup>a</sup> 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  $10^{-6}$  (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  $10^{-5}$  can be calculated by multiplying and dividing, respectively, the guideline value by 10.

<sup>b</sup> 2,4-Dichlorophenoxyacetic acid.

<sup>c</sup> 2,4-Dichlorophenoxybutyric acid.

<sup>d</sup> Dichlorodiphenyltrichloroethane.

<sup>e</sup> 4-(2-Methyl-4-chlorophenoxy)acetic acid.

<sup>f</sup> 2,4,5-Trichlorophenoxyacetic acid.

## 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<sup>a</sup>**

	Field methods		Laboratory methods				
	Col	Absor	IC	FAAS	EAAS	ICP	ICP-MS
<b>Naturally occurring chemicals</b>							
Arsenic	+++	#		++(H)	+	++(H)	+++
Barium				++	+++	+++	+++
Boron		++				+++	+++
Chromium		#			++	++	+++
Fluoride	#	+	+++				
Selenium		#		++(H)	++	++(H)	+++
Uranium							+++
<b>Chemicals from industrial sources and human dwellings</b>							
Cadmium		#			++	++	+++
Mercury				+++			
<b>Chemicals from agricultural activities</b>							
Nitrate/nitrite	+++	+++	+++				
<b>Chemicals used in water treatment or materials in contact with drinking-water</b>							
Antimony				+++ (H)		++ (H)	+++
Copper	#	+++		+++	+++	+++	+++
Lead		#			+	+	+++
Nickel		+		+	++	++	+++

<sup>a</sup> 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<sup>a</sup>

	Col		(PT-)		GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC-FD
	GC	GC-PD	GC-ECD	(PT-)										
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		++	++						++					
Nitrotriacetic acid			+++						+++					
Pentachlorophenol									+			+		
Styrene		+++							+++					
Tetrachloroethene		+++	+++				+++		+++					
Toluene		+++							+++					
Trichloroethene		+++	+++				+++		+++					
Xylenes		+++							+++					

<sup>a</sup> 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<sup>a,b</sup>

	CoI	GC	GC-PD	(PT-) ECD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAA5	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	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				+++				+++						
Molinat		+++						+++						
Pendimethalin								+++						
Simazine				+++				+++						
2,4,5-T				+++				+++				+		
Terbutylazine								+++				++		
Trifluralin		+++		+++				+++						

<sup>a</sup> For definitions and notes to Table A4.3, see below Table A4.6.

<sup>b</sup> 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<sup>a</sup>**

	Col	GC	GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC
<b>Disinfectants</b>														
Monochloramine		+++												
Chlorine		+++												
Sodium dichloroisocyanurate							+++	+++				+++		
<b>Disinfection by-products</b>														
Bromate														++
Bromodichloromethane				+++				+++					+++	
Bromoform				+++				+++					+++	
Chlorate														+++

Table A4.4 (continued)

	Col	GC	(PT-)		GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC
			GC-PD	GC-EC											
Chlorite															+++
Chloroform				+++				+++	+++	+++					
Dibromoacetonitrile				+++				+++	+++	+++					
Dibromochloromethane				+++				+++	+++	+++					
Dichloroacetic acid				+++				+++	+++	+++					
Dichloroacetonitrile				+++				+++	+++	+++					
Monochloroacetic acid				+++				+++	+++	+++					
N-Nitrosodimethylamine				+++				+++	+++	+++					
Trichloroacetic acid				+++				+++	+++	+++					
2,4,6-Trichlorophenol				+++				+++	+++	+++					
Trihalomethanes <sup>b</sup>				+++				+++	+++	+++					

**Organic contaminants from treatment chemicals**

Acrylamide									+						+
Epichlorohydrin				+++				+++		+					

**Organic contaminants from pipes and fittings**

Benzof[ <i>a</i> ]pyrene									++					++	
Vinyl chloride			++	++						+					

<sup>a</sup> For definitions and notes to Table A4.4, see below Table A4.6.<sup>b</sup> 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<sup>a</sup>

	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)				++			++	++						++

<sup>a</sup> 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	+	++	+	++	++
<b>Definitions to Tables A4.1–A4.6</b>					
Absor	Absorptiometry	HPLC	High-performance liquid chromatography		
Col	Colorimetry	HPLC-FD	High-performance liquid chromatography–fluorescence detector		
EAA5	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				
<b>Notes to Tables A4.1–A4.6</b>					
+	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.				

## 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 ( $\text{HOCl}$ ) and hypochlorite ion ( $\text{OCl}^-$ ).

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<sup>2</sup>) 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<sup>3</sup>/m<sup>2</sup>·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  $0.3\text{--}1.0\text{ m}^3/\text{m}^2\cdot\text{h}$ .

### 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  $15\text{ m}^3/\text{h}$ , 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  $0.15\text{--}0.3$  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  $0.3\text{ m}^3/\text{m}^2\cdot\text{h}$ .

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<sup>3</sup>/m<sup>2</sup>·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<sup>2</sup>/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  $\mu\text{m}$ ). 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  $\mu\text{m}$ . 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  $\mu\text{m}$ ) 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 sub-micrometre range. Microfiltration membranes have pore sizes typically in the range 0.01–12  $\mu\text{m}$  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  $\mu\text{m}$ . 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<sup>a,b</sup>**

	Chlorination	Coagulation	Ion exchange	Precipitation softening	Activated alumina	Activated carbon	Ozonation	Membranes
Arsenic <sup>c</sup>	++	++	+++	++	+++			+++ <sup>d</sup>
Fluoride	<0.005	++	<0.005	<0.005	<0.005			<0.005
Selenium	++	++	+++		<1			+++
Uranium	++	++	<0.01	++	<0.01			<1
			+++		+++			+++
			<0.001		<0.001			<0.01

<sup>a</sup> Symbols are as follows:

- ++ Approximately 50% or more removal
- +++ Approximately 80% or more removal

<sup>b</sup> 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.

<sup>c</sup> Iron oxide-based and iron hydroxide-based media have been shown to be very effective for both arsenate and arsenite forms.

<sup>d</sup> 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<sup>a,b</sup>**

	Air stripping	Coagulation	Ion exchange	Precipitation softening	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment <sup>c</sup>	UV irradiation
Cadmium		+++ <0.002	+++ <0.002	+++ <0.002	+++ <0.0001	+++ <0.01		+++ <0.002		
Mercury		+++ <0.0001		+++ <0.0001	+++ <0.0001			+++ <0.0001		
Benzene	+++ <0.01				+++ <0.01	+++ <0.01	Yes <sup>d</sup>			
Carbon tetrachloride	+++ <0.001				+++ <0.001			+		
1,2-Dichlorobenzene	+++ <0.01				+++ <0.01	+++ <0.01		Yes <sup>d</sup>		
1,4-Dichlorobenzene	+++ <0.01				+++ <0.01	+++ <0.01		Yes <sup>d</sup>		
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	UV irradiation
Nitritotriacetic acid					++				++	
N-Nitrosodimethylamine					+		++			+
Pentachlorophenol					+++			++		
Styrene	+++				<0.0004	++			+	
Tetrachloroethene	<0.02				<0.002			+		
Toluene	+++				+++	+++	+++ <sup>e</sup>		++	
Trichloroethene	<0.001				<0.001	<0.001	<0.001		<0.001	
Xylenes	<0.02				<0.02	<0.02	<0.02		++	
	+++				+++	+++ <sup>e</sup>	+++ <sup>e</sup>		++	
	<0.005				<0.005		<0.005			

<sup>a</sup> Symbols are as follows:

+ Limited removal

++ Approximately 50% or more removal

+++ Approximately 80% or more removal

<sup>b</sup> 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.

<sup>c</sup> Biological treatment includes slow sand filtration and bank filtration.

<sup>d</sup> Yes means known or likely to be effective, but performance was not quantified.

<sup>e</sup> 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<sup>a,b</sup>**

	Chlorination	Air stripping	Coagulation	Ion exchange	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment <sup>c</sup>
Nitrate				+++				+++	+++
Nitrite	+++ <0.1			<5				<5	<5 +++
Alachlor					+++ <0.001	++ <0.001	+++ <0.001	+++ <0.001	+++ <0.001
Aldicarb					+++ <0.001	+++ <0.001	+++ <0.001	+++ <0.001	+++ <0.001
Aldrin/dieldrin			+		+++ <0.000 02	++ <0.000 02	+++ <0.000 02	+++ <0.000 02	+++ <0.000 02
Atrazine and its chloro-5-triazine metabolites			+		+++ <0.0001	Yes <sup>d</sup> <0.0001	+++ <0.0001	+++ <0.0001	+++ <sup>e</sup> <0.0001
Carbofuran		+			+++ <0.001	Yes <sup>d</sup>	+++ <0.001	+++ <0.001	+++ <0.001
Chlordane					+++ <0.001	++ <0.0001	+++ <0.0001	+++ <0.001	+++ Yes <sup>d</sup>
Chlorotoluron					+++ <0.0001	+++ <0.0001	+++ <0.0001	+++ <0.0001	+++ <0.0001
Cyanazine					+++ <0.0001	+	+++ <0.0001	+++ <0.0001	+++ <0.0001
2,4-D					+++ <0.001	+++ <0.001	+++ <0.001	+++ <0.001	+++ <0.001
1,2-Dibromo-3-chloropropane		++ <0.001			+++ <0.0001			+++ <0.0001	+++ <0.0001

Table A5.3 (continued)

	Chlorination	Air stripping	Coagulation	Ion exchange	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment <sup>c</sup>
1,2-Dibromoethane		+++ <0.0001			+++ <0.0001				
1,2-Dichloropropane		Yes			+++ <0.001	+			
Dimethoate	+++ <0.001				++	++			
Endrin			+		+++ <0.0002			Yes <sup>d</sup>	
Hydroxyatrazine							+++ <0.001	Yes <sup>d</sup>	
Isoproturon	++				+++ <0.0001	+++ <0.0001	+++ <0.0001	+++ <0.0001	+
Lindane					+++ <0.0001	++		Yes <sup>d</sup>	++
MCPA					+++ <0.0001	+++ <0.0001		Yes <sup>d</sup>	
Mecoprop					+++ <0.0001	+++ <0.0001			+++ <0.0001
Methoxychlor			++		+++ <0.0001	+++ <0.0001		Yes <sup>d</sup>	
Metalochlor					+++ <0.0001	++		Yes <sup>d</sup>	++
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 <sup>c</sup>
2,4,5-T					+++ <0.001			Yes <sup>d</sup>	
Terbutylazine		+			+++ <0.0001	++			
Trifluralin					+++ <0.0001			+++ <sup>f</sup> <0.0001	

<sup>a</sup> Symbols are as follows:

- + Limited removal
- ++ Approximately 50% or more removal
- +++ Approximately 80% or more removal

<sup>b</sup> 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.

<sup>c</sup> Biological treatment includes slow sand filtration, bank filtration and biological denitrification (for nitrate removal).

<sup>d</sup> Yes means known or likely to be effective, but performance was not quantified.

<sup>e</sup> For bank filtration; slow sand filtration is not effective.

<sup>f</sup> 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<sup>a,b</sup>**

	Chlorination	Coagulation	Activated carbon	Ozonation	Advanced oxidation	Membranes
DDT and metabolites		+	+++ <0.0001	+	+++ <sup>c</sup> <0.0001	+++ <sup>c</sup> <0.0001

<sup>a</sup> Symbols are as follows:

+ Limited removal

+++ Approximately 80% or more removal

<sup>b</sup> For the most effective processes, the table indicates the concentration of the chemical (in mg/l) that should be achievable.

<sup>c</sup> 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<sup>a,b,c</sup>**

	Chlorination	Coagulation	Activated carbon	Ozonation	Advanced oxidation	Membranes	Biological treatment <sup>d</sup>
Cyanobacterial cells		+++				+++	
Cyanotoxins	+++		+++	+++	+++		+++

<sup>a</sup> Chlorination or ozonation may release cyanotoxins.

<sup>b</sup> +++ = 80% or more removal.

<sup>c</sup> 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.

<sup>d</sup> 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) <sup>a</sup>	Radio-nuclide	Guidance level (Bq/l) <sup>a</sup>	Radio-nuclide	Guidance level (Bq/l) <sup>a</sup>	Radio-nuclide	Guidance level (Bq/l) <sup>a</sup>
<sup>3</sup> H	10 000	<sup>71</sup> Ge	10 000	<sup>105</sup> Rh	1 000	<sup>129</sup> Cs	1 000
<sup>7</sup> Be	10 000	<sup>73</sup> As	1 000	<sup>103</sup> Pd	1 000	<sup>131</sup> Cs	1 000
<sup>14</sup> C	100	<sup>74</sup> As	100	<sup>105</sup> Ag	100	<sup>132</sup> Cs	100
<sup>22</sup> Na	100	<sup>76</sup> As	100	<sup>110m</sup> Ag	100	<sup>134</sup> Cs	10
<sup>32</sup> P	100	<sup>77</sup> As	1 000	<sup>111</sup> Ag	100	<sup>135</sup> Cs	100
<sup>33</sup> P	1 000	<sup>75</sup> Se	100	<sup>109</sup> Cd	100	<sup>136</sup> Cs	100
<sup>35</sup> S	100	<sup>82</sup> Br	100	<sup>115</sup> Cd	100	<sup>137</sup> Cs	10
<sup>36</sup> Cl	100	<sup>86</sup> Rb	100	<sup>115m</sup> Cd	100	<sup>131</sup> Ba	1 000
<sup>45</sup> Ca	100	<sup>85</sup> Sr	100	<sup>111</sup> In	1 000	<sup>140</sup> Ba	100
<sup>47</sup> Ca	100	<sup>89</sup> Sr	100	<sup>114m</sup> In	100	<sup>140</sup> La	100
<sup>46</sup> Sc	100	<sup>90</sup> Sr	10	<sup>113</sup> Sn	100	<sup>139</sup> Ce	1 000
<sup>47</sup> Sc	100	<sup>90</sup> Y	100	<sup>125</sup> Sn	100	<sup>141</sup> Ce	100
<sup>48</sup> Sc	100	<sup>91</sup> Y	100	<sup>122</sup> Sb	100	<sup>143</sup> Ce	100
<sup>48</sup> V	100	<sup>93</sup> Zr	100	<sup>124</sup> Sb	100	<sup>144</sup> Ce	10
<sup>51</sup> Cr	10 000	<sup>95</sup> Zr	100	<sup>125</sup> Sb	100	<sup>143</sup> Pr	100
<sup>52</sup> Mn	100	<sup>93m</sup> Nb	1 000	<sup>123m</sup> Te	100	<sup>147</sup> Nd	100
<sup>53</sup> Mn	10 000	<sup>94</sup> Nb	100	<sup>127</sup> Te	1 000	<sup>147</sup> Pm	1 000
<sup>54</sup> Mn	100	<sup>95</sup> Nb	100	<sup>127m</sup> Te	100	<sup>149</sup> Pm	100
<sup>55</sup> Fe	1 000	<sup>93</sup> Mo	100	<sup>129</sup> Te	1 000	<sup>151</sup> Sm	1 000
<sup>59</sup> Fe	100	<sup>99</sup> Mo	100	<sup>129m</sup> Te	100	<sup>153</sup> Sm	100
<sup>56</sup> Co	100	<sup>96</sup> Tc	100	<sup>131</sup> Te	1 000	<sup>152</sup> Eu	100
<sup>57</sup> Co	1 000	<sup>97</sup> Tc	1 000	<sup>131m</sup> Te	100	<sup>154</sup> Eu	100
<sup>58</sup> Co	100	<sup>97m</sup> Tc	100	<sup>132</sup> Te	100	<sup>155</sup> Eu	1 000
<sup>60</sup> Co	100	<sup>99</sup> Tc	100	<sup>125</sup> I	10	<sup>153</sup> Gd	1 000
<sup>59</sup> Ni	1 000	<sup>97</sup> Ru	1 000	<sup>126</sup> I	10	<sup>160</sup> Tb	100
<sup>63</sup> Ni	1 000	<sup>103</sup> Ru	100	<sup>129</sup> I	1	<sup>169</sup> Er	1 000
<sup>65</sup> Zn	100	<sup>106</sup> Ru	10	<sup>131</sup> I	10	<sup>171</sup> Tm	1 000

ANNEX 6. SUPPORTING INFORMATION ON RADIONUCLIDES

**Table A6.1 (continued)**

Radio-nuclide	Guidance level (Bq/l) <sup>a</sup>	Radio-nuclide	Guidance level (Bq/l) <sup>a</sup>	Radio-nuclide	Guidance level (Bq/l) <sup>a</sup>	Radio-nuclide	Guidance level (Bq/l) <sup>a</sup>
<sup>175</sup> Yb	1 000	<sup>210</sup> Pb <sup>b</sup>	0.1	<sup>231</sup> U	1 000	<sup>243</sup> Am	1
<sup>182</sup> Ta	100	<sup>206</sup> Bi	100	<sup>232</sup> U	1	<sup>242</sup> Cm	10
<sup>181</sup> W	1 000	<sup>207</sup> Bi	100	<sup>233</sup> U	1	<sup>243</sup> Cm	1
<sup>185</sup> W	1 000	<sup>210</sup> Bi <sup>b</sup>	100	<sup>234</sup> U <sup>b</sup>	1	<sup>244</sup> Cm	1
<sup>186</sup> Re	100	<sup>210</sup> Po <sup>b</sup>	0.1	<sup>235</sup> U <sup>b</sup>	1	<sup>245</sup> Cm	1
<sup>185</sup> Os	100	<sup>223</sup> Ra <sup>b</sup>	1	<sup>236</sup> U <sup>b</sup>	1	<sup>246</sup> Cm	1
<sup>191</sup> Os	100	<sup>224</sup> Ra <sup>b</sup>	1	<sup>237</sup> U	100	<sup>247</sup> Cm	1
<sup>193</sup> Os	100	<sup>225</sup> Ra	1	<sup>238</sup> U <sup>b,c</sup>	10	<sup>248</sup> Cm	0.1
<sup>190</sup> Ir	100	<sup>226</sup> Ra <sup>b</sup>	1	<sup>237</sup> Np	1	<sup>249</sup> Bk	100
<sup>192</sup> Ir	100	<sup>228</sup> Ra <sup>b</sup>	0.1	<sup>239</sup> Np	100	<sup>246</sup> Cf	100
<sup>191</sup> Pt	1 000	<sup>227</sup> Th <sup>b</sup>	10	<sup>236</sup> Pu	1	<sup>248</sup> Cf	10
<sup>193m</sup> Pt	1 000	<sup>228</sup> Th <sup>b</sup>	1	<sup>237</sup> Pu	1 000	<sup>249</sup> Cf	1
<sup>198</sup> Au	100	<sup>229</sup> Th	0.1	<sup>238</sup> Pu	1	<sup>250</sup> Cf	1
<sup>199</sup> Au	1 000	<sup>230</sup> Th <sup>b</sup>	1	<sup>239</sup> Pu	1	<sup>251</sup> Cf	1
<sup>197</sup> Hg	1 000	<sup>231</sup> Th <sup>b</sup>	1 000	<sup>240</sup> Pu	1	<sup>252</sup> Cf	1
<sup>203</sup> Hg	100	<sup>232</sup> Th <sup>b</sup>	1	<sup>241</sup> Pu	10	<sup>253</sup> Cf	100
<sup>200</sup> Tl	1 000	<sup>234</sup> Th <sup>b</sup>	100	<sup>242</sup> Pu	1	<sup>254</sup> Cf	1
<sup>201</sup> Tl	1 000	<sup>230</sup> Pa	100	<sup>244</sup> Pu	1	<sup>253</sup> Es	10
<sup>202</sup> Tl	1 000	<sup>231</sup> Pa <sup>b</sup>	0.1	<sup>241</sup> Am	1	<sup>254</sup> Es	10
<sup>204</sup> Tl	100	<sup>233</sup> Pa	100	<sup>242</sup> Am	1 000	<sup>254m</sup> Es	100
<sup>203</sup> Pb	1 000	<sup>230</sup> U	1	<sup>242m</sup> Am	1		

<sup>a</sup> Guidance levels are rounded according to averaging the log scale values (to 10<sup>n</sup> if the calculated value was below 3 × 10<sup>n</sup> and above 3 × 10<sup>n-1</sup>).

<sup>b</sup> Natural radionuclides.

<sup>c</sup> 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).

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## 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](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.

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